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The influence of level ice on the frequency domain response of floaters

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ABSTRACT

In this paper the effect of a nearby, semi-infinite, level ice sheet on the frequency domain response of a thin, floating, rigid body is studied using a 2D model. The ice is modeled using a dynamic Euler-Bernoulli beam and the finite depth water layer is described with the Laplace equation and the linearized Bernoulli equation. Eigenfunction matching is used to resolve the interface between the ice covered and open water regions.

The body is excited by external loads, generating waves. The waves are partially reflected by the ice edge and these reflected waves influence the body's response. It is this influence that this paper focuses on. Below a certain onset frequency the amplitude of the reflected waves is insignificant and consequently the body remains unaffected by the ice. This frequency is only sensitive to the ice thickness with thinner ice resulting in a higher onset frequency.

Above the onset frequency the reflected waves cause quasi-standing waves between body and ice. For frequencies at which half the wavelength of the surface wave in the water is approximately an integer multiple of the gap length, the amplitude of the standing waves is greatly amplified. This can result in (anti-)resonance depending on the phasing between the reflected waves and the body's motion.

1. Introduction

Although the interest in offshore Arctic hydrocarbons has declined in recent times, it is still a great prospect for our future. The water depths encountered in large parts of the Arctic offshore region make floating structures the main platform for drilling and production. Understanding the interaction between ice and floaters is therefore paramount in performing the eventual extraction of those resources in a safe and sustainable way.

Ice-floater interaction (IFI) is a challenging problem because of the many disciplines it combines and is further complicated by the complex material properties of sea ice (Timco and Weeks, 2010). Although full scale data is mostly limited to ice breakers and the drilling vessel Kulluk (Wright, 2001), theoretical studies have been going on for several decades (Palmer and Croasdale, 2013).

IFI has three main components: the ice, the floater and the fluid. Focus is often on the ice with the floater assumed to be immovable and rigid. The interaction is then governed by the ice and takes place through the contact. However, for the design of station-keeping systems the dynamics of the floater is of importance. Allowing the floater to move adds a second path of interaction in addition to the contact, namely through the fluid. Quite often this coupling is not included because it involves solving a coupled hydrodynamics (HD) problem.

[1] This paper addresses the hydrodynamic coupling between vessel and ice. The focus is placed on the effect of the presence of level ice on the frequency domain response of the floating vessel. The fundamental question we answer is whether the open-water response of the floater is applicable in the presence of ice. The coupling investigated in this paper has been addressed in very few studies and, therefore, its effect remains largely unexplored.

[1] Two fields of research are closely associated with the type of coupling addressed in this paper, namely the field of ice-structure interaction and the field of wave propagation in and wave reflection from ice. In the former the focus has mostly been placed on the mechanical aspects of the interaction, namely on the vessel excitation by the contact with ice and the resulting failure of the ice. Hydrodynamics has been incorporated in the sense that its effect on these mechanical aspects has been studied. To the author's knowledge the most advanced model to date that includes hydrodynamics is by Valanto (2001), who solved the 3D interaction between a forward advancing ice breaker and an ice plate. The comparison with full-scale data was very satisfactory. In this model however, the vessel was kinematically prescribed to move forward at a constant speed.

[1] Few studies have included hydrodynamic coupling between vessel and ice. Tsarau et al. (2014) studied the coupling between a floater and nearby ice rubble and found good agreement with model

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tests performed in a wave tank. They did not include the effect of the surface waves though. In Su et al. (2010) a numerical model was introduced for the interaction between an ice breaker with three degrees of freedom and level ice but hydrodynamic coupling was not accounted for either. A more rigorous approach is to use CFD but this results in extreme computation times and hardware requirements. This was done by Gagnon (2007) and Gagnon and Wang (2012) to study the collision between an iceberg and a loaded tanker.

[1] Overall it can be concluded that in this field the amount of studies on the hydrodynamic coupling between vessel and ice is limited and no qualitative studies on the coupling have been done.

[1] In the closely related field of waves in ice infested waters the interaction between ocean waves and ice sheets is studied. This field has had a steady activity since the 1990's, Squire (1995), and has seen a resurgence in the last two decades (Squire, 2007). By its very nature this field has incorporated hydrodynamics from the very beginning but its goal has been to understand the wave processes that go on in marginal ice zone (MIZ). The focus was placed on understanding the reflection and transmission of ocean waves by the ice. This process, in combination with the resulting break-up of the ice, is essential in understanding the attenuation of waves as they propagate through the MIZ. Some of the findings in this field are that when waves are at normal incidence to an ice edge, at low frequencies nearly all energy is transmitted into the ice sheet and is almost fully reflected back into the sea at high frequencies Fox and Squire (1990). For oblique waves a critical angle exists beyond which no waves propagate into the ice (Fox and Squire, 1994). In both these studies the reflection by the draft of the ice was ignored, an assumption of minor consequences as shown in, for instance, Williams and Squire (2008). Lastly Chung and Linton (2005) studied the effect of a gap between two adjacent semi-infinite ice sheets. In this case the reflection coefficient becomes periodic, having a series of resonance peaks at regular intervals. When a vessel operates in the presence of ice, the waves it radiates will also be reflected by the ice, which associates the problem considered in this paper to the work by Chung and Linton.

[1] Because of the apparent lack of studies in this overlapping region between the research fields, this work aims to improve our understanding of the hydrodynamic coupling (HD) coupling between a floater and flexible level ice. To this end a very common IFI scenario is studied, namely the dynamics of a floater in the vicinity of level ice. The main questions to be answered are:

- How is the frequency domain response of the floater that is excited by a sinusoidal load affected by the presence of a flexible level ice sheet located in close proximity of the floater?
- Under which circumstances can the floater-ice coupling be neglected?

As this paper aims at obtaining qualitative answers to the above-formulated questions, the problem is restricted to a two-dimensional vertical plane and the floater is assumed to be thin. Although the response in the presence of level ice will be quantitatively different for each floater, it is postulated that the phenomenon observed and understanding gained from this simple model are applicable to a broader range of floaters.

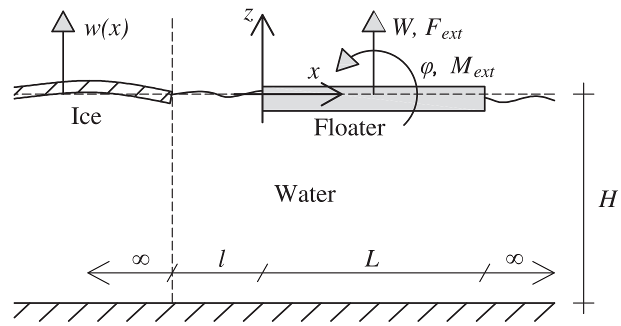

Fig. 1. The waves generated by the body's motion reflect at the ice-open water interface. The pressure exerted by the reflected waves alter the body's response.

In the next section the adopted mathematical model is defined. After this the solution strategy is explained in Sections 3 and 4. The results are then discussed in Section 5 and lastly conclusions and recommendations are given in Section 6.

2. Model description

The problem to be solved is depicted in Fig. 1. A rigid body, whose thickness is small compared to the water depth, floats on the surface of the fluid layer. At a distance l from the body there is a floating ice sheet that extends to negative infinity. The goal is to determine the body's vertical and rotational motion caused by time harmonic forces or moments acting on it, while accounting for the presence of the ice sheet.

The model is assumed 2D, which means that the out-of-plane dimension of the body is much bigger than the distance to the floating ice sheet. This scenario may be representative of the heave and roll motions of barges, tabular icebergs or large pieces of ice rubble. The extension to three-dimensional bodies would allow for more accurate analysis of other motion types, like pitch and yaw and would lift the restriction on the out-of-plane dimension of the body. The extension to embedded bodies (i.e., without ignoring the draft) would enable the analysis of horizontal motions, such as surge and sway and allow a more complex geometry of the body to be considered.

The body is excited by external loads. These push it against the fluid, which in turn offers resistance to the body's motion. Waves are generated at the body-fluid interface, and propagate away from it, see Fig. 2 on the right.

Waves that propagate to the right, find no heterogeneity and therefore do not return to the body. On the contrary, waves propagating to the left will encounter the ice sheet and will be partially transmitted and partially reflected at the ice edge, see Fig. 2 on the left. The response of the floating body is affected by the reflected wave field. The

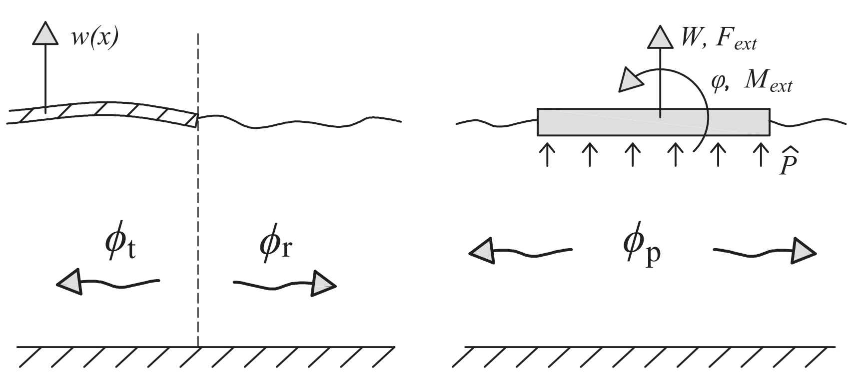

Fig. 2. Excitation of the body generates waves (right image) which are party reflected and transmitted by the ice sheet (left image).