Seasonal variability ice strength properties on the Russian continental shelf

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ABSTRACT

The problem of assessing ice loads and impacts on facilities of developing offshore oil and gas fields has been one of the most relevant in the world in recent decades.
When calculating ice loads, the physical and mechanical properties of ice, corresponding to the natural conditions of the region under consideration, should be taken into account. The lack of reliable initial data holds back the pace of design and construction of facilities, which postpones the development of deposits. Currently, there is no unified approach to the selection of standard values for ice cover parameters. Significant differences in the values of design ice loads determined by regulatory methods are due to the manifestation of high spatiotemporal variability of the parameters of the ice regime and the properties of sea ice when interacting with structures, on the one hand, and the imperfection of calculation methods, on the other. The solution to this problem requires the formulation of a wide range of experimental studies of the ice regime in order to determine the most probable range of variability of the functional parameters that determine the magnitude and nature of the loads throughout the ice period, as well as the features of the state of the ice-structure system in a particular physical and geographical area.

KEY WORDS: ice; seasonal variability; arctic shelf.

INTRODUCTION

To date, a large number of studies of sea ice have been carried out. These studies can be divided into laboratory and field tests. The former are necessary for studying the mechanics of ice under controlled test conditions. The second ones make it possible to understand more deeply the properties of the ice cover in natural conditions. In the course of such studies (Borodkin, 2016; Johnston, 2001; Johnston, 2002; Johnston, 2006), the processes of changes in some physicomechanical parameters of ice and the process of its degradation were studied. The main drawback of such studies is that many of them were conducted for a limited time in different periods of the ice season - mainly in the spring-summer period. This information does not always reflect the full picture of changes in the properties of ice and, in particular, its strength. Information on the dynamics of changes in the basic design parameters of ice is very important for assessing loads and impacts on structures and its safe operation. Such information is especially relevant for the following purposes:
- improving the accuracy of forecasting design loads and impacts on structures;
- improving the reliability of ice crossings;
- improving safety in the design and implementation of ice management systems;
- forecasting navigation conditions;
- improving the safety of offshore operations in the Arctic as a whole.

To study the variability of the physicomechanical properties of ice, design experimental studies are needed throughout the season.
It is important to determine the maximum design load on the structure. Currently, normative documents recommend calculating the maximum load at the maximum ice thickness in the water area (Pak et. All, 2012). In this case, as a rule, the maximum strength of ice is also accepted. Such a combination of these two main parameters is considered insufficiently justified. Studies of the variability of the main parameters of the ice cover will make it possible to differentiate them and increase the accuracy of determining ice loads. An important feature of field studies is the small number of experimental parameters that can be controlled. In this regard, it is necessary to develop a research methodology (Smirnov et.all, 2011), which will take into account the largest number of factors. Such a technique should ensure regularity and cyclical measurement of ice parameters. It is also necessary to take into account the effect of the changing ice thickness on the parameters of the experiments.

BRIEF DESCRIPTION OF ICE RESEARCH SITE

Field studies were carried out near stationary research bases designed to study the physicomechanical properties of ice, equipped with everything necessary for conducting experiments.
The ice base "Cape Baranova" is located on Cape Baranova, arch. Northern land, coordinates 79 ° 16'48 "N 101 ° 37'19". The test site was located on the ice of the Shokalsky Strait of the Laptev Sea, 1000 meters from the base.
The Khastir base is located on the shore of the Khatanga Bay, north of the village of Syndasco, in the Taimyr Dolgan-Nenets district, coordinates 73 ° 49'681 "N 109 ° 39'245" E. The test site was located on the ice of the Khatanga Bay, 1000 meters from the base.

On Sakhalin Island, the research team was located in the village of Nogliki. The sea ice properties study ground is located 14 km from the village of Nogliki in the northern part of Nabil Bay, coordinates 51 ° 43′39.8 ″ N 143 ° 18′31.4 ″ E.
The location of the ice bases is shown in Fig. 1.
This arrangement is connected, firstly, with the aim of assessing how interrelated are the processes of changing the properties of the ice cover in different climatic zones. Secondly, on the shelf about. Sakhalin has already operated offshore ice-resistant oil production platforms, during the design of which a number of studies of the ice regime of the water area were carried out. This design experience can be used for other projects.
The duration of the research at the northern test sites was 7 months, at the test site of Sakhalin Island - 5 months.

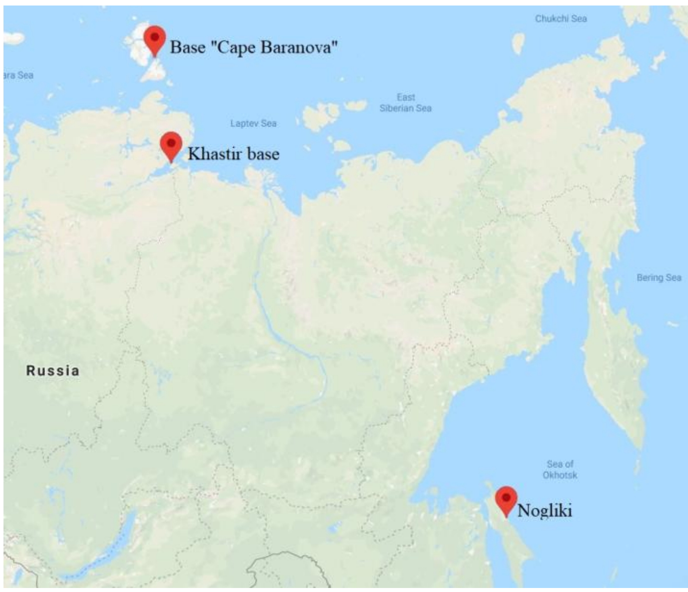

Fig. 1. – Location of the ice research bases.

FIELD RESEARCH METHODOLOGY

For research, we selected sections of flat landfast ice with a size of at least 40 by 40 meters and a water depth of at least two meters. Access to the research sites was to be provided with snowmobile access for equipment transportation. The frequency and types of tests depend on the thickness of the ice and are divided into several parts. Observations of the ice thickness were carried out with the following frequency:
- with ice thickness from 16 to 20 cm - daily;
- from 20 to 50 cm - every other day and on the last day of the month;
- from 50 to 100 cm - every 5 days and on the last day of the month;
- more than 100 cm - once a ten-day interval;
- from the beginning of ice melting - daily.
If the ice thickness is from 30 cm to 60 cm for each ten-day interval, the following parameters of the physicomechanical properties of ice should be determined:
- temperature, salinity, ice density;
- compressive strength of ice samples drilled perpendicular to the surface;
- compressive strength of ice samples drilled parallel to the surface on the same horizon;
- strength by the method of a borehole jack.
If the ice thickness exceeds 61 cm, it is necessary to measure the compressive strength of ice samples drilled parallel to the surface and the strength of the borehole jack method at two levels.

The sum of degrees of frost was determined according to meteorological observations of air temperature for each polygon, or according to a nearby meteorological station.
Based on the results of the experiments, graphs of changes in average monthly values were built.

SEASONAL VARIABILITY

Seasonal variability in this work is understood to mean a change in the properties of ice during the ice season. The ice season is understood to mean the period from the beginning of ice formation until it reaches its maximum thickness (until the beginning of melting). The start of the ice season is the date after which stable negative temperatures below the freezing point of water have come.
For an initial assessment and comparison of the results, the dynamics of the degree of frost were calculated (Fig. 1) from the data on the air temperature (Fig. 2). Despite the more northern location of the Cape Baranova base, a slightly larger degree of frost is observed at the Khastir base. For the base in Nogliki, this parameter is significantly lower due to a more southerly location.

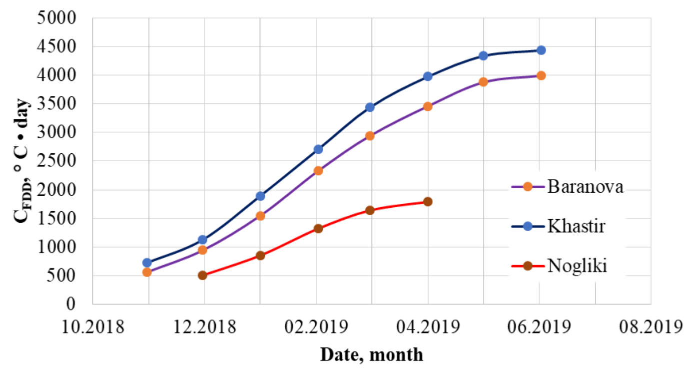

Fig. 2 - Sum of degree-days for all bases.

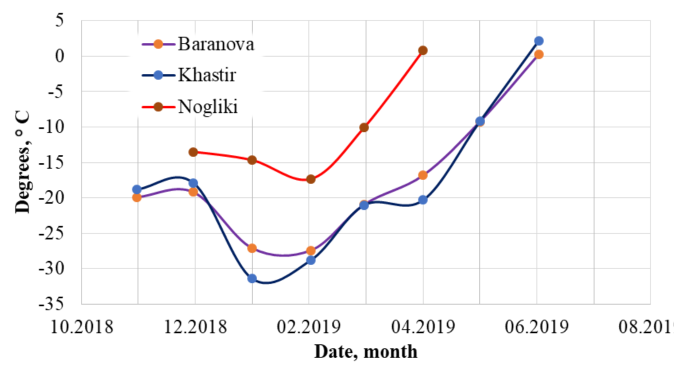

Fig. 3 - Air temperature for all bases

Assessment of seasonal variability was carried out for each parameter separately for all polygons.

Ice Thickness and Physical Properties of Ice

The ice thickness was measured with high regularity at all polygons, which is shown in Fig. 4. As can be seen from the data from the landfill in Nogliki, during ice melting, degradation of the ice cover and a decrease in the thickness of the ice were observed. At the northern bases, such a process was not recorded due to severe snow melting and lack of access to landfills.

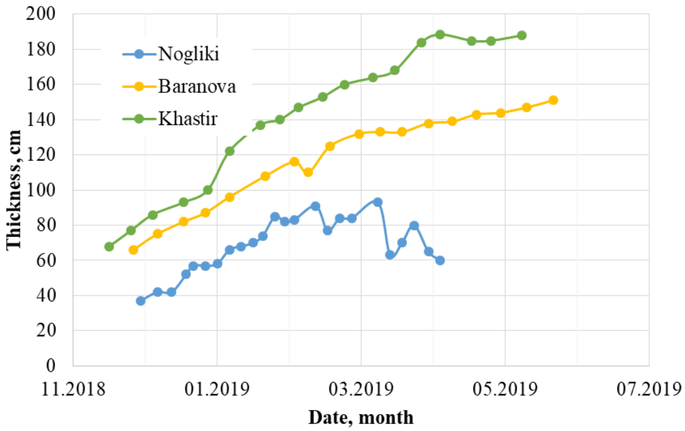

Fig. 4 - Thickness of ice for all bases.

Graphs of changes in ice density and salinity (Figs. 5 and 6) show insignificant dynamics of indicators for northern polygons. The degradation of the studied ice in April at the research site in Nogliki is confirmed by a sharp decrease in parameters due to ice melting. The change in the average ice temperature at all sites has a similar character.

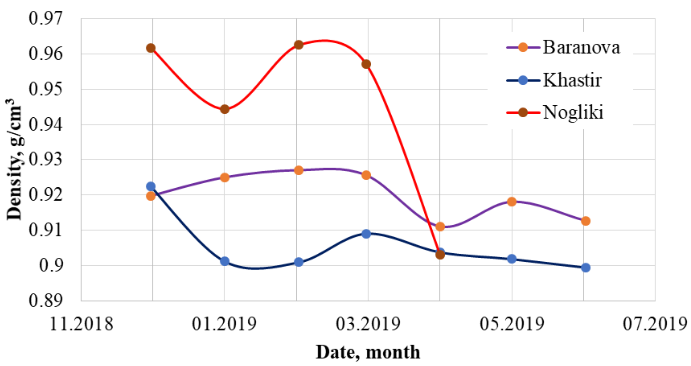

Fig. 5 - Density of ice for all bases.

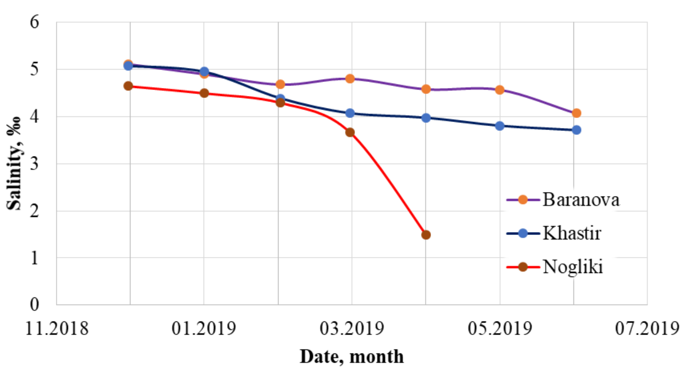

Fig. 6 - Salinity of ice on all bases.

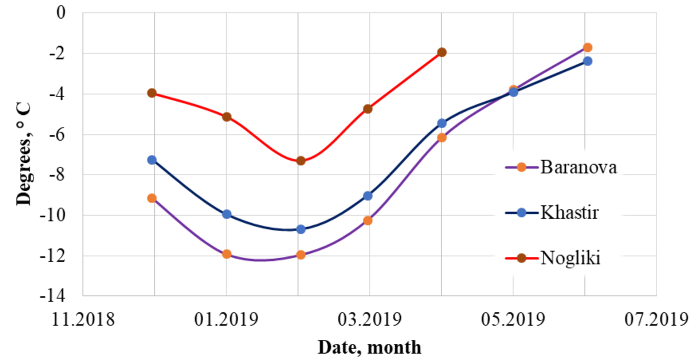

Fig. 7 – Ice temperature at all bases.

Strength properties of ice

Tests of ice for uniaxial compression and the borehole jack method were carried out at various loading speeds. As can be seen from the constructed graphs (Fig. 8 ~ 10), constructed for the average thickness value of strength, there is a general tendency to decrease at all polygons. The observed fluctuations in the middle of the season at the Khastir research site are likely to be related to the heterogeneity of the ice cover due to the close location of the river mouth.

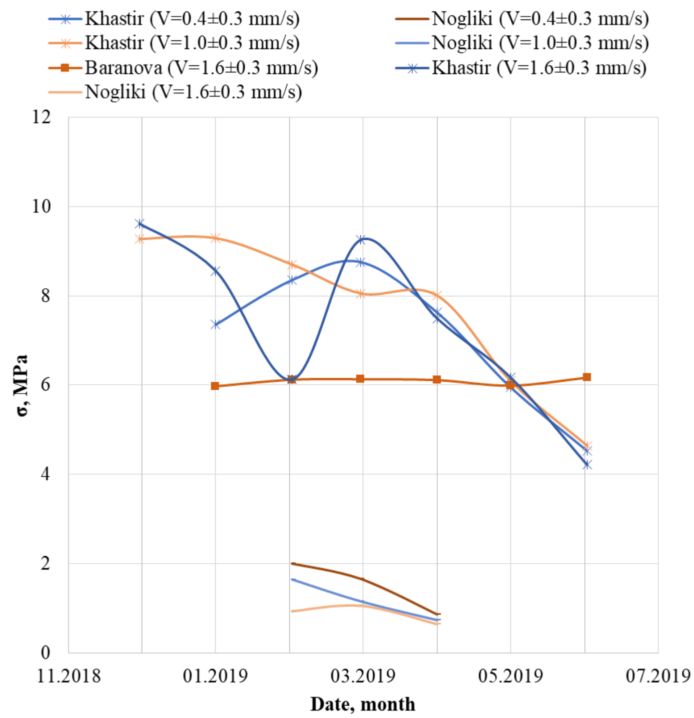

Fig. 8 - Uniaxial compression strength of samples drilled perpendicular to the surface of the ice sheet at different loading velocities for all bases.

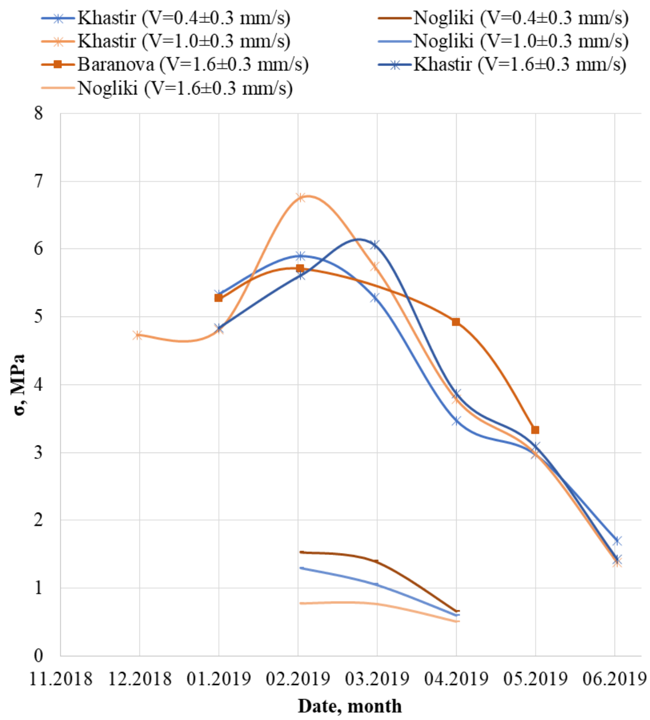

Fig. 9 - Uniaxial compression strength of samples drilled parallel to the surface of the ice sheet at different loading velocities for all bases.

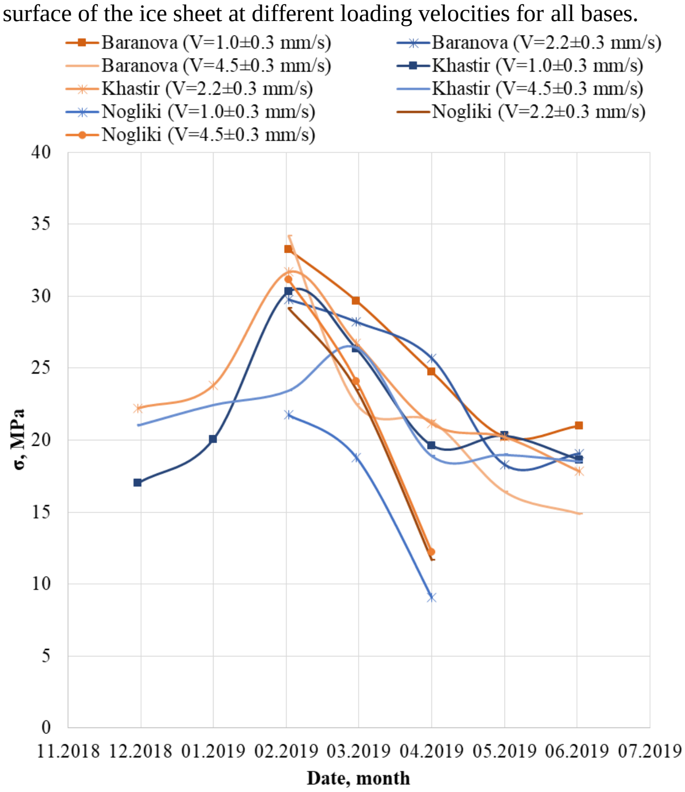

Fig. 10 – Borehole jack ice strength at different loading velocities for all bases.

THE DISCUSSION OF THE RESULTS

Most of the data obtained is consistent with the results obtained by other authors. For example, the strength, salinity, and temperature of ice at the end of the season are in good agreement with studies conducted by Johnston (2002, 2006). At the same time, some theoretical studies (Timco and Frederking, 1991) differ significantly from field data results.

Thus, the results of measurements of the parameters used to calculate the ice load were obtained. As can be seen from the graphs, there are clear trends in the change in the physicomechanical properties of flat ice. In Fig. 11, the relationship between the sum of the degrees of the frost and the thickness of the ice is clearly visible. Deviations from the main trend can be explained by short-term jumps in air temperature and the presence of snow cover. In addition, there is an obvious connection between changes in ice temperature and strength (Fig. 12), which means that the strongest ice can be expected in the coldest period of the ice season.

The decrease in the strength properties of ice was especially noticeable at the base in Nogliki, which is associated with a shorter ice season compared to the northern polygons, and, accordingly, a more visual dynamics of changes in the properties of ice. Also, based on the presented results, it can be concluded that the density and salinity of ice during the season before the beginning of ice melting do not significantly change and fluctuate within average values.

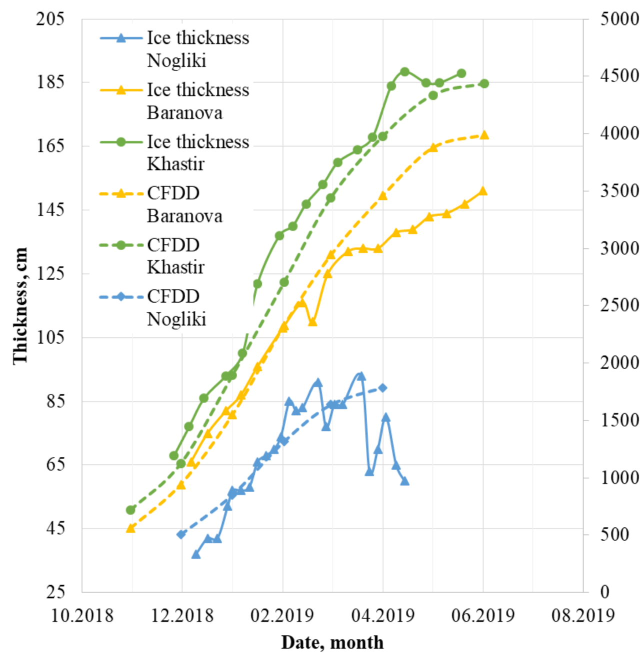

Fig. 11 - Sum of degree-days and thickness of ice for all bases.

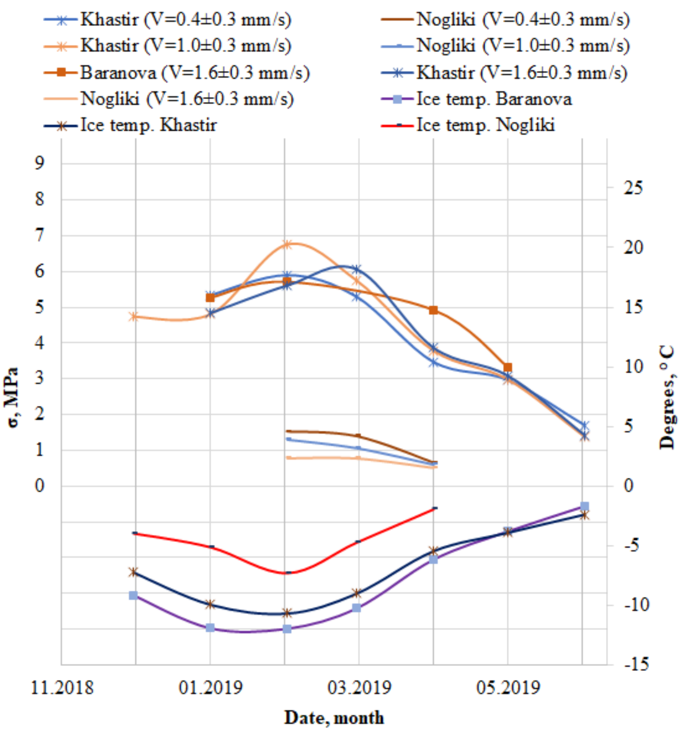

Fig. 12 – Uniaxial compression strength and ice temperature at all bases.

The obtained results indicate a significant dynamic in the basic design parameters of the ice cover used to calculate ice loads. As can be seen from the graphs in Fig. 13 the largest values of ice strength and ice thickness do not substantially coincide in time. From this, it can be suggested that the greatest ice load on the structures can be expected between these two points.

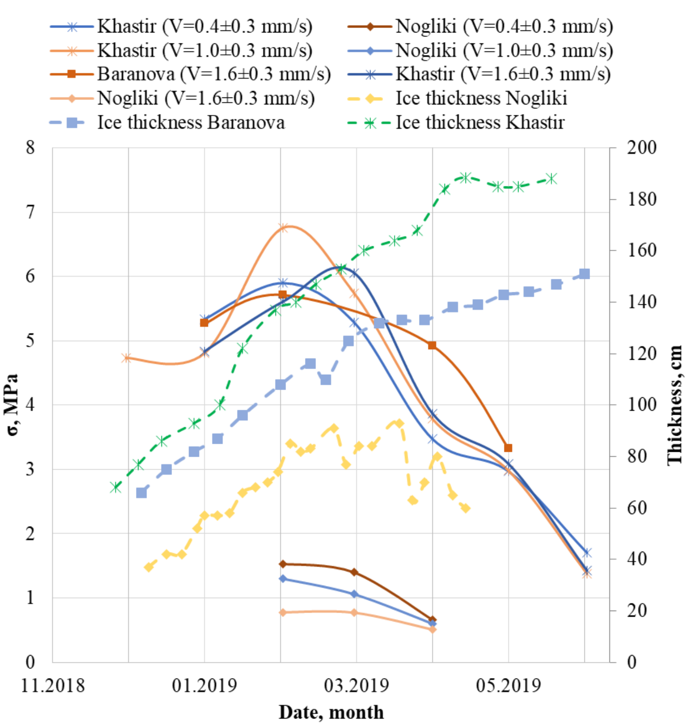

Fig. 13 - Uniaxial compression strength and thickness of ice for all bases.

CONCLUSIONS

The experiments and analysis of the data obtained show that the most characteristic seasonal variability is inherent in such parameters as ice thickness, ice temperature and strength characteristics. Due to the fact that the formation of ice is largely influenced by the sum of degrees of frost, and the strength of ice strongly depends on its temperature, we can conclude that it is necessary to study the nature of this influence and establish the corresponding dependencies. An understanding of these laws is necessary for the design of seasonal operations in the northern seas, as well as the calculation of the loads on temporary structures. It is necessary to continue this kind of research in order to accumulate statistical material and improve design standards for the northern regions.

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