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Seasonal Variability of Physical-Mechanical Characteristics of Sea Ice

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ABSTRACT

A numerical analysis of seasonal variability of the Young's modulus E and ice flexural strength σ_f is given on the basis of theoretical and experimental data, obtained in recent years. The calculations are made for six sea ice age gradations: 10-30 cm, 30-70 cm, 70-120 cm, 120-200 cm, 200-300 cm and > 300 cm. The effect of volumetric ice porosity (concentrations of salt inclusions) on seasonal variability of the Young's modulus is shown and a comparison of calculations with experimental data is given. The data of seasonal variations of σ_f calculated according to different methods are presented.

INTRODUCTION

At the present time a large number of particular dependence of some most common in engineering physical-mechanical ice characteristics on its temperature T, salinity S, crystal dimension d, density ρ, etc. have been determined. The dependence ranges from simple empirical formulas, relating two or three parameters (for instance, Gold, Berdennikov, Tabata, Pounder, etc.) for the Young's modulus in the form $E = f(T)$, $E = f(T,S)$, $E = f(\rho)$ ... or Frankenstein, Ryvlin, Payton for the ice flexural strength of the type $\sigma_f = f(S)$, $\sigma_f(C_\ell)$ etc. (for example, Bogorodsky et al. 1980) to sufficiently complex (with many parameters) phenomenological equations of ice state. The complex equations are such as the equation with rheological parameters (Zaretsky et al., 1976) to determine ice deformations at any time with a prescribed, in particular, uniaxial and hence, to possibly determine the modulus of deformation and the ice strength as a function of time.

On the basis of these dependence one can in principle estimate seasonal variability of physical ice values, characterizing its behavior under load, including for example, the ice cover bearing capacity.

Taking into account the increasing demands of engineering activity (which is connected with the organization of transportation under winter conditions and exploration of hydrocarbon resources in the Arctic shelf area, etc.), we believe it is necessary to make a numerical analysis (and if there are sufficient observation series, a probabilistic analysis) of seasonal variability of some sea ice characteristics. The analyses can be done on the basis of generalized data of theoretical and experimental studies of ice physical-mechanical properties, which have been collected in recent years. Also it is desirable to conduct the analysis in conjunction with the ice types (or its age gradations) in accordance with some commonly used ice classification and/or WMO (World Meteorological Organization) Sea Ice Nomenclature so as after that to make a probabilistic estimation of ice physical-mechanical properties in specific areas, issuing corresponding maps.

This work presents results based on some published experimental data and calculations of physical-mechanical ice characteristics for the following six age gradations of sea ice:

1) young ice (h=10...30 cm; 2) thin first-year ice (h=30...70 cm); 3) medium first-year ice (h=70...120 cm); 4) thick first-year ice (h=120...200 cm); 5) two-year ice (h=200...300 cm); and 6) multi-year ice (h > 300 cm).

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THE YOUNG'S MODULUS: EXPERIMENTAL AND CALCULATED DATA

To estimate seasonal variability of the Young's modulus, let us use experimental and calculated data, characterizing particular dependence of this elasticity characteristics on both internal parameters and ice properties and external conditions. The internal parameters and ice properties mean crystal dimensions and their distribution, isotropy of the grain structure and of crystallographic orientation, presence or absence of any inclusions, such as, for example, air bubbles, brine, etc. The external conditions are loading values, ice temperature, loading time or frequency of changing mechanical stresses in the ice, if we mean cyclic loads and strain rate. Some of these characteristics are affected by the scale effect.

Considering further the variety of available particular dependence of the Young's modulus, let us restrict ourselves to the analysis of only those dependence, which will be useful for the determination of the schedule of seasonal variability of the dynamic Young's modulus of sea ice.

First we shall consider a temperature dependence of the dynamic Young's modulus for freshwater polycrystalline ice, using the existing experimental data (Berdennikov, 1948; Hutter, 1978) presented in Fig. 1.

As it can be seen from Fig. 1, different investigators have obtained almost the same slopes of graphic dependence, which, however, differ by an absolute value. Thus, the dynamic moduli from the data of Kuroiwa and Jamaia (curve 4) and the values of the quasidynamic modulus, close to them, determined by Gold by a static method (curve 3) are on the average 20-30% less than those determined respectively by formulas of Berdennikov (curve 1) and Hutter (curve 5), if the latter are assumed as initial data.

The calculated dependence of the Young's modulus on average dimensions of the ice grains, strains in the ice during measurements, time (frequency) of the loading and temperature (Sinha, 1978) and a comparative analysis with the experimental data give a key to the understanding of a large scattering of published data on the Young's modulus for the freshwater ice. This is especially evident in the cases when the references do not have enough evidence on the properties of the ice itself and the conditions of the experiment. It should, however, be noted that, if according to numerous