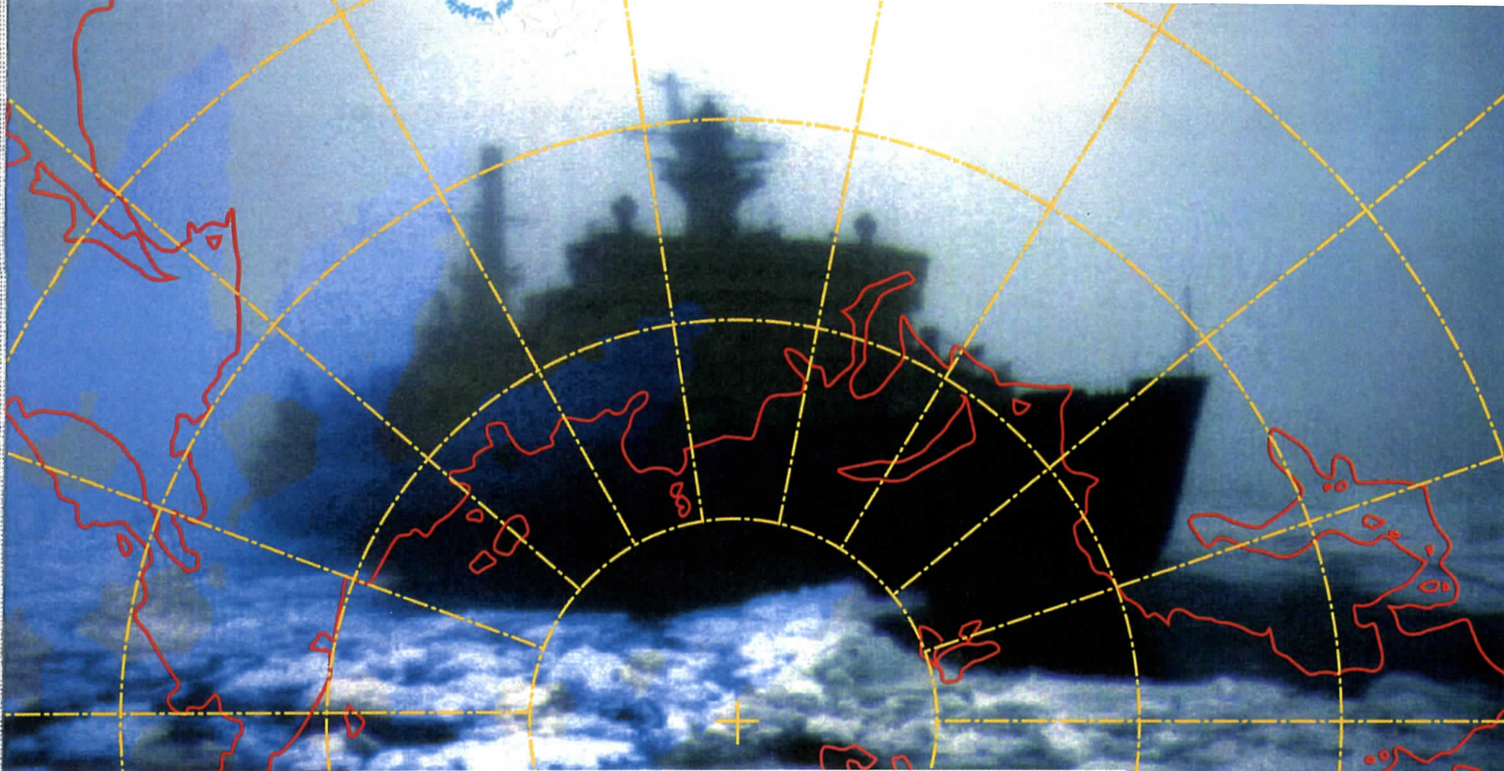
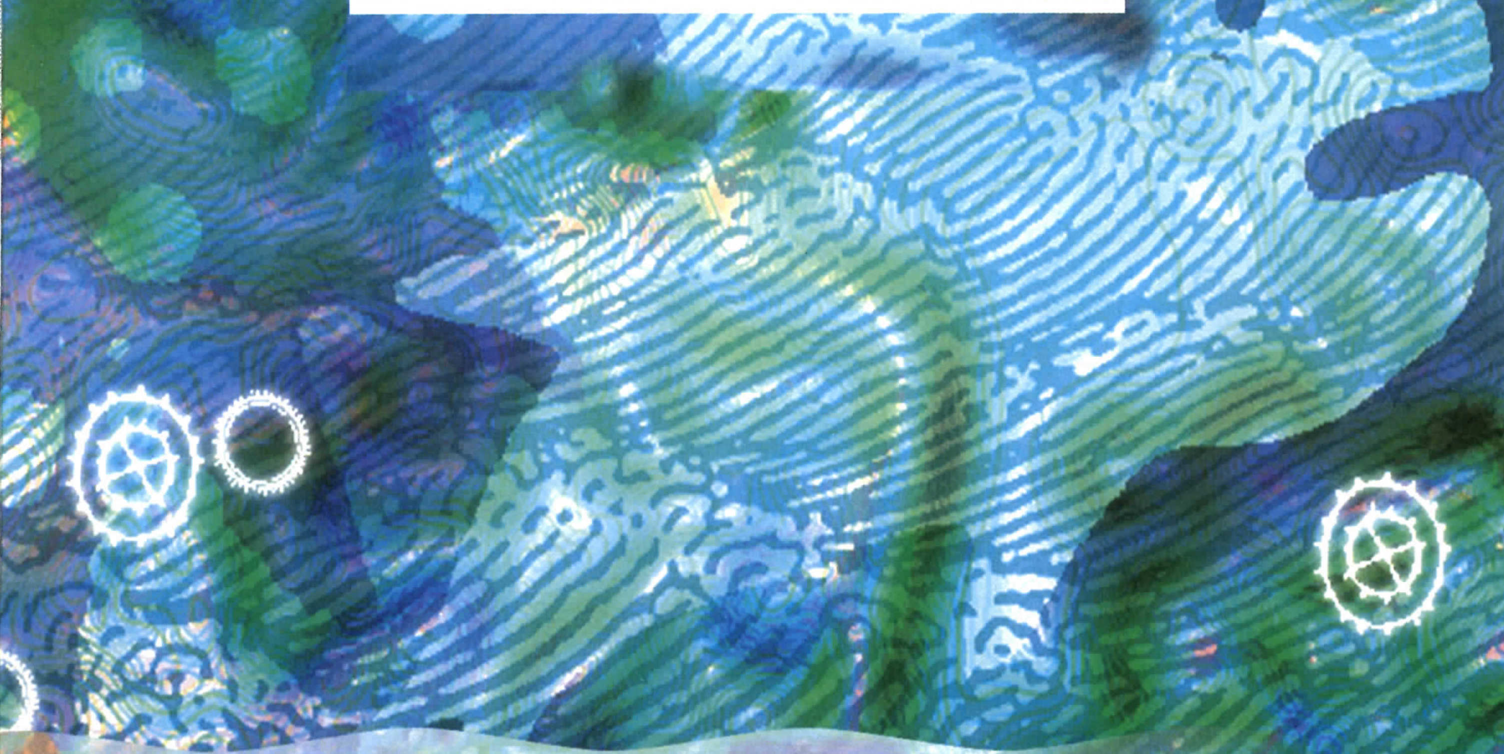


INSROP WORKING PAPER
NO. 39-1996, I.1.8

Influence of Ice Compression on Feasible Navigation on the Northern Sea Route

Torsten Heideman



INSROP International Northern Sea Route Programme

Central Marine Research & Design Institute, Russia

The Fridtjof Nansen Institute, Norway

Ship and Ocean Foundation, Japan

International Northern Sea Route Programme (INSROP)

Central Marine Research & Design Institute, Russia

The Fridtjof Nansen Institute, Norway

Ship & Ocean Foundation, Japan

INSROP WORKING PAPER NO. 39-1996

Sub-programme I: Natural Conditions and Ice Navigation.

Project I.1.8: Influence of Ice Compression on Feasible Navigation on the Northern Sea Route.

By: Torsten Heideman, M.Sc. (Nav.Arch.),
Senior Research Engineer, Arctic Research and Development

Address: Kværner Masa-Yards Inc.
Technology
Kaanaantie 3 A
FIN-00560 Helsinki
FINLAND

Date: 12 March 1996.

Reviewed by:

Dr. Norman Untersteiner, Department of Atmospheric Sciences,
University of Washington, USA.

Mr. Ken Croasdale, K. R. Croasdale & Associates Ltd., Calgary, Alberta, Canada.

What is an INSROP Working Paper and how to handle it:

This publication forms part of a Working Paper series from the **International Northern Sea Route Programme - INSROP**. This Working Paper has been evaluated by a reviewer and can be circulated for comments both within and outside the INSROP team, as well as be published in parallel by the researching institution. A Working Paper will in some cases be the final documentation of a technical part of a project, and it can also sometimes be published as part of a more comprehensive INSROP Report. For any comments, please contact the authors of this Working Paper.

FOREWORD - INSROP WORKING PAPER

INSROP is a five-year multidisciplinary and multilateral research programme, the main phase of which commenced in June 1993. The three principal cooperating partners are **Central Marine Research & Design Institute (CNIIMF)**, St. Petersburg, Russia; **Ship and Ocean Foundation** (SOF), Tokyo, Japan; and **Fridtjof Nansen Institute (FNI)**, Lysaker, Norway. The INSROP Secretariat is shared between CNIIMF and FNI and is located at FNI.

INSROP is split into four main projects: 1) Natural Conditions and Ice Navigation; 2) Environmental Factors; 3) Trade and Commercial Shipping Aspects of the NSR; and 4) Political, Legal and Strategic Factors. The aim of INSROP is to build up a knowledge base adequate to provide a foundation for long-term planning and decision-making by state agencies as well as private companies etc., for purposes of promoting rational decisionmaking concerning the use of the Northern Sea Route for transit and regional development.

INSROP is a direct result of the normalization of the international situation and the Murmansk initiatives of the former Soviet Union in 1987, when the readiness of the USSR to open the NSR for international shipping was officially declared. The Murmansk Initiatives enabled the continuation, expansion and intensification of traditional collaboration between the states in the Arctic, including safety and efficiency of shipping. Russia, being the successor state to the USSR, supports the Murmansk Initiatives. The initiatives stimulated contact and cooperation between CNIIMF and FNI in 1988 and resulted in a pilot study of the NSR in 1991. In 1992 SOF entered INSROP as a third partner on an equal basis with CNIIMF and FNI.

The complete series of publications may be obtained from the Fridtjof Nansen Institute.

SPONSORS FOR INSROP

- Nippon Foundation/Ship & Ocean Foundation, Japan
- The government of the Russian Federation
- The Norwegian Research Council
- The Norwegian Ministry of Foreign Affairs
- The Norwegian Ministry of Industry and Energy
- The Norwegian Ministry of the Environment
- State Industry and Regional Development Fund, Norway
- Norsk Hydro
- Norwegian Federation of Shipowners
- Fridtjof Nansen Institute
- Kværner a.s.

PROFESSIONAL ORGANISATIONS PERMANENTLY ATTACHED TO INSROP

- Ship & Ocean Foundation, Japan
- Central Marine Research & Design Institute, Russia
- Fridtjof Nansen Institute, Norway
- National Institute of Polar Research, Japan
- Ship Research Institute, Japan
- Murmansk Shipping Company, Russia
- Northern Sea Route Administration, Russia
- Arctic & Antarctic Research Institute, Russia
- ARTEC, Norway
- Norwegian Polar Research Institute
- Norwegian School of Economics and Business Administration
- SINTEF NHL (Foundation for Scientific and Industrial Research - Norwegian Hydrotechnical Laboratory), Norway.

PROGRAMME COORDINATORS

- **Yuri Ivanov, CNIIMF**
  Kavalergardskaya Str.6
  St. Petersburg 193015, Russia
  Tel: 7 812 271 5633
  Fax: 7 812 274 3864
  Telex: 12 14 58 CNIMF SU
- **Willy Østreng, FNI**
  P.O. Box 326
  N-1324 Lysaker, Norway
  Tel: 47 67 53 89 12
  Fax: 47 67 12 50 47
  Telex: 79 965 nanse n
  E-mail: Elin.Dragland @fni.wpoffice.telemax.no
- **Masaru Sakuma, SOF**
  Senpaku Shinko Building
  15-16 Toranomon 1-chome
  Minato-ku, Tokyo 105, Japan
  Tel: 81 3 3502 2371
  Fax: 81 3 3502 2033
  Telex: J 23704

INSROP
PROJECT I. 1. 8
Influence of Ice Compression on Feasible Navigation on the NSR

1. Summary

The different forms of ice compression are identified and briefly described. Wind is by far the most important factor causing ice compression.
Based on long term Russian statistics the probability of encountering ice compression is claimed to be in the order of 60%. However, this figure is not undisputed since it is not supported by observations from numerous Arctic voyages undertaken by KMY.
The present means of observing ice compression are briefly presented and found inadequate.
In the Russian database the ice compression is expressed with the help of a 0-3 ball scale. It is not possible to directly link this ball scale to the actual stresses in the ice field.
The obvious continuation to this investigation is to find a way to relate the readings of the ball scale to physically defined measures, such as stresses in the ice field or forces exerted on ships and structures.
Model tests in ice are considered the most cost efficient way to proceed.

2. Introduction

Ice compression is a phenomenon that has a drastic influence on the feasibility of Arctic operations. Experience has shown that today, even the most powerful icebreakers will become immobilised during events of severe ice compression. It is also known that even two nuclear icebreakers of Arktika-type cannot keep a single cargo vessel in motion during severe ice compression. This means that the influence of compression must be taken into account when calculations regarding NSR shipping operations are performed.
Despite its big importance there has been published surprisingly little systematic data about ice compression and how to account for it. In calculations ice compression is normally sidelined with the help of an unspecified down-time allowance which in turn is based on various subjective judgements.
From an analytic point of view there is a clear need to develop a procedure to include the effects of ice compression into the performance calculations.

2. 1. The Objective of the Report

The ultimate objective of INSROP Project I. 1. 8 is to develop the first ever tool to assess the influence of ice compression on ship operation, both from a technical and an economic point of view. It was decided that the total project will be covered by two reports.
This first one deals with the present knowledge of ice compression and the second one concentrates on creating the analytical computational tool to account for it.

In order to get started it was decided to survey the present status of Russian knowledge of ice compression along the NSR. The Arctic and Antarctic Research Institute in St. Petersburg was contracted to go through their databases and reports and compile a report. This present INSROP report is a translated and shortened version of the rather comprehensive AARI report in Russian. In our report we have extracted results of major interest from a navigational point of view.

The first part of this report describes briefly the different forms of ice compression and the factors that influence it.
The second part describes the present means to identify ice compression
The third and last part is a review of existing data on the occurrence of ice compression along the NSR.

2. 2. The Ball Scale in General

The ball scale is a relative, arbitrary scale widely used in Russian maritime and ice related science.
For instance, wind force is graded according to a ball scale, which supposedly is the same as the Beaufort scale.
Ice concentration is recorded on a 10-ball scale, where 0 means open water and 10 total ice cover.
Ice ridging is described on a 5-ball scale, which relates to the ratio between ridged ice area and level ice area.
Ice compression is graded on a 3-ball scale.
The ball scale does not necessarily have to be linear, which obviously seems to be the case when talking about ice compression or wind force, while ice concentration is graded using a linear ball scale.

3. The Different Forms of Ice Compression

Ice compression is normally divided into categories, based on their origins. The Russian practice is to divide the ice compression as follows:

Dynamic Ice Compression due to wind, tide and current
Static Ice Compression due to thermal expansion

Generally speaking the dynamic ice compression is the result of changes in the velocity field of the moving ice having a concentration of no less than 9-10 tenths.

3. 1. Ice Compression due to Wind

Wind is by far the most common factor causing ice compression. The wind has a predominant effect on the development of the ice cover of the Arctic Ocean. It forces the ice into motion, creating relative movements between masses of ice. The results of these movements are ice compression, rafting of level ice fields, ridging and the formation of polynias.

3. 2. Ice Compression due to Tide

The predominant feature of the tidal ice compression is its regular cycle, the intensity of which follows the orbit of the moon. The tidal ice compression is strong at new and full moon compared to what it is at half moon.
The tidal ice compression is mainly noticeable on the continental Arctic shelf and hardly detectable on the deep Arctic ocean.
From a navigational point of view, tidal ice compression is of much less importance than wind and current induced ice compressions are. In practice it can be noted in the Kara and Vilkitsky Straits and in the Gulfs of Ob and Yenisey. The main reason for mentioning the tidal compression at all is that it can magnify the ice compressions induced by wind and current.

3. 3. Ice Compression due to Current

As to ice compression the most problematic currents are those generated by "wind rises" and "wind descents". As these expressions are not self-evident an explanation might be appropriate.
"Wind rise" or "wind descent" is defined as the situation when a sharp change in the elevation of the ocean surface over a very short distance can be detected.
This situation arises when water masses with different velocity vectors, driven by wind, tide and current, meet each other. The phenomenon is aggravated in straits and areas, where the water depth rapidly changes.
In practice these "wind rises" and "wind descents" create local ice movement and ice compression. The flow of ice can be quite dynamic and the Russian expression for the phenomenon translated into English is "ice-river".
In "ice-rivers" speeds in excess of 6 knots have been recorded. Based on airborne ice reconnaissance the length of such "ice-rivers" vary between one to twenty nautical miles having a width ranging from hundreds of meters to a few miles. The duration of this phenomenon ranges from hours to days.
The flow speed is greatest in the middle of the "ice-river" decreasing towards the interface between the stationary and the moving ice. This change of velocity within the "ice-river" causes the pieces of ice to grind against each other forming brash ice.
Experience has shown that dangerous situations might arise if ships are caught in such "ice-rivers". The combined effects of rapidly flowing brash ice and ice compression have caused total losses of ships. Even icebreakers have difficulties to get out of these "ice-rivers". The normal navigational practice is to either try to circumnavigate the "ice-river" area or to wait for the phenomenon to cease.
"Ice-rivers" have often been observed in the Kara Strait, to the north of Dikson Island and at the mouth of the Gulf of Yenisey.

3. 4. Ice Compression due to Thermal Expansion

Thermal compression appears in connection with fast and big changes in the air temperature.
The prerequisite is compact, level ice and the presence of confining shorelines.
Field measurements have recorded 6 m horizontal movements.
From a navigational point of view thermal expansion is not considered a problem but it should be accounted for when designing for instance bottom founded structures. Due to its static nature the

contact conditions between the structure and the ice can become favourable for large ice forces to be transmitted.
If a ship is trapped by thermal expansion it is easily released by opening an adjacent channel by an icebreaker.

4. Means to Identify Ice Compression

The most common method to identify ice compression is to study the behaviour of the channel behind the ship. Due to the effect of ice compression the channel closes behind the ship and the length of the open channel is an inverse measure of the intensity of the ice compression.
For Arctic icebreakers the Russians have developed the use of the "Observation Mile", fig. 1.

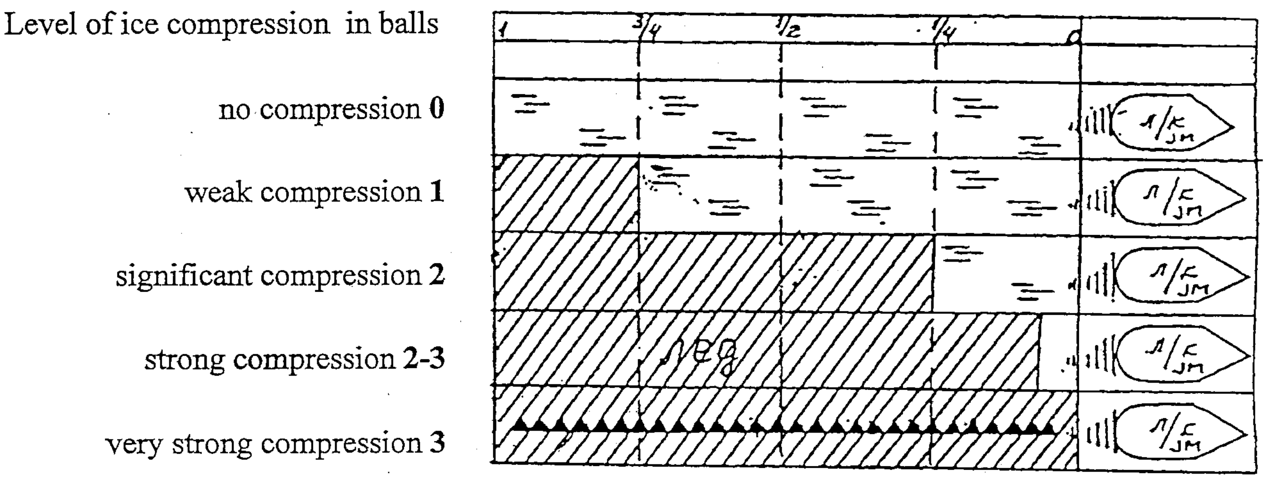


Fig. 1. Definition of the level of ice compression based on the closure of the channel behind the icebreaker using the "Observation Mile".

As mentioned before the thickness of the ice influences its behaviour under compression. Young ice, less than 30 cm, normally becomes rafted. 30-50 cm thick ice becomes partly rafted and partly ridged while ice more than 50 cm always becomes ridged.
In the Russian data base ice compression is generally expressed with the help of the 0-3 ball scale. The ball reading is to a great extent dependent on the visual impression of the dynamic behaviour of the ice. It is known that the dynamic behaviour of ice decreases with increasing ice thickness. This means that the same ball reading in thin ice and in thick ice corresponds to different compressive forces. This fact together with the subjectivity of the ball scale and its non-physical background are the major drawbacks of the ball scale.

From the mariner's point of view there has been developed a table to classify the ice compression.

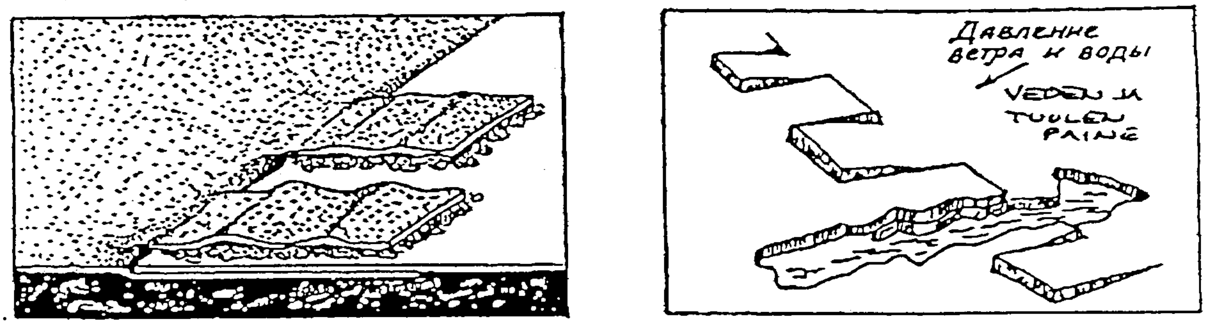
Identified by:	Intensity of ice compression		
	1 ball = weak	2 balls = significant	3 balls = severe
The channel behind the icebreaker in grey-white ice	The channel closes slowly	The channel is closed, a pressure ridge is formed in the channel	The pressure ridge moves out of line causing ridging and rafting beside the channel
The behaviour of the ice along the sides of the assisted vessel	Individual floes of ice rise	Ridging along the ship's side. The ice does not reach the deck	Heavy ridging. The ice builds up and falls eventually onto the deck
The response of the ship and the hull girder	The ship experiences occasional blows both in transverse and longitudinal directions	Strong blows, the ice and the ship's hull make noise, 1-2° heel	Constant blows, the shell plating bends, ice damage possible, more than 4° heel
The behaviour of the ice at the channel edges	The ice does not move aside or break when the icebreaker cuts the assisted vessel	Ice floes become rafted when the icebreaker moves	Multiple rafting when the icebreaker moves
The effectiveness when the icebreaker assists ships of UL or ULA classes	The assisted ship has difficulties to follow the icebreaker and it stops occasionally	The assisted ship has to be cut continuously and the icebreaker sometimes moves by ramming	The assisted ship is unable to move and the icebreaker moves by ramming and becomes occasionally stuck
The speed of a convoy in 60-80 cm thick ice with ridges	8-12 knots	2-6 knots average 4 knots	0-2 knots average 1 knot

Table 4.

5. The Occurrence of Ice Compression Along the NSR

5. 1. Wind Induced Ice Compression

When young ice, that is less than 30 cm thick ice, is subjected to ice compression it normally responds by rafting. This means that larger floes are pushed upon or dive under each other to form layer type ice formations. The presence of ice compression in young ice is often visualised by "finger rafting", fig. 2.



1　　　　　　　　2

Fig. 2."Finger rafting" of young ice during ice compression.

1-at the interface between drifting ice (left) and stationary level ice
2-among drifting ice

When the young ice reaches more than 30 cm in thickness it is called thin first year ice. At this stage it starts to lose its rafting capability under compression and instead it forms pressure ridges. The amount of ridging depends clearly on the intensity and duration of the ice compression. Close to the shoreline the ridges might cover 80% of the surface, which in Russian ball units corresponds to a ridge rating of 4-5 balls on a 5-ball scale.

The deformation of an ice cover under compression depends on its ability to bend, break and pile up. This means that the compressive force and the strength properties and the thickness of the ice are interconnected, the stronger or thicker the ice, the higher compressive force can be transmitted at the same rate of deformation.

The presence of the shoreline, islands, shoals and shallow water bring changes to the velocity field of the moving ice, causing compression. During onshore winds the intensity of the ice compression grows towards the shore.

There is a direct relationship between the ice compression and the wind stating that the compressive force and the events of compression depend on the speed, duration and direction of the wind. In the open sea the wind speed is predominant while closer to shore the duration and direction become more important.

Fig. 3.:shows the correlation between the ice compression on the 3-ball scale and the wind force according to the Beaufort scale at different locations in the western Arctic and fig. 3. the correlation between the ice compression and the wind speed in the south-western Kara Sea during the fall-winter season.

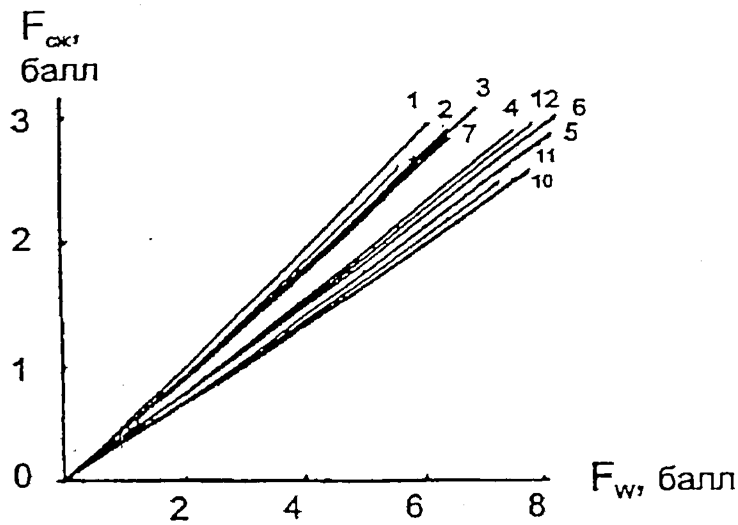


Fig. 3. The correlation between the ice compression on the ball scale and the wind force on the Beaufort scale at different sites in the western Arctic.

1-Kara Gate	2-Cape Kharasevey	3-Golomiannyi Island
4-Pravdy Island	5-Belyi Island	6-Cape Chelyuskin
7-Amderma	8-Dikson Island	9-Cape Peschanyi
10-Preobrazhenia Island	11-Bay of Pronchischeva	12-Andreia Island

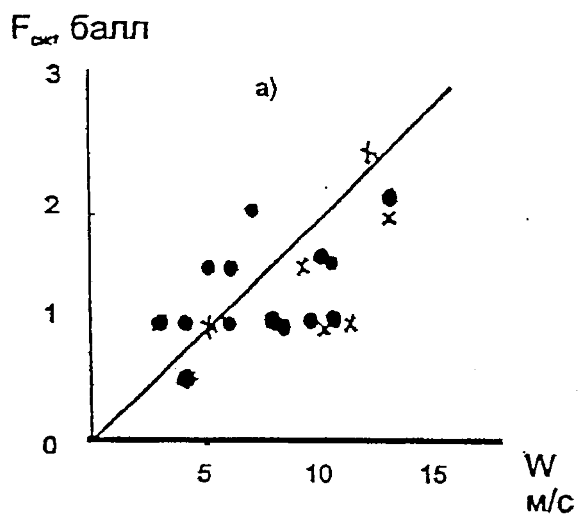


Fig. 4. The correlation between the ice compression on the ball scale and the wind speed in m/s on the south-western Kara Sea during the fall-winter period.

O-observations made on board icebreaker Lenin
X-observations made on board icebreaker Murmansk

Figs. 3. and 4. clearly show the strong correlation between ice compression and wind speed. Generally this means that ice compression is more frequent during the windy season of the year.

Fig. 5. gives an idea of the probability of severe wind induced ice compression in the area between Belyi and Dikson Islands.

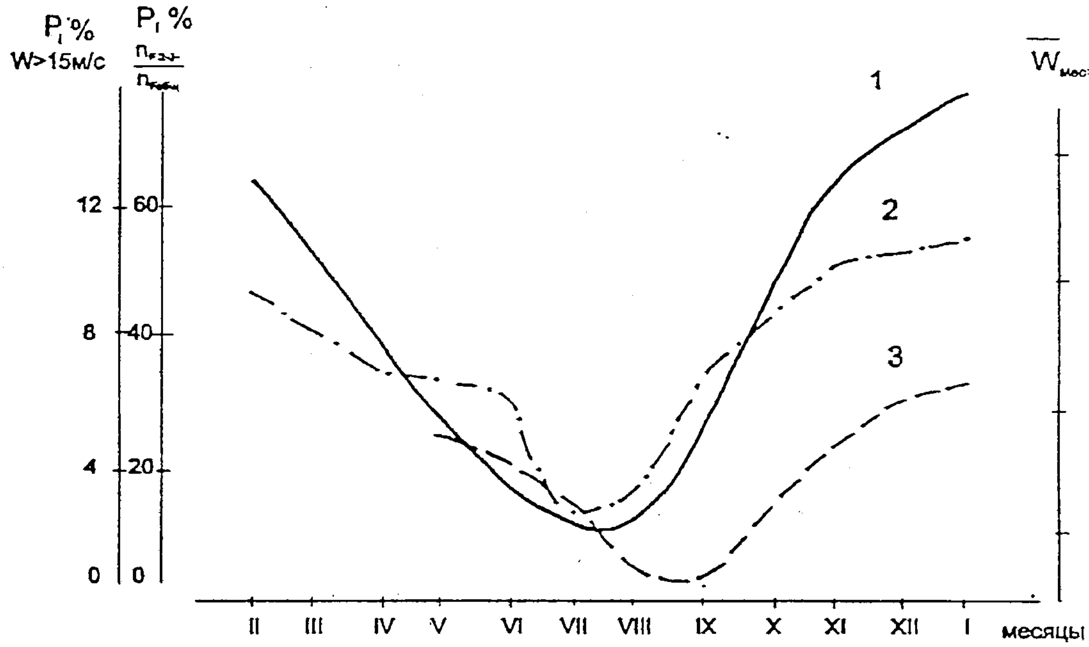


Fig. 5. The seasonal fluctuations of wind speed and probability of severe ice compression in the area between the Belyi and Dikson Islands.

1-P% (W>15 m/c) means probability of wind speed over 15 m/s
2-W m/c is monthly average wind speed m/s
3-P% (n_{F2-3} / n_{all}) is the relative amount of strong ice compression (2-3 balls) events to all events of ice compression

Likewise the fraction of the total distance that is navigated in ice under compression is strongly dependent on the average wind speed or wind force. Fig. 6. gives an example of this.

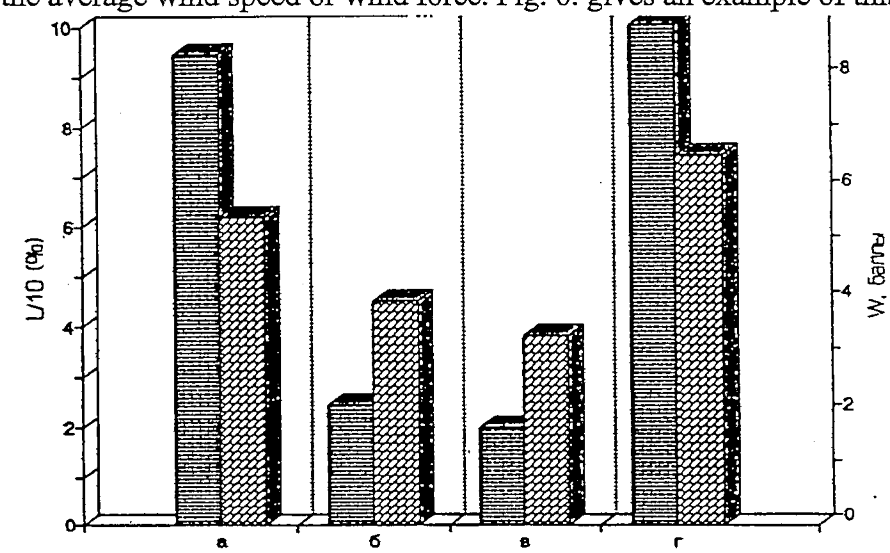


Fig. 6. The correlation between the wind force on the Beaufort scale and the relative distance spent in compressive ice on the south-western Kara Sea during the fall-winter season.

1-relative distance spent in compressive ice to the total distance in ice
2-average daily wind force on the Beaufort scale

Statistics from the Kara and the Laptev Seas reveal that in the cases of 2-3 and 3 ball ice compressions the directions of the compressions were the same as those of the winds in 88% of the cases.
Furthermore statistics show that the ice compression intensity distribution changes from year to year in the same area. Fig. 7. shows the ice compression frequency distribution for three different years on the route from the Kara Gate to the Gulf of Yenisey based on icebreaker observations.

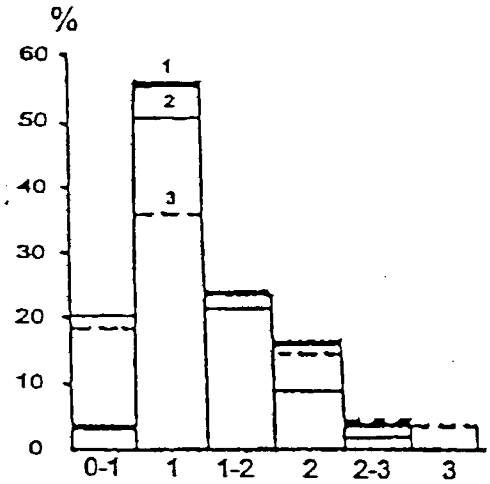


Fig. 7. The ice compression frequency distribution for three different years on the route from the Kara Gate to the Gulf of Yenisey during the fall-winter navigation season.

1-November-December 1970
2-November-December 1971
3-November 1972-January 1973

The present knowledge of the wind induced ice compression on the NSR is summarised in the following three tables.

Table 2. shows the correlation between the wind speed and duration, and the probability of the occurrence of ice compression expressed in %.

Wind speed (m/s)	Duration (hours)			
	6	12	18	24
0-5	0	20	92	100
6-10	46	100	100	-
more than 11	67	100	100	-

Table 2.

Table 3. shows the correlation between the wind speed and the intensity distribution of the occurring ice compression expressed in %.

Intensity of ice compression (balls)	Wind speed (m/s)		
	0-5	6-10	more than 11
3	-	3	4
2-3	-	7	6
2	-	10	15
1-2	20	30	30
1	40	30	35
0-1	40	20	10

Table 3.

Table 4. finally shows the probability of the occurrence of ice compression along the NSR during the winter period expressed in %.

Period	Ice compression (balls)					
	3	2-3	2	1-2	1	0-1
Sept.-Nov.	1	2	4	13	21	17
Dec.-Feb.	1	2	4	12	24	17
March-May	1	2	3	12	21	17

Table 4.

5. 2. The Effects of Shorelines and Shallow Water on Ice Compression

During onshore winds, with a force of 4-5 Beaufort and a duration of 1-2 days, the ice compression grows almost linearly towards the shore. With offshore winds the situation is the opposite. Fig. 8. gives an example of this.

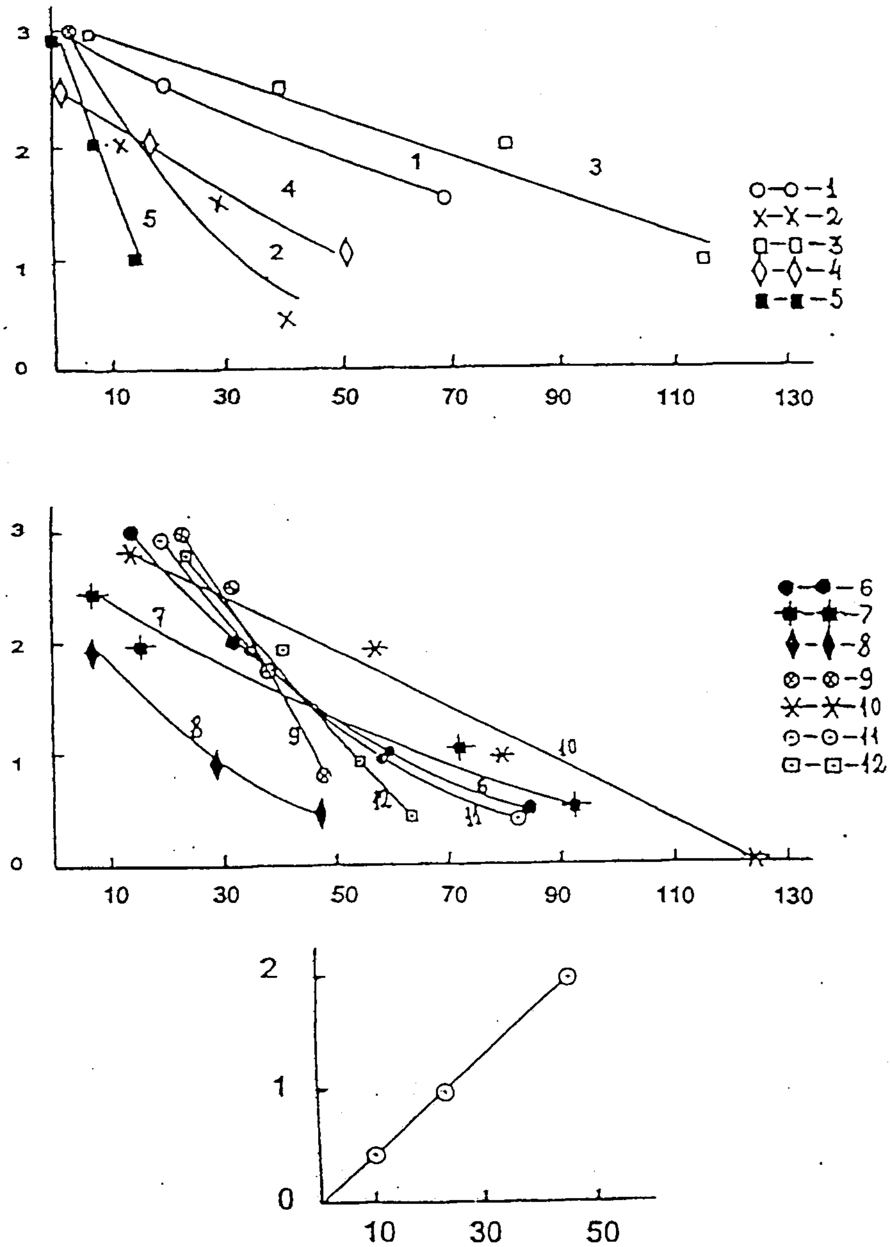


Fig. 8. The correlation between the degree of ice compression in balls and the distance from the shore in nautical miles at different locations during onshore winds, the two upper graphs. The lower graph shows an opposite tendency during offshore winds.

1-Amderma
2-Marre-Sale
3,4-Cape Kharasevey
5-Vilkitsky Strait

6,7-Belyi Island
8-Dikson Island
9-Buffin's Sea
10-12-Vilkitsky Island

During onshore winds strong compression can be found 0-10 nautical miles from the shore. The reason for this is that the pack ice becomes grounded when approaching the shore. Investigations around Belyi Island reveal that the boundaries of the ice compression zone quite closely follow the 20 m depth curve, fig. 9

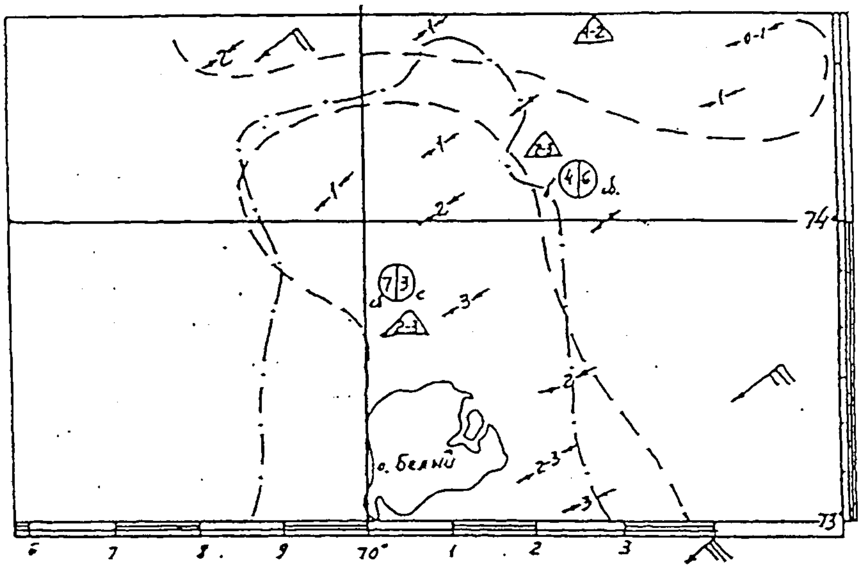


Fig. 9. The zone of ice compression around Belyi Island

1-The boundary of the ice compression zone
2-The 20 m depth curve

6. Conclusions

Wind is by far the most important cause of ice compression. In almost 90% of the cases of severe ice compression, that is more than 2 balls, the direction of the wind coincides with that of the ice movement.
Offshore the duration of the wind is more decisive for ice compression while closer to the shore the direction of the wind is more important.
During onshore winds it is generally advisable to navigate as much offshore as possible and vice versa.
There are indications that ice compression is common in the 15-20 m water depth area.
Much of the navigation in the coastal Arctic waters, particularly from the Belyi Island to the east, takes place in water depths around and below 20m and consequently active avoidance of ice compression is from a navigational point of view hard to achieve. In practice the vessels have to be designed so that they can operate in ice compression up to a certain level.
In order to establish this level the probabilities of occurrence of ice compression in table 3 will be presented in the form of cumulated probability in fig. 10 below.

Fig.10 Cumulative probability of ice compression

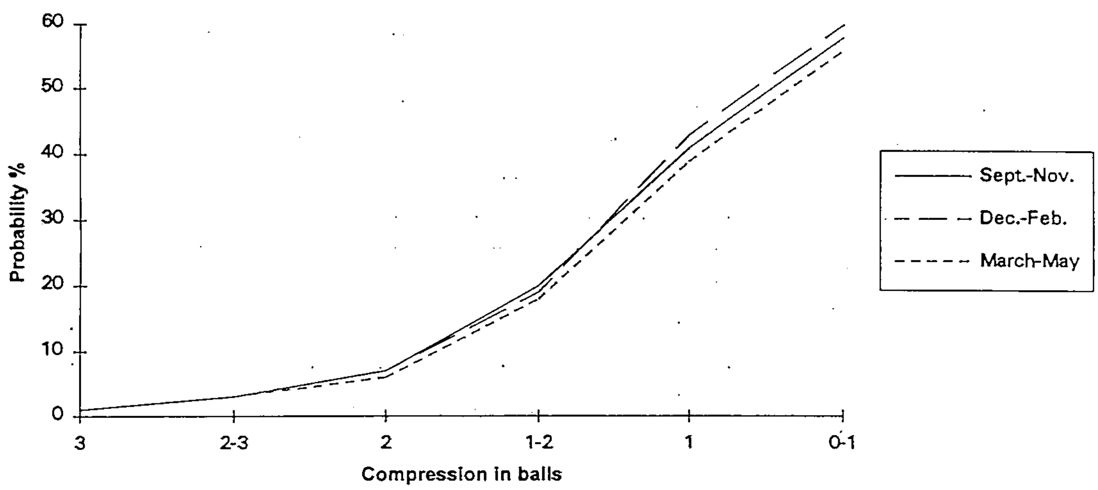


Fig. 10. claims that the probability of encountering ice compression on the NSR is as high as almost. 60%. Further it tells that the bulk of this ice compression is of lower intensity, less than 2 balls.
Because this probability distribution is supposed to apply to the entire NSR, in every point at any time it means that the probability figures also apply to distances. In other words it means that roughly 60% of the navigated distance in ice is under pressure on the NSR.
The experience of KMY regarding Arctic shipping, collected over a period of more than 20 years, does not support this 60% probability figure for ice compression.
During this period of time one event of severe ice compression was recorded. In this incident a cargo vessel of the UL-class was damaged which according to table 4 requires 3 balls of ice compression. Several events of less intensive ice compression have been recorded but not so many that the 60% figure can be supported.
The reason for this discrepancy could maybe be that even experienced observers sometimes tend to overestimate both the presence and the intensity of ice compression due to the lack of objective ways to record it. The icebreakers operate usually with a four hour watch system and it is normal procedure that ice conditions are recorded once during each watch unless something

extraordinary happens. This leads to that ice compressions of low intensity in particular become over represented.
The general assumption, supported by table 4, is that navigation is stopped by ice compressions greater than 2 balls. Considering the alleged conservativeness of fig. 10 this corresponds to a down-time figure of roughly 5%.
Such a down-time figure is quite acceptable according to KMY's experience from transit calculation results. It will not cause a demand for additional storage capacity beyond what normally would be considered appropriate for Arctic shipping operations. Much greater down-time figures are however not acceptable, for instance, if ice compression with an intensity of 1-2 balls were allowed to stop the navigation this would raise the down-time figure to an unacceptable 20%.
The result of the discussion about the acceptable down-time figure is that a ship should be able to operate in ice compressions up to the intensity of 1-2 balls, which based on fig. 10, even considering the uncertainties in the presented figures, by far are the most common ones.
When designing a ship capable of operating in 1-2 balls of ice compression the designer needs information about how this intensity of ice compression translates into terms of physical added ice resistance. Unfortunately the present survey of the Russian knowledge did not reveal any conclusions about the correlation between the ice compression in ball units and physically measurable units.
It is the opinion of KMY that the continuation of this project should be directed towards finding this link.
The Russians have published results from icebreaker tests where the parameters are speed of advance and intensity of ice compression on the ball scale, (V. A. Voevodin: To the Problem of Ice Compression Effect on Navigation, AANII Transactions 384, 1981).
It is possible to reproduce the results from the full scale tests in an ice model basin where the compressive force can be monitored and controlled. As a result the relationship between the compressive force and the ice compression expressed in balls can be established.
The obvious next step would be to apply the compressive force corresponding to 1-2 balls to a model of a representative Arctic cargo vessel to find out what that ice compression means in the form of added ice resistance.

ЛИТЕРАТУРА (Часть I)

1. Аппель И.Л.,1976. О силах сжатия и внутреннего сопротивления в ледяном покрове при нажимном дрейфе.Тр.ААНИИ, т.32О, с.153-16О.
2. Арикайнен А.И. Чубаков К.Н., 1987. Азбука ледового плавания. М.,изд-во "Транспорт", 224 с.
3. Атлас ледовых образований, 1974, ААНИИ, Л., Гидрометеоиздат, 140 с.
4. Бенземан В.Ю., 1989. "Ледовые реки" арктических морей. Тр.ААНИИ, т.417, с.91-99.
5. Бородачев В.Е., Бацких Ю.М., Михайличенко В.В., Потапов В.Р. 1987. Термические сжатия ледяного покрова и обеспечение мер безопасности транспортных судов и инженерных сооружений. Пробл. Аркт. и Антаркт., вып.63, с. 99-1О2.
6. Бузуев А.Я., Федяков В.Е., 1979. Вероятностная оценка повторяемости условий возникновения ветрового сжатия льда в зимний период. Тр. ААНИИ, т. 364, с.70-74.
7. Bradford D.,1972. Sea ice pressures observed in the second "Manhatten" voyage. Arctic, Vol.25, N 1, pp.34-39.
8. Воеводин В.А.,1975a. О методике определения сжатия льда с судна в осенне-зимний период. Тр.ААНИИ, т.126, с.134-141.
9. Воеводин В.А.,1975b. О некоторых особенностях осенне-зимних сжатий льда. Тр.ААНИИ,т.126, с.53-58.
10. Воеводин В.А.,1978a.Особенности ветрового сжатия льда а Северном Ледовитом океане.Тр.ААНИИ, т.354, с.97-1О3.
11. Воеводин В.А.,1978b, Роль сжатия в формировании ледяного покрова Арктики. Тр.ААНИИ, т.354, с.113-118.
12. Воеводин В.А.,1978c, Образование зубчато-наслоенного льда в результате сжатия. Тр.ААНИИ, т.354, с.85-88.
13. Воеводин В.А.,1978d. Ветровые сжатия морских льдов и их влияние на судоходство.Тр.ААНИИ. Л.(автореф. диссертации на соиск. уч.степ. канд. географ.наук).
14. Воеводин В.А.,1979a. Особенности ледовой авиаразведки и ее эффективность при проводке судов в условиях сжатия льдов. Тр.ААНИИ льдов.Тр.ААНИИ, т.363, с.134-139.
15. Воеводин В.А., 1979b. Применение газо-турбинного вертолета "МИ-2" для проводки судов во льдах. Пробл.Аркт.и Антаркт.,вып.35, с.113-114.
16. Воеводин В.А., 1981a. Сжатие льда в осенне-зимний период на трассе пролив Карские Ворота - Енисейский залив. Тр.ААНИИ, т.372, с.147-154.
17. Воеводин В.А., 1981b. К вопросу о влиянии сжатия льдов на судоходство. Тр.ААНИИ, т.384, с.135-138.
18. Воеводин В.А., 199О. Зависимость сжатия морского льда от различных параметров поля атмосферного давления. Тр.ААНИИ, т.418, с.81-88.
19. Voevodin V.A.,1993. Regularites and specific features of wind-induced ice compaction in the Arctic Ocean and Antarctic. Nansen Centenuial Symposium, Bergen,Norway,Poster 36.
20. Воеводин В.А., Лощилов В.С., 1972. Определение элементов дрейфа ледяного покрова и перемещения кромки льда с помощью радиолокационной станции бокового обзора "Торос". Пробл.Аркт.и Антаркт., вып.4О, с.23-3О.
21. Воеводин В.А., Драбкин В.В., Лощилов В.С., 1977. Инструментальные аэрометоды для определения сжатия льда."Вест.Ленингр.ун-та", N 6, с.123-133.
22. Воеводин В.А., Лощилов В.С., Борисов Р.А., 198О. Применение самолетной РЛС БО для исследования морских льдов. В сб."Иссл.и освоен.Мирового океана", изд.ЛПИ, вып.72, с.4О-5О.

APPENDIX

REVIEWS AND THE AUTHOR'S RESPONSE TO THEM

UNIVERSITY OF WASHINGTON
DEPARTMENT OF ATMOSPHERIC SCIENCES, BOX 351640
SEATTLE, WASHINGTON 98195-1640
Tel: (206) 543-4250
Fax: (206) 543-0308

FAX COVER SHEET

DATE: December 14, 1995

TO: Ms. Elin Dragland **FAX:** 47 67 12 5047

FROM: Norbert Untersteiner **FAX:** 206 543-0308

TOTAL NUMBER OF PAGES, INCLUDING THIS COVER PAGE: 3

Comments....

University of Washington

Department of Atmospheric Sciences, Box 351640 *14 Dec.1995*
phone: 206-543-4250 / fax: 206-543-0308

Ms Elin Dragland
INSROP
The Fridtjof Nansen Institute
PO Box 326
N-1324 Lysaker, Norway

Dear Ms Dragland,

In accordance with your request I offer the following comment on the INSROP Discussion Paper entitled "Influence of ice compression on the feasible navigation on the NSR".

The title should read "....on the **feasibility** of navigation along the NSR".

This article does not conform with any of the usual types of technical publication. It is too selective and brief to be a monograph or treatise, it does not qualify as a scientific article for lack of new material, and it is too brief to be called a review article. Among other unusual features, the article does not refer to any basic scientific literature, and it does not mention from what data the given statistical information was derived. Yet, the manuscript contains assorted items of information that are useful and perhaps not easily found under one cover in the standard technical literature.

As the author points out, the paper was derived from a much larger manuscript prepared by the staff of AARI in St.Petersburg. an institute founded 75 years ago and in possession of a very large data base. On the other hand, it is possible, or even likely, that some of the data pertaining to ice conditions along NSR are restricted in light of their value to Russian naval operations. Thus it seems difficult for the reviewer to guess to what extent the brevity light content of this manuscript are the result of compression, omission, or limited data..

Some specific points are summarized below :

- Section 1 should be called "Summary".
  The probability of encountering ice compression along the NSR is quoted to be 50 % according to Russian date, and to be some other value according to KMY data. I don't know how to interpret such a statement

because the probability of encountering any **possible** event must approach 100 % as the duration of the journey increases.

- The word "ball" in Russian means "number". It is often used in the sense of "scale" (as in the 12-step Beaufort Scale for wind). The Russians define ice pressure on a qualitative four-step scale of none-weak-medium-strong. If this scale is explained in the beginning of the manuscript it could, for instance, be called PS (for pressure scale) throughout the text. The term "ball" is not acceptable in English. (On p.5 another "ball" scale, this time for ice ridging, is mentioned but not explained.)
- If Table 4 were moved to the beginning (Section 3), the reader would understand from the beginning how the pressure scale is defined.
- Several graphs in Section 4 show the relationship between wind velocity and ice compression. The obvious importance of the proximity of land is mentioned, but the level of discussion is extremely simple and descriptive.
- Section 5 should be at the beginning of the essay.
- In section 6 (Conclusions) it is again stated that the probability of encountering compression along the NSR is 60 % (compared to 50 mentioned in the summary) or that, in an equivalent sense, 60 % of the length of the NSR are under pressure. Since these probabilities are not related to units of time, the information is practically meaningless.
- Toward the end of the manuscript we find the sentence ".....the present survey of Russian knowledge did not reveal any conclusions about the relation between the ice compression in ball units and physically measurable units....". This is not surprising because the state of stress in natural, fractured sea ice is so complex that it has so far resisted all attempts by scientists and engineers to devise generally applicable mechanics. There is an enormous body of technical literature about this subject in existence, and the suggestion (at the end) that INSROP should settle the problem by conducting compression tests with the model of an arctic cargo ship seems extremely naive.

I am not sufficiently familiar with INSROP editorial policies to recommend specific action. The present manuscript is quite readable (although in need of some minor style editing) but very light in content. Its primary message are a few practical and empirical operating rules based Russian shipping experience.
With the improvements suggested above, this manuscript might become an appendix to some more substantial treatise about ice and navigation along the NSR.

Yours sincerely,

N. Untersteiner

Norbert Untersteiner

Fax Message from
K. R. Croasdale & Associates Ltd.

To: Elin Dragland

Organization: INSROP Secretariat

Fax. No: 011 47 6712 5047

Date: Jan 7 1996

Number of Pages (including cover): 4

Re: Review of Discussion Paper for Project 1.1.8

I attach my review, I hope that it will be useful.

Yours sincerely,

Ken Croasdale

K. R. Croasdale & Associates Ltd.
334, 40th Ave. S.W.
Calgary, Alberta, Canada, T2S 0X4

Phone: 403 243 7787

Fax: 403 287 7889

INSROP Project 1.1.8: "Influence of Ice Compression on the Feasible Navigation of the NSR"

A Discussion Paper by Anders Backlund

Reviewed by Ken Croasdale

Review comments are provided in point form below:

- This is an interesting paper containing useful data on an important topic. I believe that there are some improvements to the structure of the paper which, if implemented, will make it more logical. Specifically, Section 5 which describes how the ball scale is defined should probably go ahead of Section 4 which discusses occurrence of ice compression in terms of the ball scale.

- The reference to the 5 ball scale on page 4 is an isolated definition which should probably be integrated into, or cross-referenced in, Section 5.

- The discussion on page 4 is useful and to a large extent is a summary of the conclusions which can be drawn from examination of the Russian data which follows.

- One point made which does not seem to be supported by the Russian data is the effect of ice strength and thickness. It is certainly logical and probably true that the compressive forces that can be transmitted through an ice field are limited by the ice ridging forces, which in turn, should be a function of thickness and strength (see Croasdale and others, 1992). However, examination of Table 3 shows very little difference in the occurrence of ice compression with time of year. All other factors being equal, one might have expected the December - February period to show the highest incidence of ice compression as the combination of ice strength and thickness is the highest, but this is not the case. Perhaps this point deserves some discussion.

- Overall, although somewhat empirical, the Russian data on ice compression is very enlightening and useful to the study at hand. The discrepancy between the Russian data and KSL experience should not be dismissed as simply as it has been. In a scientific sense, an objective comparison of the experience of the two groups will require that detailed data from both groups be equally presented. In this paper the reader only has the detailed data from the Russian experience, and only some overall comments on the KSL experience. It is recommended that specific statistics from the KSL experience be included if the paper is to have scientific credibility.

▪ On the other hand, if the main conclusion is to be that ice compression of greater than about 2 balls is limited to a probability of about 5 %, then the KSL experience is somewhat irrelevant, as even the Russian data only shows about 7 %. The additional conclusion of a 20% downtime for ice compression of 1-2 balls does not seem to be supported by Russian experience, which from table 4 would seem to suggest an average speed of about 6 knots could be sustained for 1 - 2 balls.

▪ In my opinion, the direction the study proceeds from now depends to some degree on the priorities and future scenarios for the NSR. If the main emphasis is to construct a prediction model for ice compression which will help determine transit times using vessels of existing design; then the need for model tests is somewhat doubtful. Surely, model tests would only be useful in improving hull and propulsion design to better cope with ice compression. Such research could be useful in enabling transit times to be reduced. But on the assumption that a major investment in new ships is likely to be made. It would also be necessary to trade-of any increased capital and operating costs of new vessels to cope with ice compression against the benefits of reduced transit times.

▪ In terms of a prediction model and possible forecast model, I would recommend that a more detailed examination of experience to date might be a better way to go. Can the Russian and KSL statistics and experience be more precisely linked to vessel stoppages or transit times ? Should some specific routes be examined in more detail ? Such work could lead to a better assessment of downtime and/or influence of ice compression on transit speeds.

▪ From the perspective of linking the ball scale to some physical parameters, a longer-term field program is probably needed. Physical parameters of influence such as ice field compressive strain and/or in-situ compressive stress could be linked to simultaneous ship performance and the ball scale. It is recommended that the experience of measuring these parameters should be reviewed before such a program be implemented in the Russian Arctic. (Work has been conducted in the N. American Arctic as well as East of Greenland). Some references on this work are supplied as an attachment to this review.

I hope that the above comments will be of use to author and supervisor of this report, as well as to the future direction of research on the important topic of ice compression. The reviewer is willing to further communicate with the author and supervisor as required.

Possible Useful References on Review, Measurement and Interpretation of Pack Ice Stresses. (not comprehensive).

Croasdale K.R. and R.W. Marcellus (1981) " Ice Forces on Large Marine Structures" Proceedings of IAHR Intl. Symposium on Ice, Quebec City, 1981. Vol. 2. pp 755 - 765.

Comfort, G and Ritch R. (1990). "Field Measurements of Pack Ice Stresses" Proceedings of OMAE Conference Houston 1990.

Comfort, G., Ritch R. and Frederking R. (1992). " Pack Ice Stress Maesurements" Proc. OMAE Conference, Calgary, 1992.

Croasdale and others. (1987). "A Pilot Program to Measure Pack Ice Driving Forces" Proc. POAC conf. Fairbanks, Alaska 1987.

Coon. M.D., and others, (1989). "Observations of Floe Stresses in the Eastern Arctic" Proc. POAC Conf. Lulea Sweden, 1989.

Coon and others (1995). "Sea Ice Deformation and Stress, a comparison across Space Scales" in Proc. of Sea Ice Mechanics and Arctic Modelling Workshop , Anchorage, April 1995 (sponsored by US Office of Naval Research).

Sandwell, 1994. "Processing of Pack Ice Stress Data", Final Report, Sandwell Report 113027. Submitted to the National Research Council, Ottawa. (sponsored by the National Energy Board, Calgary).

Tucker and Perovich (1992) "Stress Measurements in Drifting Pack Ice". Cold Regions Science and Technology, 20:119-139.

Fleet Technology Ltd. 1994. " Limit Force Ice Loads and Their Significance to Offshore Structures in the Beaufort Sea". Prepared for the National Research Council, Ottawa.(Sponsored by the National Energy Board, Calgary)

Croasdale K.R. (1984). The Limiting Driving Force Approach to Ice Loads. OTC paper 47, Houston, 1984.

Croasdale K.R, Frederking, R.,Wright, B. and Comfort G.(1992) Size Effect on Pack Ice Driving Forces. Proceedings of IAHR Ice Symposium 1992, Banff.

RESPONSE TO COMMENTS BY THE REVIEWERS

The reviewers are thanked for the time they spent reviewing this paper. Their comments were valuable and they certainly helped to improve the paper. The comments will briefly be discussed individually.

Comments by Mr. Norbert Untersteiner:

General comments:

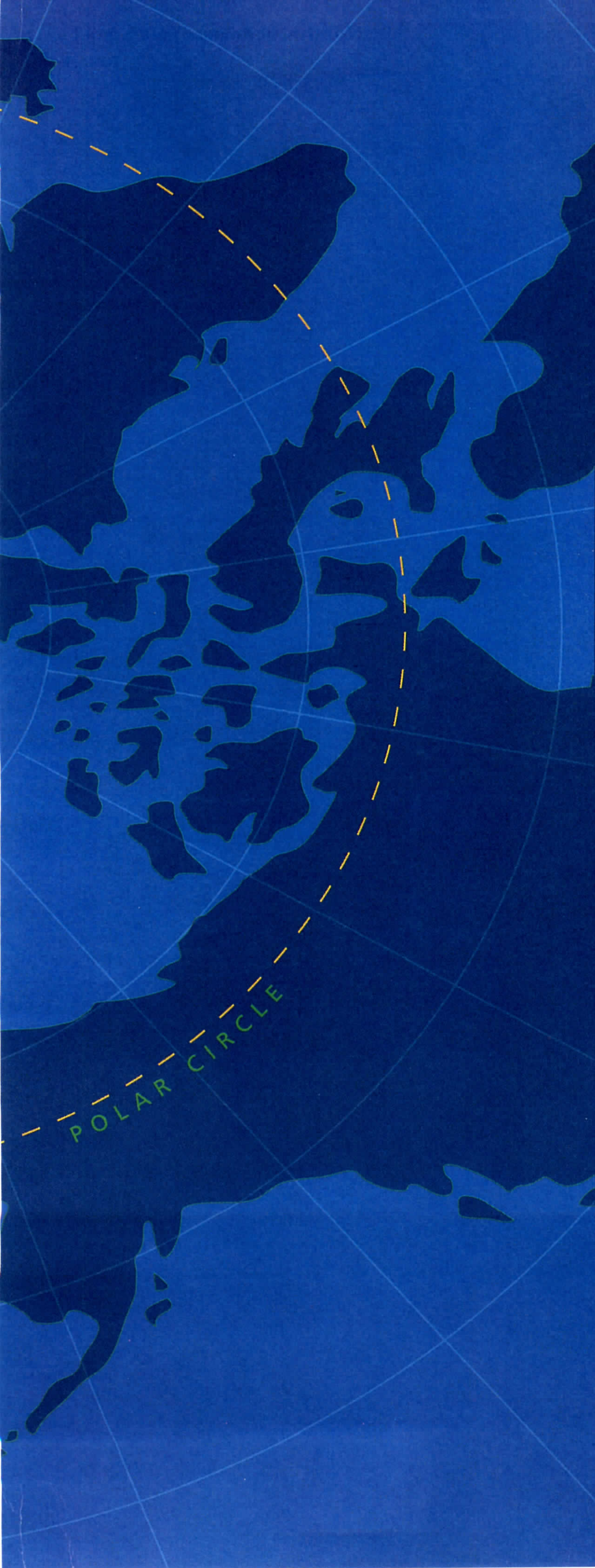
- The title of the project was stated in the INSROP Project Catalogue and there was no reason to change it.
- The objective of this report was to try to gather the rather fragmented Russian knowledge of ice compression along the NSR and to present it in such a form that it has practical use. Small scale operations in wintertime by western operators on the NSR have already started and more are being planned so there is a real demand for practical information.
- A reference list will be included in the final report.
- It is not known to what extent AARI is allowed to exploit their data bases.

Specific comments:

- Section 1 will be called "Summary" in the final report.
  The probability figures relate to distances in ice.
- A brief description of the ball-scale will be included in the final report.
- Chapters 4 and 5 will change places in the final report.
- The model tests are proposed because despite of the "enormous body of technical literature", that it is referred to nobody has yet been able to link the ball-scale to physically measurable parameters. It is naive to believe that model tests would "settle the problem" from a scientifical point of view. The model tests would provide INSROP with a practical tool to preliminary assess the influence of ice compression on the technical and economical performance of a shipping operation on the NSR.

Comments by Mr. Ken Croasdale:

- Chapters 4 and 5 will change places in the final report.
- A brief description of the ball-scale will be included in the final report.
- It is probably true that the maximum stress in an ice field is governed by ridging forces and thereby by ice thickness and strength properties. However, the main driving force is the wind and normally the midwinter is a period of high pressure and light winds. It must also be remembered that the ball-scale does not directly relate to the compressive force, generally, in thin ice the same ball-reading as in thick ice is achieved at a lower compressive force.
- The KMY data is not a scientific, systematic set of data, it is a general experience base, gained during different voyages, mostly in the Western parts of the NSR.
- The speeds mentioned in table 4. apply to icebreaker assisted operation while the discussion in chapter 6 refers to independent operation.
- It is doubtful if detailed examination of the Russian data would give significantly more information and the KMY data is not systematic.
- The research on ice compression has barely started yet. There are several parallel paths to proceed. Model tests, long-term field studies and theoretical research are all necessary. However INSROP is not a forum for basic research and it was felt that model tests best could serve the interests of INSROP to produce practical information.



The three main cooperating institutions of INSROP

Ship & Ocean Foundation (SOF), Tokyo, Japan.

SOF was established in 1975 as a non-profit organization to advance modernization and rationalization of Japan's shipbuilding and related industries, and to give assistance to non-profit organizations associated with these industries. SOF is provided with operation funds by the Sasakawa Foundation, the world's largest foundation operated with revenue from motorboat racing. An integral part of SOF, the Tsukuba Institute, carries out experimental research into ocean environment protection and ocean development.

Central Marine Research & Design Institute (CNIIMF), St. Petersburg, Russia.

CNIIMF was founded in 1929. The institute's research focus is applied and technological with four main goals: the improvment of merchant fleet efficiency; shipping safety; technical development of the merchant fleet; and design support for future fleet development. CNIIMF was a Russian state institution up to 1993, when it was converted into a stock-holding company.

The Fridtjof Nansen Institute (FNI), Lysaker, Norway.

FNI was founded in 1958 and is based at Polhøgda, the home of Fridtjof Nansen, famous Norwegian polar explorer, scientist, humanist and statesman. The institute spesializes in applied social science research, with special focus on international resource and environmental management. In addition to INSROP, the research is organized in six integrated programmes. Typical of FNI research is a multi-disciplinary approach, entailing extensive cooperation with other research institutions both at home and abroad. The INSROP Secretariat is located at FNI.