Initial measurements of physical and mechanical properties of ice from Hobson's Choice Ice Island

Frederking, R.; Timco, Garry; Jeffried, Martin O.; Sackinger, W.

Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/23002141
IRC Paper; no. 1619, 1999

National Research Council Canada
Conseil national de recherches Canada

Institute for Research in Construction
Institut de recherche en construction

Initial Measurements of Physical and Mechanical Properties of Ice From Hobson's Ice Island

by R.M.W. Frederking, G.W. Timco, M.O. Jeffries and W.M. Sackinger

Appeared in
Proceedings of the 9th International Symposium on Ice
Sapporo, Japan, August 23 - 27, 1988
IAHR Committee on Ice Problems, Vol. 1
p. 188-198
(IRC Paper No. 1619)

NRCC 30751

Canada

Résumé

Des analyses de salinité/conductivité électrique, des isotropes de l'oxygène et de la structure granulaire de carottes de glace récupérées à la surface d'une île de glace ont indiqué que la glace était à l'origine de l'eau douce. La structure granulaire était quelque peu columnaire; la masse volumique variait de 875 à 900 kg/m^3. Sept essais de compression uniaxiale ont été effectués avec des échantillons d'un diamètre de 60 mm, d'une longueur variant de 110 à 160 mm et orientés verticalement par rapport à la surface de l'île de glace. Les résistances à la compression variaient de 1,4 à 3,5 MPa (à $\dot{\epsilon}_{nom} = 10^{-5}s^{-1}$), valeurs comparables à celles obtenues pour la glace d'iceberg.

IAHR Ice Symposium 1988
Sapporo

INITIAL MEASUREMENTS OF PHYSICAL AND MECHANICAL PROPERTIES OF ICE FROM HOBSON'S ICE ISLAND

R. Frederking and G.W. Timco
Research Officers
Institute for Research in Construction
and Division of Mechanical Engineering
National Research Council Canada
CANADA

M.O. Jeffries and W.M. Sackinger
Geophysical Institute
University of Alaska, Fairbanks
U.S.A.

ABSTRACT

Salinity/electrical conductivity, oxygen isotope and grain structure analysis of ice cores recovered from the surface of an ice island showed the ice to be of freshwater origin. The grain structure of the ice was somewhat columnar; density ranged from 875 to 900 kg/m^3. Seven uniaxial compression tests were done on specimens 60 mm in diameter, 110 mm to 160 mm long and oriented vertically with respect to the surface of the ice island. Compressive strengths ranged from 1.4 MPa to 3.5 MPa (at $\dot{\varepsilon}_{nom} = 10^{-5}s^{-1}$), comparable to values for iceberg ice.

Introduction

Ice islands in the Arctic are large tabular ice features that calve from the ice-shelves on the north coast of Ellesmere Island, Canada (Fig. 1). The first confirmed ice island sighting was in 1946 (Koenig et al., 1952), and since then there have been numerous ice island calvings and sightings (e.g. Hattersley-Smith, 1963; Jeffries and Serson, 1983). Once they calve, ice islands drift with the Beaufort Gyre, and some have been known to remain in the gyre for up to 35 years. The clockwise drift of these massive ice features means that they periodically enter the coastal waters of the Beaufort Sea. With the advent of exploration and the potential development of hydrocarbon resources in this region, it has been recognized that ice islands represent a potential hazard to bottom-founded offshore structures (Sackinger et al., 1985).

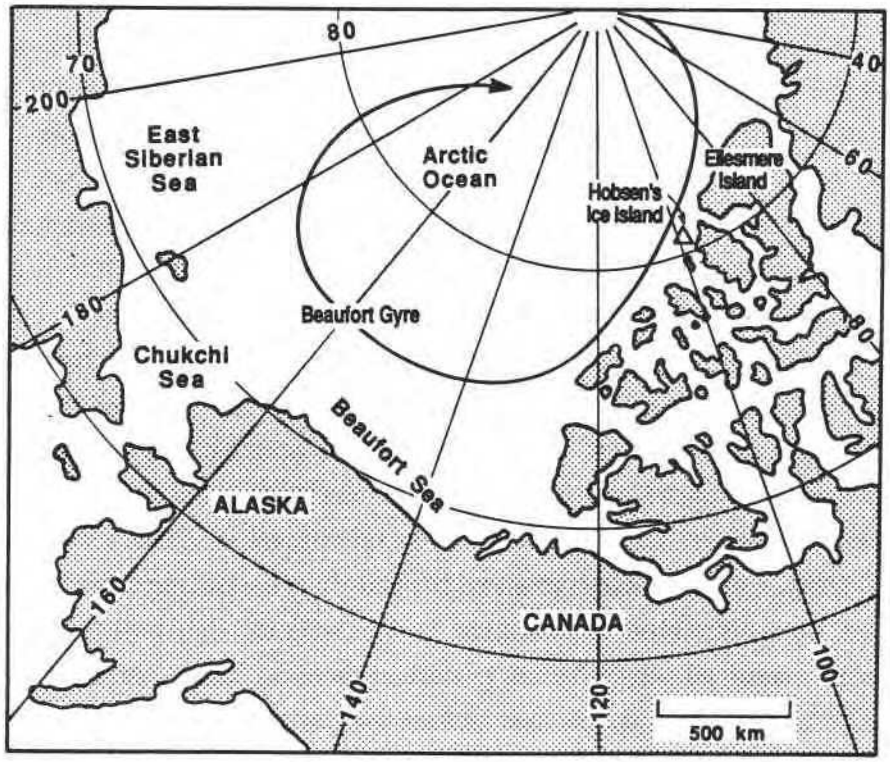

Figure 1: Map showing location of Hobson's Ice Island in May 1987, Ward Hunt Ice Shelf and Arctic Ocean/Beaufort Gyre.

With regard to the potential hazard represented by ice islands, particular interest is focussed on the number, size, and volume, as well as the physical, structural and mechanical properties of the ice. The physical and structural properties of ice islands depend on the structure and growth history of the ice shelves from which they calve. Ice core studies of ice shelves and ice islands have found five basic ice types. They are found alone or in combination with each other and comprise sea ice, brackish ice, freshwater/lake ice, iced-firn and glacier ice (see Jeffries, 1987 for a review of ice shelf growth, structure and disintegration). Elsewhere in this volume, Jeffries et al. (1988a) present the first results of measurements of the mechanical properties of sea ice and brackish ice from Ward Hunt Ice Shelf. In this paper we report the first published data on the mechanical properties of ice from an ice island.

Hobson's Ice Island

At the present time, there are approximately 30 ice islands known in the Arctic Ocean, including those that calved from east Ward Hunt Ice Shelf in 1982-83 (Jeffries and Serson, 1983; Jeffries et al 1988b). The largest of the latter ice islands is Hobson's Ice Island. It has an area of about 4 x 9 km, a mean thickness of 42.5 m over 64% of its area, and a mass slightly exceeding 700 x 10^6 tonnes (Jeffries et al., 1988b). Although it is relatively small compared to Antarctic tabular icebergs, Hobson's Ice Island is two orders of magnitude larger than a medium-size Greenland iceberg. It has been shown that 36% of the area of the ice island is multiyear landfast sea ice (previously attached to the front of east Ward Hunt Ice Shelf and as much as 10 m thick) and the remaining 64% of the area is former shelf ice with a mean thickness of 42.5 m (Jeffries et al., 1988b). Preliminary studies of the physical-structural properties of deep ice cores drilled from Hobson's Ice Island have shown that the shelf ice is composed entirely of granular, non-saline ice (Jeffries et al., 1988b,c). The ice specimens tested in the present study are similar to the granular non-saline ice found previously.

Specimen acquisition, preparation and handling

In May 1987 a few shallow 75 mm diameter cores were drilled at the crest of a hillock on Hobson's Ice Island using a PICO (Polar Ice Coring Office) lightweight coring auger. Ambient air temperatures were -15°C to -20°C. The cores were packed and sealed in polythene bags prior to shipment to Resolute Bay where they were stored at -18°C. In November 1987 the specimens were shipped by air to Montreal and by road to Ottawa. During the air flight, the ice warmed significantly and some melting occurred. Although this unfortunate occurrence must be taken into account in the interpretation of the results, it probably did not significantly affect the physical-structural properties. This will be discussed further.

Shortly after their arrival in Ottawa, the cores were examined and seven specimens of adequate length and diameter were selected for mechanical properties measurement. The test program determined uniaxial compressive strength and failure modulus of the ice at a nominal strain rate of about $1 \times 10^{-5}s^{-1}$ (cross head rate 0.1 mm/min). The test specimens were prepared on a lathe and reduced to diameters of 59.1 mm to 66.4 mm. The ends of the specimens were finished using a band saw and emery paper. All but two of the specimens had length-diameter ratios exceeding a value of two. A standard specimen size could not be selected because of partial melting of the ice in transit. A strategy of maximizing specimen size was adopted, the consequences of which will be discussed later. Specimen dimensions were measured with a vernier calliper and bulk density was determined after each specimen had been weighed on an electronic balance.

Uniaxial compression tests were performed using a 100 kN capacity "Instron" model TTDM-L test machine, with a swivel-head platen, at a temperature of -10°C. Specimens were oriented vertically with respect to the surface of the ice island and fitted with 100 mm gauge length extensometers for the measurement of specimen deformation. After each specimen had been tested, samples were taken for electrical conductivity (salinity) and stable isotope analysis, and vertical thin sections were cut. Horizontal thin sections were cut prior to testing, and all sections were photographed in cross-polarized light. The specific electrolytic conductivity (SEC) of samples was measured using a Beckman Conductivity Bridge.

Physical and structural properties

A detailed explanation of the application of stable isotopes in ice core studies is inappropriate here. It is sufficient to note that the isotope values are indicative of fresh water ice. The non-saline origin and nature of the ice is evident in the SEC values (Table 1) and the ice structure. In terms of salinity, the SEC values are equivalent to a very low salinity range of 0.02°/.. to 0.03°/... The density of the samples ranged from 872-893 kg/m^3 (Table 1). The absence of brine, and the bubbly nature of the ice gives rise to density values somewhat lower than are generally found in sea ice (Table 1). The four odd-numbered specimens which were closer to the ice surface had lower densities than the three even-numbered specimens which were from a greater depth (0.2 to 0.4 m) in the ice cover.

Table 1: Specific electrolytic conductivity (SEC), density and grain size of test specimens.

Core No.	Specimen No.	Depth(m)	SEC*(μS.cm^{-1})	Density(kg.m^{-3})	Mean Grain Diameter(mm)
1	0709	0.0-0.2	35.5	875	7.1
1	0710	0.2-0.38	26.9	892	14.7
2	0711	0.0-0.2	39.1	881	12.4
2	0712	0.2-0.4	33.0	893	13.1
3	0713	0.0-0.2	26.6	887	19.5
3	0714	0.2-0.37	41.3	892	17.3
4	0715	0.0-0.17	26.0	872	11.5

*A SEC value of 165μS.cm^{-1} approximately equals a salinity of 0.10°/...

The physical and structural properties of the ice tested are quite similar to those of other ice island samples which were not transported to Ottawa (Jeffries et al., 1988b and unpublished data). These similarities and the virtual absence of salinity in the ice imply that the ice was not significantly altered as a result of the partial melting in transit. This partial melting could be looked upon as simply another summer melt period to which the ice was subjected.

Horizontal thin sections show the ice to generally have large grains (Fig. 2a; Table 1). The mean grain diameter in each section varies from 7.1 mm (medium-grained) to 19.5 mm (coarse-grained) (Table 1). Vertical thin sections reveal a quasi-columnar structure (Fig. 2b). The grains are up to 5 cm long and 1.5 cm wide. Only specimen 0714 exhibited a classical continuous columnar structure.

Mechanical properties

A typical result of a strength test is presented in Figure 3a. Stress and strain are each plotted versus time. The strength, σ_f, is the maximum stress which the specimen sustained during the test, in this case, where it yielded. Note that all 7 specimens failed by yielding. The time at which this occurred is the failure time, t_f. The strain at failure ε_f, is the strain at time t_f. Examining the strain-time portion of the plot shows that, while the test was run at a constant cross-head rate, the actual strain rate experienced by the specimens is not constant. It can be

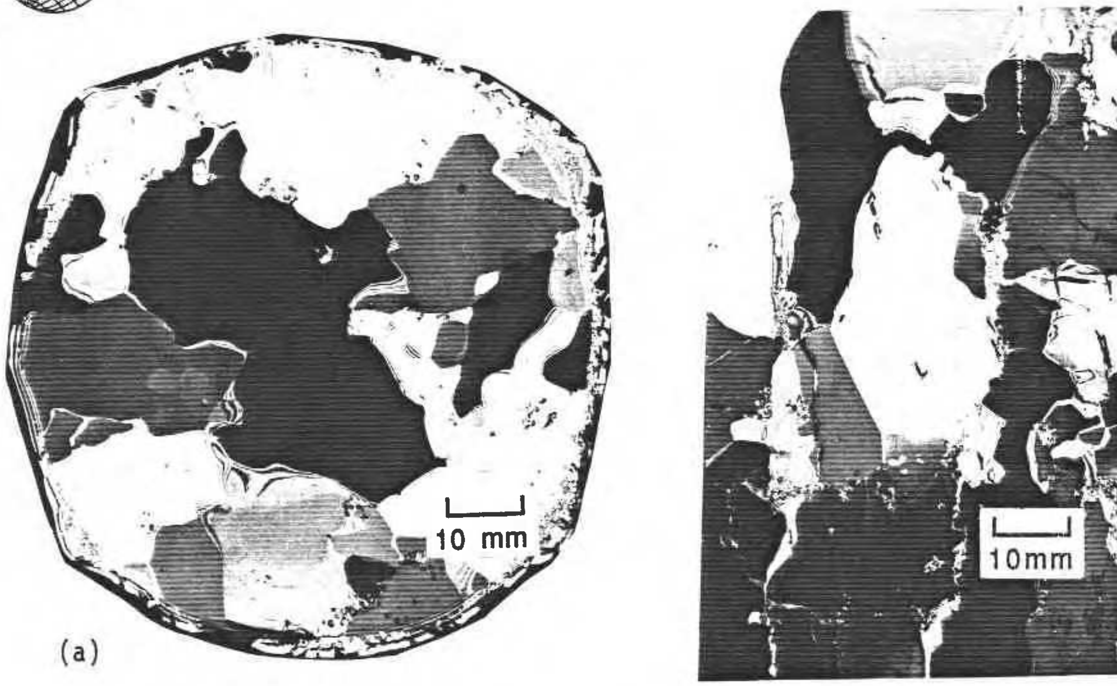

Figure 2: Thin sections of coarse-grained ice photographed in cross-polarized light (specimen 0710).
(a) horizontal section (depth 0.2 m) (mean grain diameter 14.7 mm),
(b) vertical section (depth 0.2-0.38 m).

seen that the strain rate measured on the specimen is initially very low and only approaches the nominal rate (cross-head rate divided by specimen length) when the specimen yields, i.e. has no stiffness. This characteristic of constant cross-head rate tests was pointed out by Sinha (1981).

The actual strain-time path followed in a particular test is a function of the relative stiffness of the specimen and the test system. Stress is plotted versus strain in Figure 3b, showing the non-linear behaviour of ice. From this plot two moduli can be defined, a tangent modulus, E_t, which is tangent to the stress strain curve at a particular point, and a secant modulus, E_s, drawn from the origin to a particular point. The secant modulus to the failure point (ε_f, σ_f) is referred to as the failure modulus, E_f. Specimen stiffness is a function of its geometry end elastic properties. In this test series each specimen, as explained earlier, had a different geometry so a different strain path was followed.

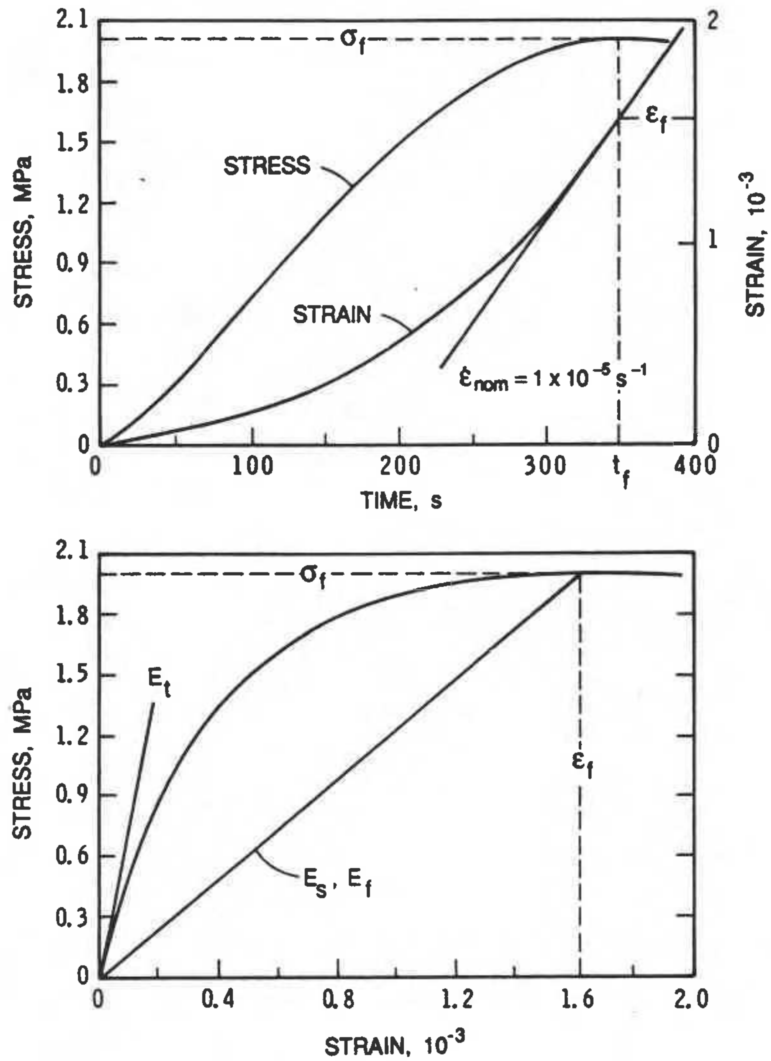

Figure 3: Test results for ice island specimen 0712, $\dot{\varepsilon}_{nom} = 10^{-5}s^{-1}$, temp = -10°C.
(a) stress and strain versus time,
(b) stress versus strain (E_f = 1.27 GPa, E_t = 7 MPa).

Timco and Frederking (1984) proposed a method to correct the nominal strain rate for the effect of relative specimen to test system stiffness. The following formula was derived:

$$\dot{\varepsilon}_{cor} = \frac{1}{1 + \dfrac{\bar{E}A}{\ell \bar{K}_{\ell s}}}\,\dot{\varepsilon}_{nom} \qquad (1)$$

where $\bar{E}$ is the average tangent modulus up to yield, A and ℓ are specimen cross-sectional area and length and $\bar{K}_{\ell s}$ is the average stiffness of the test system. The failure modulus E_f is a good approximation of the average tangent modulus and reflects the intrinsic stiffness of the ice, i.e. temperature, grain size, etc. With this correction, strength results compared favourably with those of true constant strain rate tests performed on a closed-loop test machine (Timco and Frederking, 1984).

Table 2: Results of mechanical properties tests of ice island ice at -10°C.

Specimen No.	length mm	diameter mm	σ_f MPa	t_f s	ε_f 10^{-3}	E_f GPa	$\dot{\varepsilon}_{nom}$ $10^{-5}s^{-1}$	$\dot{\varepsilon}_{corr}$ $10^{-5}s^{-1}$
0709	163.55	63.80	1.38	360	0.92	1.50	1.02	0.68
0710	134.11	69.29	2.48	405	1.58	1.57	1.24	0.86
0711	164.67	63.80	2.07	440	2.05	1.01	1.01	0.79
0712	165.36	63.68	2.00	345	1.58	1.27	1.01	0.72
0713	114.68	62.06	1.48	285	1.59	0.93	1.45	0.78
0714	118.29	66.42	3.57	540	3.23	1.10	1.41	1.24
0715	145.61	63.96	2.26	425	2.37	0.95	1.15	0.86

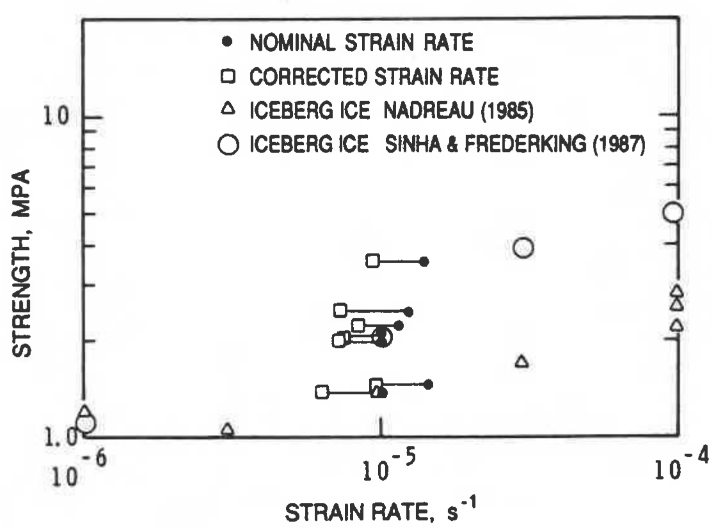

Figure 4: Strength versus strain rate for ice island ice at -10°C.

The results from the seven specimens tested are summarized in Table 2. In addition to strength, failure time and strain at failure, failure modulus, E_f, nominal strain rate, $\dot{\varepsilon}_{nom}$, and corrected strain rate, $\dot{\varepsilon}_{cor}$ are included. Note from equation (1) that the corrected strain rate, $\dot{\varepsilon}_{cor}$, contains the factor A/ℓ which takes into account specimen geometry.

The strength versus strain rate results are plotted in Figure 4. Also shown in this figure are individual test results from two test series performed on iceberg ice at -10°C, a reasonable agreement between the strength results for ice island ice and those for iceberg ice. Nadreau's (1985) results are given in terms of nominal strain rate and application of a correction would move his data into a closer agreement with the data of Sinha and Frederking (1987). Comparing the results for failure modulus, E_f, from Table 2, it can be seen that they are generally lower than the value of 2.5 GPa which Sinha and Frederking (1987) found for iceberg ice. This is partially due to the lower density of this ice (884 kg/m^3) compared to iceberg ice (892 kg/m^3) and the fact that the iceberg ice tests were performed on a closed loop test machine with strain rate control on the specimen.

CONCLUSIONS

Stable isotope analysis and salinity showed the ice cores recovered from the top 0.5 m of Hobson's Ice Island to be of fresh water origin. The ice is probably iced firn. The strength properties of this ice, when corrected for test system stiffness effects on strain rate, are similar to those of iceberg ice. The ice showed somewhat greater ductility at yield, i.e. lower failure modulus than iceberg ice. It can be concluded that, when grain structure and fabric, density and salinity are taken into account, ice island ice from the upper levels has mechanical properties which fall within the range of those of other ice types with similar physical properties. More work, however, is required on determining the overall physical and mechanical properties of ice island ice.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the assistance of the PCSP in gaining access to Hobson's Ice Island to retieve the cores. M.O. Jeffries and W.M. Sackinger also acknowledge the support of the Geophysical Institute, University of Alaska, Fairbanks (S.-I. Akasofu, Director) and the U.S. Department of Energy, Morgantown Energy Technology Center. Also the assistance of J.D. Neil, Technical Officer at IRC/NRCC in performing the laboratory tests was much appreciated.

REFERENCES

Hattersley-Smith, G., 1963. The Ward Hunt Ice Shelf: recent changes of the ice front, Journal of Glaciology, Vol. 4, pp. 415-424.

Jeffries, M.O., 1987. The growth, structure and disintegration of Arctic ice shelves, Polar Record, Vol. 23, pp. 631-649.

Jeffries, M.O. and Serson, H.V., 1983. Recent changes at the front of Ward Hunt Ice Shelf, Ellesmere Island, N.W.T., Arctic, Vol. 36, pp. 289-290.

Jeffries, M.O., Sackinger, W.M., Frederking, R.M.W., and Timco, G.W., 1988a. Initial mechanical property measurements of sea and brackish ice from Ward Hunt Ice Shelf, Canada, IAHR Symposium on Ice, 23-27 August 1988, Sapporo, Japan.

Jeffries, M.O., Sackinger, W.M., and Shoemaker, H.D., 1988b. Geometry and Physical Properties of Ice Islands, in Port and Ocean Engineering Under Arctic Conditions, Vol. 1, W.M. Sackinger and M.O. Jeffries (eds.), Geophysical Institute, University of Alaska, pp. 69-83.

Jeffries, M.O., Sackinger, W.M., Krouse, H.R. and Serson, H.V., 1988c. Water circulation and ice accretion below Ward Hunt Ice Shelf (Northern Ellesmere Island, Canada) deduced from salinity and isotope analysis of ice cores, Annals of Glaciology, Vol. 10, pp. 68-72.

Koenig, L.S., Greenaway, K.R., Dunbar, M. and Hattersley-Smith, G., Arctic Ice Islands, Arctic, Vol. 5, pp. 67-103.

Nadreau, J.P., 1985 Lois de comportement et de fluage de la glace granulaire simulée de crêtes de pression. Ph.D. thesis, Civil Engineering Department, Laval University, Quebec City.

Sackinger, W.M., Serson, H.V., Jeffries, M.O., Shoemaker, H.D. and Yan, M., 1985. Ice island generation and trajectories north of Ellesmere Island, Canada, Proceedings of the 8th International Conference on Port and Ocean Engineering under Arctic Conditions (POAC-85), Narssarssuaq, Greenland, 7-14 September 1985, pp. 1009-1040.

Sinha, N.K., 1981 Rate sensitivity of compressive strength of columnar-grained ice. Experimental Mechanics, Vol. 21, No. 6, pp. 209-218.

Sinha, N.K. and Frederking, R., 1987 Preliminary observations on compressive strength, deformation and Poisson's ratio of iceberg ice. Proceedings of Workshop on Extreme Ice Features, Banff, Alberta, November 3-5, 1986, National Research Council of Canada, Associate Committee on Geotechnical Research, Tech. Memo. No. 141, pp. 413-426.

Timco, G.W. and Frederking, R., 1984 A proceedure to account for machine stiffness in uni-axial compression tests. Proc. 7th IAHR Symposium on Ice, Hamburg, Germany, August 27-31, 1984, Vol. 1, pp. 39-47.

This paper is being distributed in reprint form by the Institute for Research in Construction. A list of building practice and research publications available from the Institute may be obtained by writing to the Publications Section, Institute for Research in Construction, National Research Council of Canada, Ottawa, Ontario, K1A 0R6.

Ce document est distribué sous forme de tiré-à-part par l'Institut de recherche en construction. On peut obtenir une liste des publications de l'Institut portant sur les techniques ou les recherches en matière de bâtiment en écrivant à la Section des publications, Institut de recherche en construction, Conseil national de recherches du Canada, Ottawa (Ontario), K1A 0R6.