

handled it can saddle the northern communities with a permanent social and financial liability.

Finally, it must be understood that northern communities, no less than communities elsewhere in Canada, find themselves in a rapidly changing world. No longer can they mark the passing years by the arrival of the annual or semi-annual supply boat or mail run. Aircraft, radio telephone, and even taped television programs are symbolic of the degree to which change has come to the North as well, and are increasingly taken for granted by northerners. There is a comparable change in the need for northern communities. Some of these, while useful in fur trade days have become as redundant as the small elevator hamlets along the railways on the Prairies. Like them it may be better for the long-term opportunities of the residents, to encourage a migration to larger centres within the North—though this is conceded to be a delicate and difficult task.

There will always have to be communities in the North, but these probably will be fewer and larger centres, better situated to meet the transportation and development needs of the present and future. It is only in larger centres that the costly and permanent service facilities now expected by all Canadians can be justified. Quite possibly smaller "camps" of relatively short life expectancy may operate out from one major centre, with a variety of commuting developed between them, as was the case for example between Yellowknife and Discovery.

With the increasing capital outlay involved in establishing a modern community in the North, it clearly will be more and more difficult to abandon or relocate it in later years. To an unprecedented degree northern communities now represent long-term commitments in the area, involving very large capital investment. Only a thorough, balanced assessment of the regional potential can provide the necessary background for such vital decisions. Community and region always have been inseparably linked in northern development, but never more critically than at present.

William C. Wonders
Department of Geography
University of Alberta
Edmonton

REFERENCES

- ¹Little, A. D. Inc. 1958. *Economic Survey of Northern Manitoba, 1958*. Manitoba Department of Industry and Commerce, Winnipeg. 200 pp.
- ²Richards, J. H. 1967. Perspective on Regional Planning. *Community Planning Review* 17 (1):18-24.
- ³Erskine, R. 1960. Town planning in the Swedish sub-arctic. *Habitat*, III (6):2-6.
- ⁴New Town for Churchill Falls. 1968. *Community Planning Review*, 18 (1):20.
- ⁵Fried, J. 1963. White-dominant settlements in the Canadian Northwest Territories. *Anthropologica*, 5 (1):57-68.

Frictional Resistance to a Ship's Passage through Converging Ice

It is well known that an icebreaker which can normally navigate through several feet of ice can be brought to a halt in much thinner ice if that ice is converging. From some recent measurements it is now possible to estimate the pressure developed in a converging ice field and to calculate the resulting frictional resistance which would be encountered by a ship attempting to navigate through such ice.

WIND STRESS

In many areas of drifting ice the principal driving force is provided by the wind. The wind stress may be represented by

$$\tau = \rho C_{10} V^2$$

where ρ is the density of the air ($\approx 1.2 \times 10^{-3}$ gm./cm.³) and V is the mean wind speed at 10 m. height. Until very recently we have not been in a position to calculate this force because the drag coefficient C_{10} of wind on ice was not known. In the spring of 1969, during the McGill University Ice Drift Study, a three-component sonic anemometer was used to measure a drag coefficient¹

$$C_{10} = 2.6 \times 10^{-3}$$

over very loose and relatively rough pack ice in the Gulf of St. Lawrence. A repetition of this measurement during the 1970 Ice Drift Study² gave a value of 1.3×10^{-3} over a much smoother continuous ice field.

Suppose a uniform ice pack is acted on by a uniform wind V and is restrained by a shoeteine from moving at the downwind end; then the wind stress must be balanced by an equal and opposing force or "internal ice stress" and any ice floe or other object in the ice field must be under pressure from the neighbouring floes. This pressure must increase linearly with the fetch F from the upwind edge of the ice field to the point of measurement. Suppose the wind is $V = 20$ m./s. and the fetch is 20 km., then for pack ice if $C_{10} = 2.6 \times 10^{-3}$ the pressure in the ice field is

$$\begin{aligned}\tau \times F &= \rho C_{10} V^2 F \\ &= (1.2 \times 10^{-3} \text{ gm./cm.}^3) \times (2.6 \times 10^{-3}) \\ &\quad \times (2 \times 10^8 \text{ cm./s.})^2 \times (2 \times 10^6 \text{ cm.}) \\ &= 25 \times 10^6 \text{ dyne/cm.} = 25 \text{ kg./cm.}\end{aligned}$$

If a vessel the size of the *Manhattan*, of length $L = 300$ m. long, has a coefficient of friction $K = 0.15$ between steel and ice,³ then the retarding friction on two sides of the ship would be

$$\begin{aligned}\tau F \times 2L \times K &= 25 \text{ kg./cm.} \times 2 \times 3 \times 10^4 \text{ cm.} \\ &\quad \times 0.15 = 22.8 \times 10^4 \text{ kg.} \\ &= 0.50 \times 10^6 \text{ lb.}\end{aligned}$$

This friction must be overcome by the thrust from a ship's propellers. Several slightly different formulas are in use, and Barnaby⁴ (p. 296) gives

$$T = 221.4 (K_i/K_e^{2/3}) \times (P \times D)^{2/3}$$

Again taking *Manhattan* as an example, with $P = 43,000$ horsepower and propellers of diameter $D = 22$ feet, and assuming a typical value of $(K_i/K_e^{2/3}) = 3.0$ from a range of 2.9 to 3.1 in four examples given by Barnaby⁴ (Table 32A), the available thrust is approximately 0.65×10^6 lb. This would be just adequate to operate in the conditions assumed in the previous paragraph, and the presence of ridges or local concentrations of pressure might stop a ship with such a small reserve of thrust.

FRICITION WITH ICE AT BREAKING STRESS

Another means of calculating the pressure exerted by the ice is to note that the ice in a converging field is under enough stress to crush at least in some places. Compressional strengths of sea ice from 18 to 107 kg./cm.² have been reported (Pounder⁵, p. 107). A block of ice the size of a ship is bound to contain flaws and faults which decrease its effective strength, so let us assume that the worst case might be $P = 35$ kg./cm.² or 500 psi. In ice $H = 3$ m. thick a 300 m. vessel would experience frictional force of

$$\begin{aligned}P \times H \times 2L \times K &= (35 \text{ kg./cm.}^2) \times (300 \text{ cm.}) \\ &\quad \times 2 \times (3 \times 10^4 \text{ cm.}) \times 0.15 \\ &= 94 \times 10^6 \text{ kg.} = 210 \times 10^6 \text{ lb.}\end{aligned}$$

The thrust required would be comparable to the weight of the vessel! If the hull could withstand the tremendous pressures, 300 times the thrust of a typical large ship would be required to overcome friction. Perhaps the strength of ice has been overestimated by as much as a factor of 10, but it remains clear that the power necessary to navigate in ice which is failing in compression would be prohibitive.

J. Keys

Defence Research Establishment
Ottawa, Canada.

S. D. Smith

Atlantic Oceanographic Laboratory
Bedford Institute, Dartmouth, Canada.

REFERENCES

- ¹Smith, S. D., E. G. Banke and O. M. Johannessen. 1970. Wind stress and turbulence over ice in the Gulf of St. Lawrence. *Journal of Geophysical Research*, 75: 2803-12.
- ²Johannessen, O. M., et al. 1970. Cruise report from the ice drift study in the Gulf of St. Lawrence 1970. *Marine Sciences Centre, McGill University, Report 15*, 53 pp.
- ³Landtman, C. 1969. Finnish icebreakers. *U.S. Naval Institute Proceedings*, 95 (2):73-81.
- ⁴Barnaby, K. C. 1967. *Basic Naval Architecture*. London: Hutchinson & Co. 507 pp.
- ⁵Pounder, E. R. 1965. *Physics of ice*. Oxford: Pergamon Press. 151 pp.

Oil Spills in Ice: Some Cleanup Options

In early June, 1970 a spill of diesel oil and gasoline (reported to be about 367,000 gallons of Arctic diesel fuel and 59,000 gallons of gasoline) occurred in Deception Bay, Quebec (western Hudson Strait) after a slide of snow and water moved through a "tank farm" (Fig. 1) located close to the shore. At the time, a flat expanse of sea ice covered all of the bay and closely spaced blocks of ice existed over most of the intertidal zone. Almost all of the oil was contained by the ice so that we were able eventually to dispose of the spill completely. This was accomplished mainly by burning the oil, either after it had been pumped on to the sea ice or where it was contained by the nearshore ice.

Much of the time at the site (June 12 to 26) was spent in survey of the distribution of oil and with evaluation of possible methods of disposal, or recovery, which included pumping the oil on the sea ice to evaporate. It was ascertained relatively soon that pumping and burning did not present major difficulties, but it was some time before adequate estimates of the distribution of oil were obtained, especially of that oil contained by the ice on the intertidal zone in the slide area. Nearby on the intertidal zone, oil could be seen in the spaces between the blocks of ice there.

The containment provided by the ice is, of course, a unique aspect of the spill and it permitted consideration and application of pumping and burning as methods of disposal. The pumping capacity, although small, was considerably greater than the capacity to