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Oscillations During Iceberg Towing

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This paper describes a mathematical model of iceberg towing that considers an iceberg's shape in an explicit form. The developed model allows for the analysis of oscillations appearing in towing systems in both stationary and dynamic modes. The proposed numerical model can be used to assess the nonlinear dynamics of the "vessel-rope-iceberg" system. An understanding of the peak values in the tow force should help to increase iceberg towing efficiency and ensure the safety of operations as a result of reduced iceberg roll and rope slide-off.

INTRODUCTION

To ensure the safety of marine operations in iceberg waters, a complex ice management system must be implemented in exploration or production activity. The physical impacting of drifting icebergs is one of the main ways to prevent their collision with fixed or floating offshore facilities (Efimov and Kornishin, 2016; Pashali et al., 2018). Perhaps the most effective technology to change an iceberg's drift trajectory is to deflect it with the help of a tug vessel equipped with a special towing system. However, this operation can be complicated by a number of technical challenges associated with the dynamics of icebergs and towing system interaction.

Despite the significant amount of iceberg towing experience accumulated in offshore projects off Canada's east coast and west Greenland, there has been very limited research devoted to understanding iceberg dynamics during towing operations. Works by McKenna et al. (2003), C-CORE (2004), and Rudkin et al. (2005) investigated the relationship between iceberg stability and towing parameters such as the tow force, rope attachment point, vessel's acceleration, and tow speed. Some more recently published works focused on the theoretical study of the iceberg towing process (Yulmetov et al., 2016; Yulmetov and Løset, 2017; Efimov et al., 2019). These works describe numerical models based on the analytical dependency of mechanics, and they reveal significant difficulties in the modeling of iceberg towing and the importance of nonlinear dynamic effects in the "vessel-rope-iceberg" system.

In Sazonov (2012), issues involving the towing process and emerging oscillations were analytically investigated. At the same time, Sazonov underlined the need to reduce the vessel acceleration time at the beginning because of the maneuverability problems experienced by some vessels at low speeds in conditions of high winds and rough seas. The work by Sazonov considers certain approximations of the shape of icebergs. This simplification significantly affects the dynamics of the iceberg and subsequent oscillations.

Describing the dynamic processes that appear in the iceberg towing system is a difficult task that requires reasonable assumptions and a comprehensive assessment of all possible external forces acting on the mechanical system.

Mathematical modeling and numerical modeling provide information on peak loads during iceberg towing and the influence of towing loads on the dynamics of the "vessel-rope-iceberg" system.

This paper describes numerical mathematical models that consider individual features of the iceberg shape (see also Pavlov et al., 2018). This approach can help to analyze oscillations in the vessel-rope-iceberg system emerging in both the stationary and dynamic modes.

MATHEMATICAL MODEL

General mathematical three-dimensional (3D) models of nonstationary iceberg towing require application of principles of continuum mechanics. Using fundamental conservation laws, it is possible to build a coupled system of nonlinear equations that will describe, with minimum assumptions, the processes taking place in the vessel-rope-iceberg system.

These comprehensive numerical simulations require space-time discretization and significant computational resources. To formulate the system of equations, it is important to introduce reasonable assumptions. In this paper, the *vessel-rope-iceberg* system is mathematically formulated as the movement of two rigid objects: a vessel connected to an iceberg by an elastic line; see Fig. 1 for a simplified diagram. A time-dependent propulsive force is applied to the iceberg by the vessel. The movement of the two rigid bodies is characterized by six degrees of freedom and described using

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