Mathematical Model of Ice Sheet Deformation Caused by Submarine Motion

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ABSTRACT

A model for the stress-strain state of ice cover under hydrodynamic loads caused by the motion of a submarine is constructed. Numerical calculations using this model are carried out. The deflections and stresses in the ice cover predicted by the model are computed using a finite element method (FEM) in combination with a boundary element method (BEM). The diffraction of gravity waves in ice cover that has longitudinal cracks or bands of open water are computed. The results for various open cracks and open-water widths are presented together with the corresponding data from a model test basin.

KEY WORDS: submarine; ice; FEM; BEM; time domain simulation; bending-gravity waves.

INTRODUCTION

The transport system of the Northern Sea Route (NSR) is of low efficiency at the moment. The fleet of ice breakers and Arctic transports has been in existence for many years (Tokmakov, 1965). The long experience of using military submarines in Northern regions demonstrates their ability to cover long distances under ice. But when they need to surface a danger of emergency arises. Traditionally, submarine surfacing is carried out by the static loading from beneath the ice sheet which is achieved by creating positive buoyancy by emptying ballast cisterns. The experience of actual surfacing this way has proved to have some problems, namely: the small possible thickness of a broken ice sheet, the necessity of increasing the strength of a hull structure, the threat of losing stability, etc. Hence, it becomes expedient to investigate the possibility of breaking ice sheets by hydrodynamic loads created by submarine motion near the ice surface. It is established (Kozin and Onischuk, 2005) that submarine motion brings about wave oscillations under the ice sheet surface and the oscillation amplitude reaches its maximum when the submarine gains certain velocity corresponding to the highest intensity of the wave formation that is when the flexural-gravity resonance appears. At this point the capability of the submarine to rupture the ice sheet increases considerably (Kozin and Others, 2005; 2008).

A survey of the results of theoretical and experimental investigations of the generation by moving loads and propagation of flexural-gravitational waves in ice cover can be found in (Kheisin, 1967; Squire and Others, 1996; Kozin and Others, 2008). The numerous experimental researches, in particular, in paper (Takizawa, 1986) were conducted. The researches of hydroelastic waves in ice cover with various abrupt changes of material properties (cracks, open and refrozen leads and others) has been summarised in review by Squire (2007; 2008). In many works (Milinazzo, Shinbrot and Evans, 1995; Zhyostkaya and Kozin, 2003) interesting calculation results about deformations of an ice cover by rectangular moving loads are received. However in the majority of theoretical investigations the effect of loads which are directed onto ice cover only from above is studied. Traditionally, submarine surfacing is carried out by the static loading from beneath the ice sheet which is achieved by creating positive buoyancy by emptying ballast cisterns. The experience of actual surfacing this way has proved to have some problems, namely: the small possible thickness of a broken ice sheet, the necessity of increasing the strength of a hull structure, the threat of losing stability, etc. Hence, it becomes expedient to investigate the possibility of breaking ice sheets by hydrodynamic loads created by submarine motion near the ice surface. It is established (Kozin and Onischuk, 2005) that submarine motion brings about wave oscillations under the ice sheet surface and the oscillation amplitude reaches its maximum when the submarine gains certain velocity corresponding to the highest intensity of the wave formation that is when the flexural-gravity resonance appears. At this point the capability of the submarine to rupture the ice sheet increases considerably (Kozin and Others, 2005; 2008).