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Formation of the Ice Cover's Flexural Oscillations by Action of Surface and Internal Ship Waves — Part II. Internal Wave Manifestations in Ice Bend

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ABSTRACT

This work is an extension of the three-dimensional ice cover bend investigations presented in Part I (March 1997 issue). It is devoted to estimating the contribution from the forced internal wave manifestations to the flexural deformations of the ice floating on the surface of exponentially stratified fluid of finite depth. The waves are induced by either a concentrated load moving rectilinearly over the ice surface or by a hydrodynamic source of constant intensity moving at the given depth in fluid. A dependence of the structural features of ice cover bend topography caused by internal waves on the ice thickness, generator displacement speed and its submersion depth is studied.

INTRODUCTION

In Part I (March 1997 issue) we developed a theoretical model allowing the investigation of the topographies of the ice bend caused by surface waves of the ship type when the pressure area of constant intensity is moving. However, under seawater density stratification conditions, internal waves are induced in addition to surface ones. The series of theoretical works was devoted to investigating the internal waves under ice conditions. They are based on the hydrodynamic model involving the seawater density jump (for example, Bukatov, 1972, 1976; Savchenko, 1974; Bukatov and Cherkessov, 1976) or on the models involving continuous density stratification (for example, Bukatov and Cherkessov, 1974). The free waves, as well as the waves induced by an impulse generator, or a time-periodic one acting in the given region, were considered.

It was shown that the internal wave phase characteristics may be traceable in the ice bend, practically without distortions. The amplitude of the bend caused by internal waves depends on the water density vertical gradient and ice conditions. It is much smaller than the internal wave amplitude inside the water column. Nevertheless, it may be measured experimentally under field conditions. Smirnov (1972) and Bogorodskii et al. (1978) cited results of such measurements.

The character and structure of the internal wave surface manifestations are evaluated not only by oceanographic conditions but also by the generator. If the generator is moving, these manifestations depend on its movement speed. In the case of a moving planar front of time-periodic pressure, this problem was considered by Bukatov and Cherkessov (1979) involving a model of the fluid with a density jump. An asymptotic analysis of the development of the wave disturbances in the far field was carried out. Dotsenko and Cherkessov (1974) considered steady waves far from a moving planar front of pressure of constant intensity, but their investigation was based on the model involving a complicated distribution of fluid density.

The problem of estimating a possible contribution from manifestations of the three-dimensional internal waves of the ship type to the ice flexural deformation was considered by Bukatov and Zharkov (1986, 1990) and Schulkes, Hosking and Sneyd (1987) for the case of the two-layer fluid density model. In the case of a density model approximating real stratification for one of the Arctic Ocean regions, the ice bend caused by internal waves was considered by Bukatov and Zharkov (1992) for the ship wave wake in the far field only.

Here we present an investigation of the ice flexural deformations caused by internal ship waves in the case of uniformly stratified fluid. We consider two types of generator. This may be either a load of constant intensity moving over the ice or an underwater hydrodynamic source moving at the given depth in fluid. We investigate the ice bend in the near zone of the generator and in the wave wake.

MANIFESTATIONS OF INTERNAL WAVES WHEN A PRESSURE AREA IS MOVING OVER ICE

Problem Statement and Solution in Integral Form

Let us continue investigating the floating ice cover's three-dimensional bend formed by waves when the load:

$$P = p_0 f(x+Ut,\, y) \tag{2.1}$$

is moving. We consider the contribution introduced by internal wave manifestations to the bend.

In Part I we used linearized equations of movement of the continuously stratified fluid:

$$Lu = -\frac{1}{\rho_0}\frac{\partial p}{\partial x},\quad Lv = -\frac{1}{\rho_0}\frac{\partial p}{\partial y},\quad Lw = -\frac{1}{\rho_0}\left(g\rho + \frac{\partial p}{\partial z}\right),$$
$$L = \frac{\partial}{\partial t} + U\frac{\partial}{\partial x} \tag{2.2}$$

and an equation of continuity:

$$\partial u/\partial x + \partial v/\partial y + \partial w/\partial z = 0 \tag{2.3}$$

with boundary conditions of nonseparating oscillations of the ice cover:

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KEY WORDS: Moving load, ice deflection, ice flexural deformations, internal wave manifestations, moving hydrodynamic source, ship wave wake.