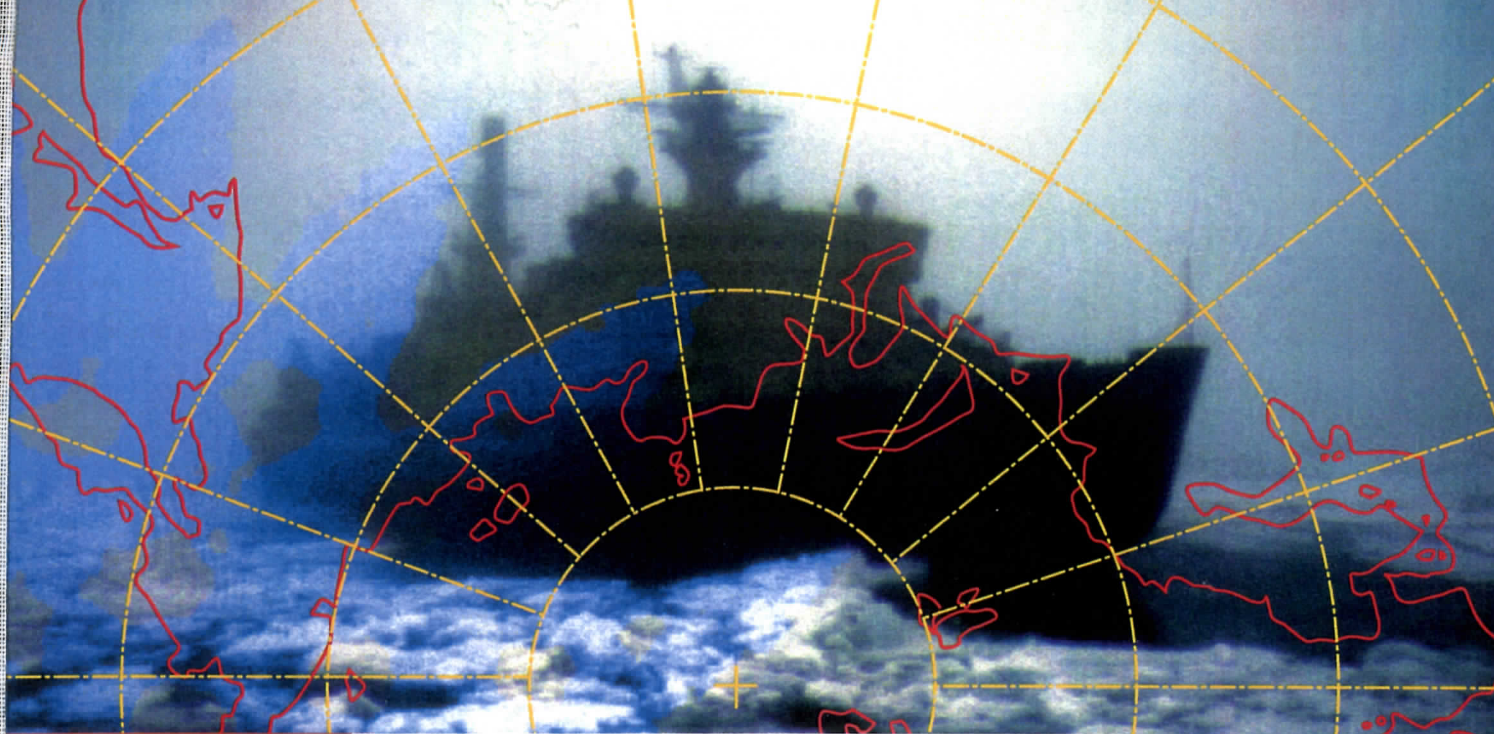

INSROP WORKING PAPER
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Some Aspects of Port and Harbour Management along the NSR

By H. Kitagawa, K.Izumiyama and T. Ozeki

INSROP International Northern Sea Route Programme

Central Marine Research & Design Institute, Russia

The Fridtjof Nansen Institute, Norway

Ship and Ocean Foundation, Japan

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Supervisor:	Hiromitsu Kitagawa
Title:	**Some Aspects of Port and Harbour Management along the NSR**
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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.

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ABSTRACT

Undoubtedly the Northern Sea Route necessitates a further development of ports and harbours along the route, which are to be open for non-Russian merchant and fishing fleets. To ensure safety of navigation of the NSR commercial vessels and firmly establish the route, sufficient number of ports and harbours, well designed, functionally constructed, excellently organized, and well maintained, are essential to the NSR. Some major issues for management of harbours in the arctic environment are discussed with emphasis on ice and snow control. Some related technical issues, such as methods and techniques effective to ice control in the harbours, harbour structures and facilities, are also discussed.

KEY WORDS:

NSR Port, NSR Harbour, Ice Management, Ice Load, De-icing Technique

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1. INTRODUCTION

Ports and harbours with modern facilities for ship operations in harbour, navigation control and harbour management will be vital to the improvement of surface transport efficiency and the safety of navigation. The present ports and harbours along the Northern Sea Route could not fully ensure the safety of navigation of NSR commercial vessels. The NSR vessels should require many more open, well-equipped and well-organized ports. The harsh nature of the sites of ports and harbours to be required to be open in future along the NSR would demand construction even in hazardous conditions. Underground permafrost and heavy covering of ice on water surface will be the most serious hindrance to construction. Fortunately permafrost features do not change much in general, but ice cover is affected by climate and its extent varies greatly. Statistical information on ice cover in a planning port and the adjacent outer area is essential for design and construction of ports and subsequent harbour management.

Rational design and construction of ports and harbours requires statistical data and information on natural conditions, such as temperature, precipitation, current, wind and waves as well as geomorphological and geological data. Those data and information will lead to selection of basic port configuration. Unfortunately, no detailed data are available at most of sites possible for new ports.

It is natural that most ports and harbours have been developed in estuaries, with adequate potential, natural, social and technical. For the convenience of future NSR vessels there might be several ports constructed away from estuaries, along the Arctic coastlines facing the Arctic Ocean. This might be another challenge to the arctic nature, being based on a full understanding of the characteristics of arctic coastlines.

In this report some typical technical issues required for planning of ports and harbours along the NSR in future are discussed with emphasis on ice management and harbour-related technical items and problems.

2. POSSIBLE SITES FOR NSR PORTS

2.1 Estuaries and Riversides

Estuaries and large riversides have given the most popular sites for ports. In such places, in general, ice conditions in winter and wave conditions in summer are expected to be moderate. Tidal problems, continuous sedimentation and flooding in the melting season will be major issues to be solved when designing and constructing port facilities. Present ports and harbours have eventually been developed mostly in estuaries. In such areas, data and information about marine processes have generally been collected to understand basic features of arctic estuaries.

In future, however, the NSR vessels will be required to be on a scale of several hundred thousand DWT with far deeper draft than vessels of the present Russian fleet. Water depth in port should ensure that the margin for safety of operation of the vessels is sufficient. The harbours in estuaries might not provide sufficient water depth for navigating vessels. It seems too ideal for every port to maintain facilities and equipment for dredging and other port maintenance, while transport of the equipment from port to port is largely limited. Along the NSR, dredging work could be done only during the summer.

The appearance of tidal effects may suggest floating structures for cargo handling and other necessary treatment of commercial vessels in port. Recent developments in design and construction of large floating structures could afford useful guidelines for the floating marine structures in the arctic regions.

2.2 Coastlines

Water depth and other natural conditions as well as the need for stable transport through the NSR might necessitate new ports and harbours to be built along the coast.

Unconsolidated and permafrost-affected sediments form low tundra bluffs, while the seasonal presence of sea ice affects the marine processes in the arctic coastal regions. Rising relative sea level is another characteristic, particularly in the eastern Siberia. It can be said that the general features of the arctic coastlines have been well understood, the distribution of ground surveys, in comparison to the outline, relatively discrete and sparse. Measurement of marine processes, such as waves, currents and sea ice, is extremely limited in both duration and geographic distribution, as the presence of sea ice makes equipment moorings hazardous and almost everything inefficient. Studies during autumn and spring time have been largely limited due to logistic difficulties, which indicates a strong bias toward the existing data collected only in the summer season. Unfortunately, it is apparent that these periods of year have considerable significance in terms of important coastal processes and marine activities as well as a reasonable design of new ports and harbours. Statistical analyses of the results of the measurement, particularly long-term expectations, necessitate much more reliable data over many years.

Sea ice and permafrost phenomena are undoubtedly typical zonal factors characterizing arctic plain shorelines.

(1) Sea ice

Although the aggregates of first year ice of less than 2 m, multi-year ice of approximately 3 m in thickness and pressure ridges generally exist in the Arctic Ocean, open water is present during the summer along most sections of the arctic coast[1]. Atmospheric forces, oceanic circulation, wind stress and river discharge in some areas affect the extent of open water along the coast which is highly variable from year to year. Recently river discharges into the Arctic Ocean were found to affect sea ice and open water features over a considerably broad area through flooding appreciable amounts of low salinity water.

The presence of sea ice, as a complex surface layer consisting of slush ice, frazil ice and fragments of multi-year ice, or as a large block, characterizes erosion and deposition of sediment. Large blocks of sea ice often erode the near-shore seabed through the moving process of ice blocks driven by wind, waves and current. Creeping, rocking and wallowing of grounded ice blocks, ice gouging or ice scouring in other words, creates crater-like erosions on the surface of the seabed. Ice scouring is more typically and frequently caused by the impact of ice-ridge keels or hummocked multi-year ice on the seabed. Ice scouring threatens underwater harbour facilities and equipment. In the Beaufort Sea, Barnes et al. [2] found the highest intensity of ice scouring occurs on the seabed below the shear zone between the moving Arctic pack ice and the more stable landfast ice. Frequent ice scouring also occurs in shallow water by the grounding of isolated ice floes particularly during summer. The extent of the scouring is dependent on geology and geomorphology of the seabed. Grounded ice block, which would be unstable over a year or so, is a serious hindrance to vessel operations as well as ice control in the area. The ice scouring necessitates additional dredging expenses to keep the vessel passages safe as well as pipelines and other cables buried under the seabed. A near-shore bathymetric profile is shown in Fig.1, as an example of seabed erosion attributed to ice scouring in the Tuktoyaktuk Peninsula[3]. Though ice scouring causes marked deformation of post-transgression sediments, as Blasco et al.[4] described, a clear ravinement surface can be recognized across the shelf.

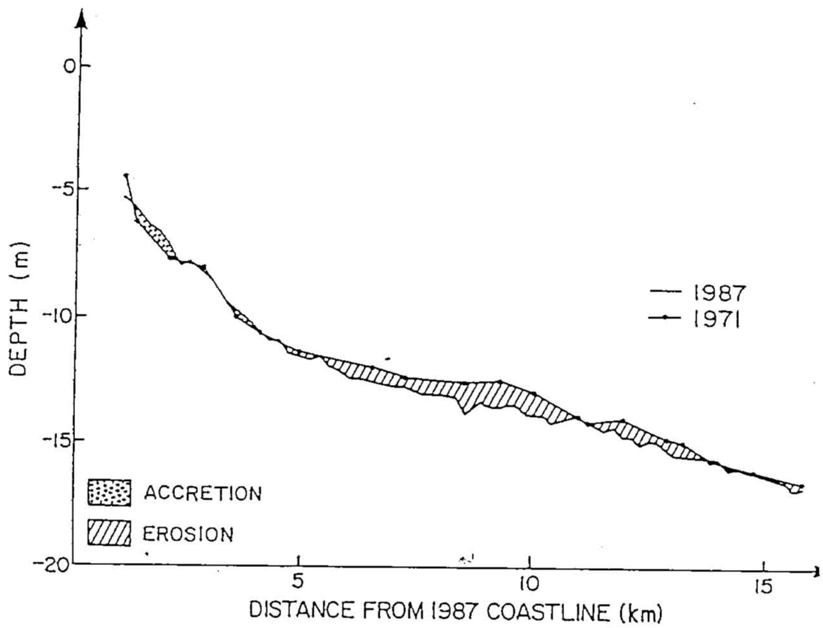

Fig 1: Nearshore bathymetric profile: Tuktoyaktuk Peninsula [2]

The frazil ice generated largely in the autumn is sticky and adheres together and to harbour structures, port facilities and various objects. The downward transport of frazil ice induced by water flow and turbulence and the presence of supercooled water might cause the formation of anchor ice on the seabed. The anchor ice, released by heat and buoyant effects, will then float up and mix up into development of the ice canopy.

A layer of slush ice is a concomitant feature at the sea surface before complete freezing of ice canopy. The slush ice will filter out high frequency wave components, which results in decrease of occurrence of wave breaking and eventually different features of erosion and sediment movement.

Pile-up and ride-up of ice, resulting from pushing of ice onto the shoreline in winter, are other potential phenomena that cause damage to the beach and harbour facilities. Ride-up of ice may destroy buildings and structures constructed on the beach. Large sheets or floes of ice slide up onto the shore and in some instances ice advances for hundreds of meters. Kovacs[5][6] indicated that ice overrides bluffs several meters high.

Time scale of ride-up and pile-up in general is relatively short. Ride-up and pile-up ice leaves a deposit of sediment on the beach when it melts out. In some cases, this also constitutes a serious nuisance for harbour management.

(2) Wave Actions

The shorelines in general are subjected to wave actions and erosion as a consequence. The wave actions and resulting erosion are dependent on the sea level. Fluctuations of water level at the coast are influenced by meteorological events, with positive and negative effects of surges which cause an additional amplitude, as much as 1m. Water level elevations resulting from strong storm surges are extremely important. The arctic shorelines have quantitatively little data of the surge actions and the responses. The existence of near-shore bars and shallow-water benches which will be deformed by ice scouring also affects the wave actions on the shoreline, just as in Fig.2[7]. Hill-Frobel[7] indicated that the presence of a few bars, shore-parallel ones in particular, on the lower foreshore, accreted sand beach and intertidal platform, all of which varies from year to year, has a vital effect on the wave regime.

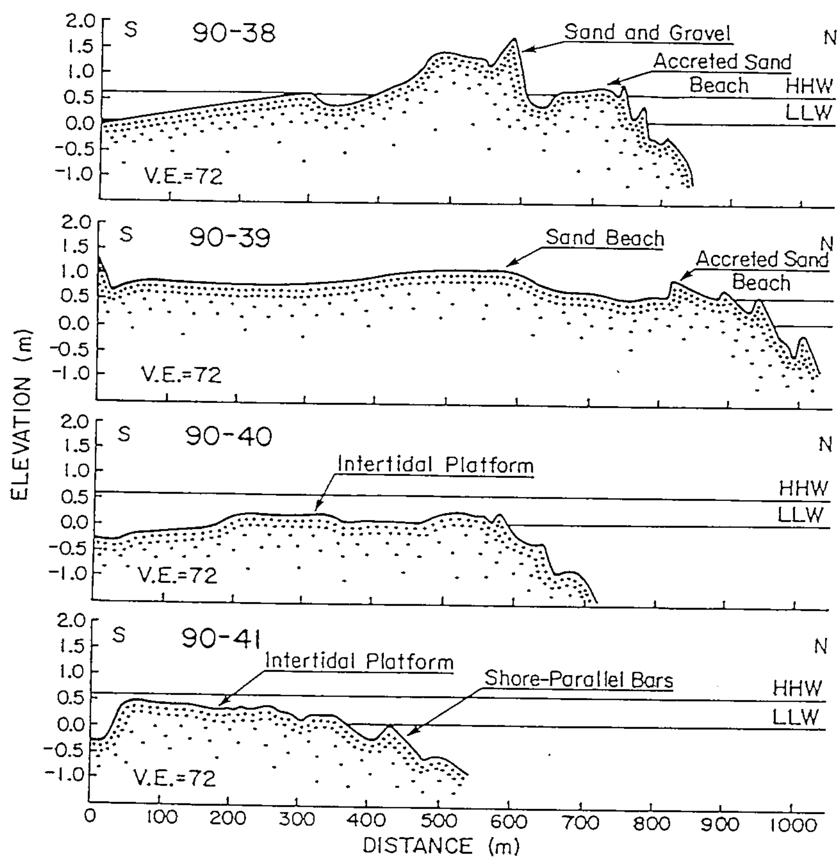

Fig 2: Beach profiles from Wolfe Spit, Canadian Beaufort Sea [7]

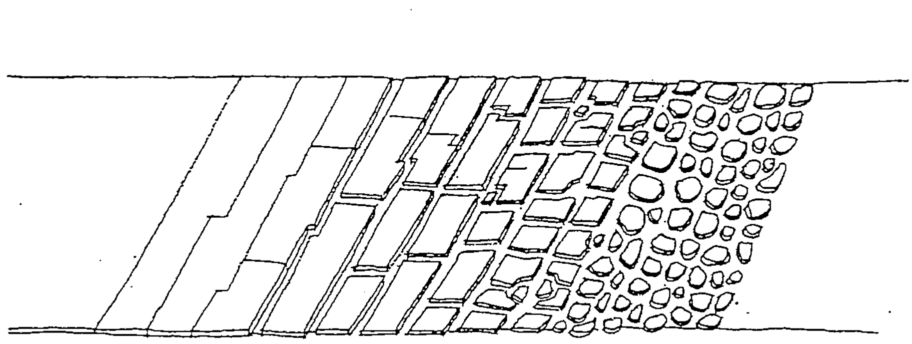

Fig. 3: Waves and ice sheet / ice floe interactions

The presence of sea ice has a significant effect on the fetch and inhibits waves from development and damps waves down. The shorelines will be eroded by combined actions of waves and ice floe driven by waves and wind, particularly in the break-up season. In principle, the development of waves depends on the fetch distance. If the fetch is restricted, ice-related processes are dominant, for instance in sediment transport.

Incident waves cause breaking of ice sheets, and form a typical pattern of broken ice floe, as illustrated in Fig.3.

Understanding of generation, development and decaying of waves in the presence of ice has not fully been deepened. In collaboration with the INSROP, the Ship & Ocean Foundation therefore organized a research programme on wave damping due to the presence of ice floe. The research programme was carried out by the Iwate University, and a part of the results was published in the proceeding of IST'95 in Tokyo[8]. A linear theory for wave motion under ice cover was developed. Transmission rate of wave height through ice cover from the open water and the minimum wave height to cause the ice cover failure was discussed, on an assumption that the ice cover fails when the maximum stress at the crest and trough of the wave profile reaches the failure stress of the ice cover. The theoretical prediction of ice cover failure was

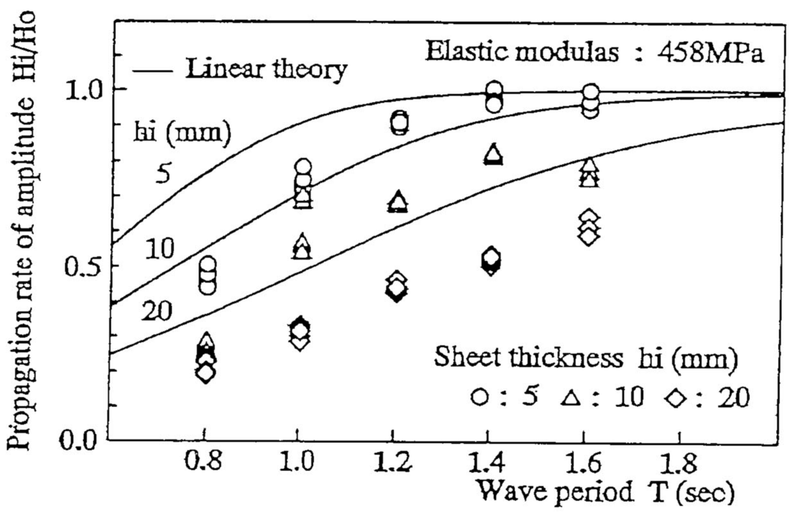

Fig. 4: Propagation rate of wave amplitude in ice [9]

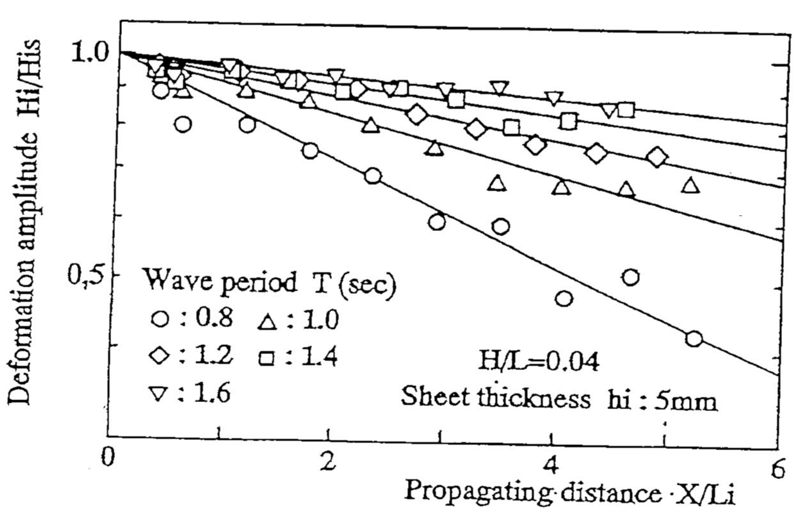

Fig. 5: Wave damping in ice [9]

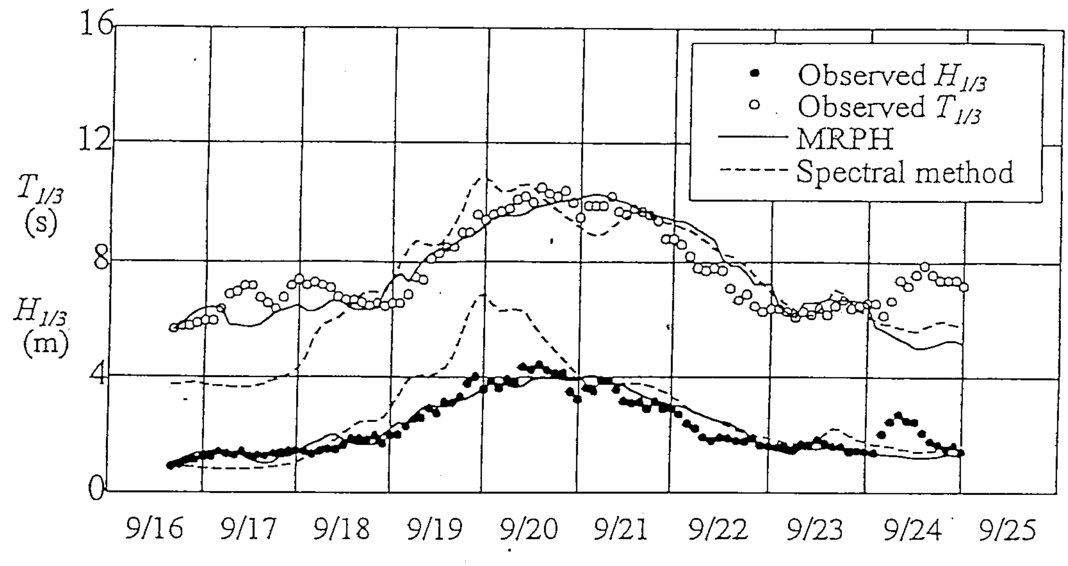

Fig. 6: Comparison between observed and predicted wave data in open water [10]

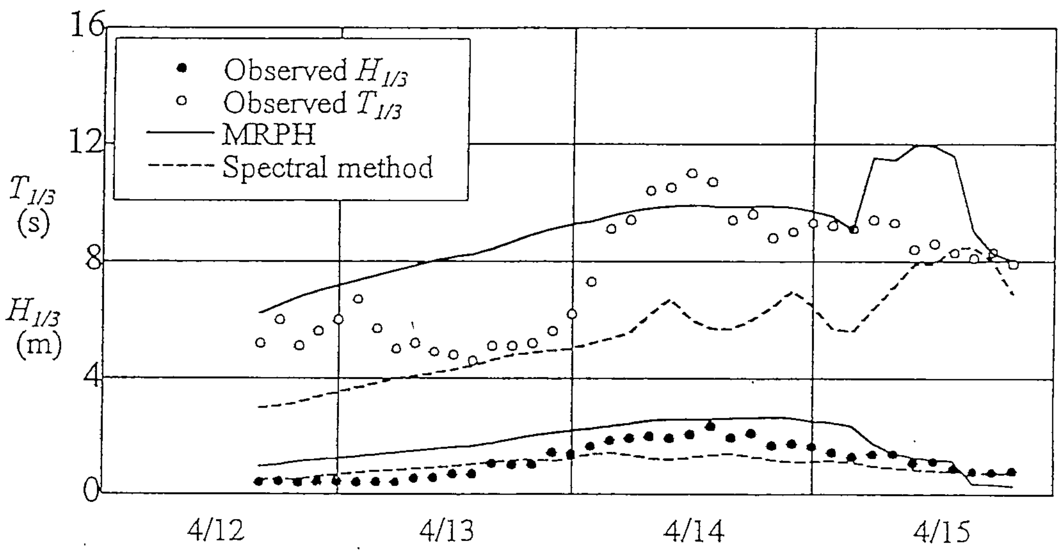

Fig. 7: Comparison between observed and predicted wave data in the presence of ice. [10]

found to amply explain the experimental results carried out by Sakai et al[9]. Figs. 4 and 5 show some of their results. The wave regime in the presence of ice has been extensively investigated at the Iwate University.

Forecasting of waves in the presence of sea ice has been studied by various methods. For instance, Hayakawa et al.[10] examined the applicability of a spectrum method based on energy equilibrium of generation, development and decay of wave and compared with a regression analysis method(MRPH) based on measured wave data in the presence of sea ice. They found that the common spectrum method could not give satisfactory results, as shown in Figs.6 and 7. The regression method seems to be more reliable, but its accuracy depends primarily on the data quality, and the method necessitates sufficient full-scale field measurements over many years. The wave forecasting is indispensable for control of the NSR vessels navigating along the NSR and approaching a port as well.

The wave regime to be characterized by wave height, periods and predominant directions should be given in digits for the sites of ports and harbours in planning. For a more complete understanding of the near-shore hydrodynamics and morphodynamics, field research needs to be carried out in the autumn and the winter, although the natural circumstances of these seasons demand hazardous and inefficient observation and measurement.

(3) Permafrost

Throughout northern Siberia permafrost is ubiquitous, and permafrost is aggradational on land, which happens to reach even 700m depth, basically corresponding to the depth of the 0°C isotherm. In the continental shelf offshore permafrost is also found, but, for the moment, this shows a trend of degrading seaward of the bottomfast ice zone due to the warming influence of the seawater. In the case of the Canadian Beaufort Shelf, the 0°C isotherm is found to exist at up to 600m depth below the seabed. As a consequence of the presence of sea water, saline pore-water into the sediments, however, may prevent the sediments to freeze to this level.

The perennially frozen ground of the arctic coastal plains contains both interstitial pore ice and larger ground ice bodies. The quantity of the both is dependent on the particular lithology and local processes of ground water migration. Ground ice is found to be in several forms such as veins, lenses and massive ice bodies, as typical as in a textbook. The melting pore and ground ice in bluff faces results in mass failure, as thaw flow slides and as thermoerosional falls along ice wedges. It is recognized that these processes often result in very rapid local and short-term bluff retreat.

Thermally triggered slumping also contributes to the development of thermokarst topography, a morphology typical of arctic coastal plains. This morphology is formed by continuing ground ice melting and development of an unfrozen talik beneath the standing water. The presence of standing water primarily causes the process. The pond, therefore gradually expands in size due to preferential consolidation of the unfrozen sediments, assisted by thaw flow slide along the margins. Eventually, the terrain becomes dominated by numerous ponds and lakes, commonly several kilometers in diameter and a few metres deep. Thermokast topography has a considerable influence on the development of shoreline morphology in arctic coastal plain settings, through the development of narrow headlands and wide embayments[11].

A less understood phenomenon related to permafrost is undoubtedly the subsidence associated with degrading permafrost at the coastline. In a general sense, the shoreline and nearshore zone represent the boundary between regions of aggrading and degrading permafrost.

Careful considerations should be taken for the permafrost and its dynamic effects in every stage of design and construction of the NSR ports and harbours, on a basis of authentic permafrost data.

3. ICE LOADS

In the arctic, local loads due to ice action on harbour facilities present a serious challenge to their design and operation. Local pressures are considered in terms of pressure and contact area.

A state of the art review of local loads on offshore structures and other marine facilities has been presented by various scientists in the symposium proceedings, technical papers, and technical books[12],[13]. Most of them, however, discussed ice loads with emphasis on fixed offshore structures.

The majority of the reviews indicate that the existing technology for local pressures is far from satisfactory and there are no well established rational design procedures for ice induced local loads for offshore structures and harbour facilities. Large differences still exist among all these and their applicability to the marine structures is a continued problem.

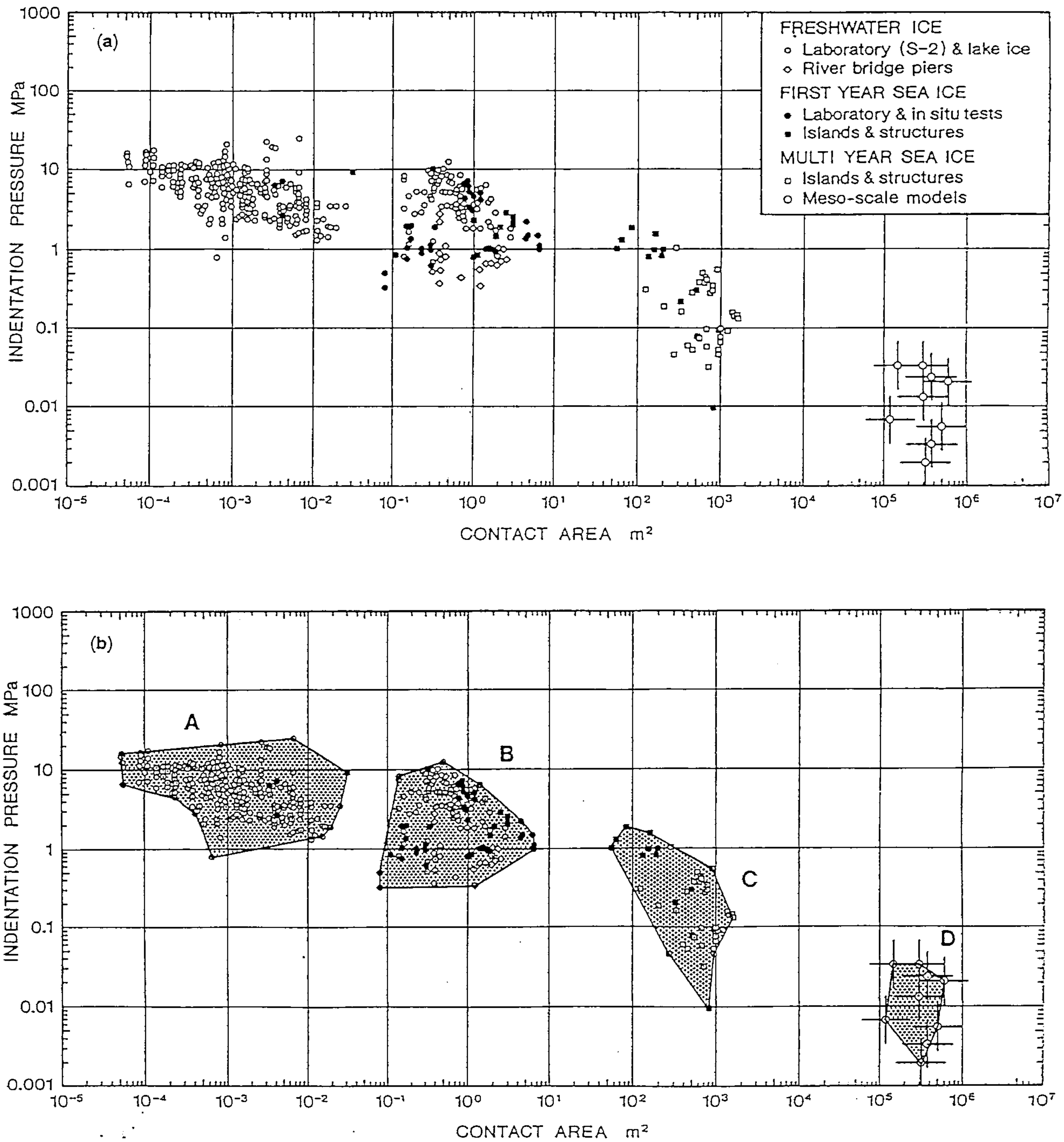

Fig. 8: Pressure-area curve for edge indentation of ice [16]

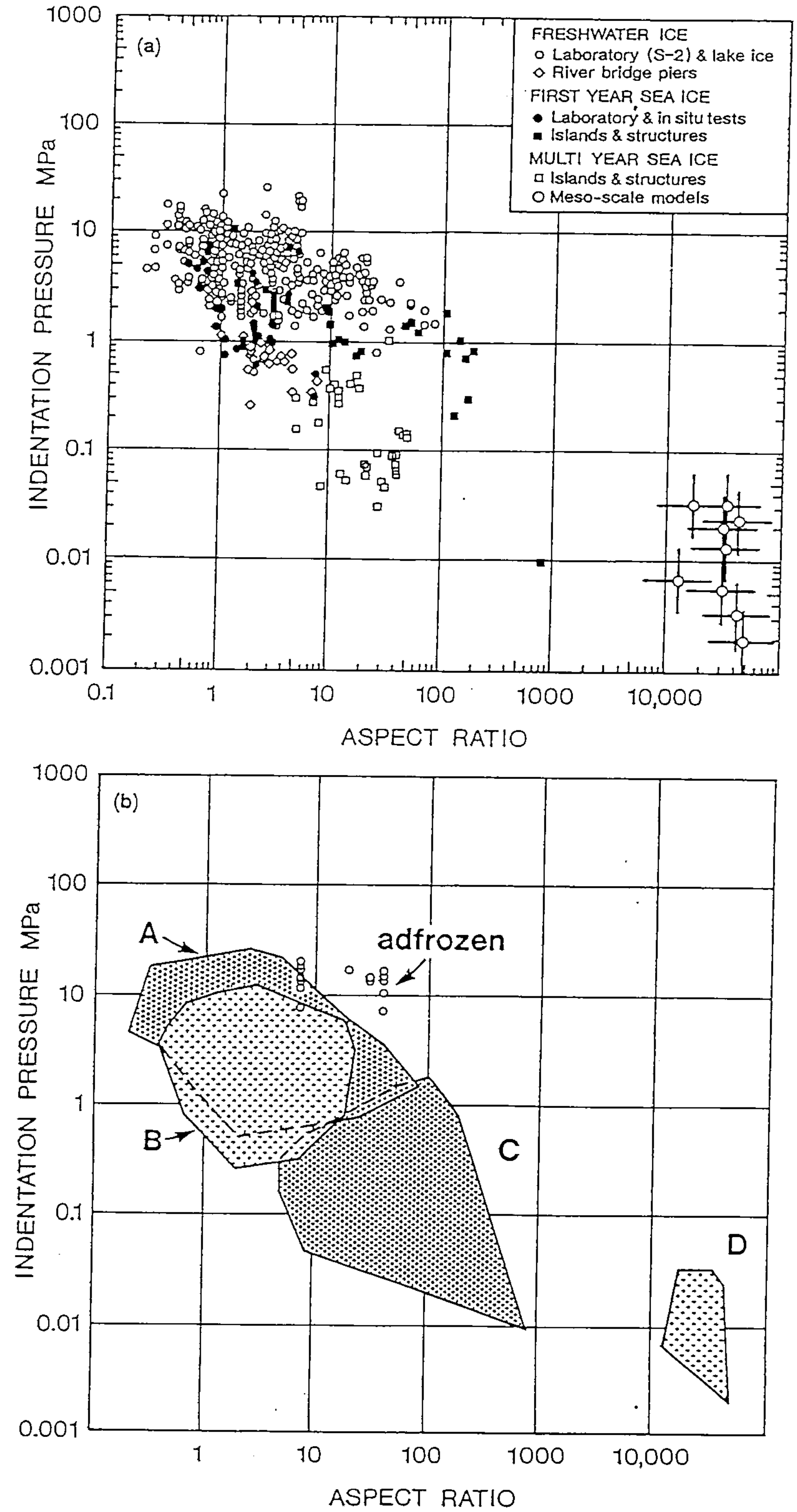

Fig. 9: Plot of peak indentation pressure against aspect ratio D/h for edge indentation of ice [16]

(1) Global ice loads

Ice mechanics has been investigated considerably over the past twenty years. There have been published considerable amounts of literature on the ice mechanics and global loads. Nessim[14] and Croasdale[15] presented excellent state of the art reviews on global loads, and well classified data and information can be found in the text book by Sanderson[16], including the topics on structure of ice, worldwide occurrence of ice, mechanical properties of ice, laboratory studies on ice, full scale measurements, theoretical analysis of ice failure, calculation of design ice loads.

Major test data on ice loads are summarized and shown in Figs. 8 and 9. The figures are summaries of collected data from laboratory tests, medium-scale tests, full-scale islands and meso-scale models. The laboratory test data come from Hirayama et al[17], Frederking-Gold[18], Zabilansky et al.[19], Michel-Toussaint[20], Kry[21], Michel-Blanchet[22], and Timco[23]. The medium-scale data come from Croasdale[24],[25], Lee et al.[26], Inoue-Koma[27], Taylor[28], Miller et al.[29], Nakajima et al.[30], Lipsett-Gerard[31], Määttänen[32], Engelbrektson[33], Hikkanen[34], Blenkarn[35], including data of in situ jacking tests, measurements on river bridge piers and sea ice data from lighthouse. The full-scale data group comes from Metge[36], Strilchuk[37], Johnson et al.[38], Roggers et al.[39], and Danielewicz-Cornett[40], including the test results of Beaufort Sea artificial islands and Hans Island programmes.

Fig.8 shows a marked dependence of ice pressure on size, or contact area.
The pressure seems to also depend on aspect ratio. Aspect ratio, however, is certainly not the only factor responsible for the stress reduction observed.

The discussion is still going on the question which is a key factor, aspect ratio or contact area.

(2) Local ice loads

When an ice feature collides against a structure, the global pressure is given by the average contact pressure at the contact area. The actual pressure distribution is not uniform. The high local pressure which occurs in a small area is considered to be due to a combination of worst grain orientation and high confinement. In the case of wide structures such as marine facilities in harbours, the global impact is generally in a two-dimensional biaxial state and the smaller local area is in a three-dimensional triaxial confined state of stress. Area for local pressures is in different states of confinement, which indicates a single pressure curve for design will not be appropriate (for instance, Iyer[41]). The interaction of ice with an offshore structure is a complex process affected by several factors.

The current practice for local ice load is largely empirical, and furthermore, the data base is limited to establish any reliable approach. The difficulty in properly defining design ice loads demands serious considerations of risk and consequences to meet appropriate safety requirements. Remarkable progress, however, has been made in the last several years. The structures designed with the existing knowledge and techniques have withstood severe ice loads without noticeable damage, such as the Dome/Gulf Tarsiut concrete caisson-retained island, the Dome Single Steel Drilling Caisson(SSDC), the Esso Steel Caisson-retained island(CRI), the Global Marine Concrete CIDS, the Gulf''s floating steel drilling unit, Kulluk, and the Gulf Molikpak(monolithic steel caisson). They have been quite successful in their performance and under local ice loads no failures have been reported. They have provided useful data and information of both local and global ice loads, which will be useful for design of the marine facilities of the future NSR harbours as basic data and design guidelines.

4. ICE MANAGEMENT

When a plan is arranged for the construction of piers, wharves and any other harbour and fleeting facilities, careful consideration should be given to whether or not they will bring about any serious change in hydrodynamic features in the planning site, particularly unfavourable ones in wave attenuation and ice floe movement. In the estuary, they might reduce the hydraulic capacity of the river. When the river and the estuary is covered with ice in large area, traffic in and out the fleeting area has considerable effects, both adverse and beneficial, on the natural condition of the site. In general, any artificially constructed facilities have certain effects on them.

An ice management or ice control system is indispensable to any port and harbour along the NSR. There have been numerous techniques developed or tested for controlling ice. Among them mechanical systems driven by hydraulic or electrical power have primarily been developed with the aim of removing ice from undesirable areas, and on the other hand thermal methods prevent the ice cover from thickening or/and are expected to melt it by generating heat flux. Some of those systems, however, might not be applicable to the NSR ports and harbours where much more severe ice conditions are to be expected.

The ice control techniques in general will be classified into four categories as follows:

(1) Ice deflection or diversion
   booms, structures preventing impingement of ice into control area, flow generators in the form of bubblers, propellers, water jets, wavemakers

(2) Ice removal
   equipment for towing, pushing ice, or excavating ice from control area, pipeline systems, conveyors

(3) Ice breaking or cutting
   icebreakers of displacement type, air-cushion vehicles, combination of air-cushion vehicle and pusher barge, archimedean screw tractor, ice-cutters of mechanical or thermal type, water jets, chemical jets, explosives

(4) Ice suppression or prevention of ice formation
   bubblers, warm water discharge, floats and pontoons, wavemakers, ice dusting(coal dust, fly ash), insulation by sheets or aqueous foams, enclose of control area

Major techniques are described briefly in the following sections.

4.1 Ice Booms

Floating ice booms have been frequently applied for ice control in reservoirs for hydroelectric power plants, river harbours and fleeting areas. Floating ice boom, as shown in Fig.10[42], is a line of floating timbers or pontoons to collect and retain floating ice, or in some cases, remove ice. In general ice booms have some anchoring system to fixed structures on banks or piers. The timber-type will be one of the most economic and temporary devices, which composes a line of timbers connected to a wire rope structure. The timber line will have a few anchor lines to the sea bottom or harbour structures. Ice booms can be used in conjunction with backwater structures or other water flow controlling devices and also be operated by moving ships or similar moving structures with variable length.

The total force on an ice boom consists of the following;

water drag under ice cover,
wind drag over the cover,

weight of collected ice,
momentum effects of water and ice floes impinging against the upstream ice edge or front edge,
wave effects, including waves generated by moving vessels nearby.

Large ice sheet will often cause high loads at the outer ends of the boom, and result in the failure of the ice boom.

Perham and Raciot[43] measured the forces acting on ice booms on the St.Lawrence River at locations in the International Section, the Beauharnois Canal and Lake St. Peter. Douglas, where fir timbers 0.36m thick, 0.56m wide and 9.1m long are used. The timbers were connected to the wire rope by two chains near their ends. It was found that in the early winter the forces on the boom due to ice floes and slush ice varied from 0.61 to 2.8kN/m, while Ontario Hydro measured a maximum loading of about 8.4kN/m. The main boom elements were double steel pontoon on the Beauharnois Canal. They were 0.91m in diameter and 6.1m long, and connected at their upstream edge to the wire ropes. The force data taken each winter from 1973 through 1981 indicated that the maximum early winter loading varied from 1.6 to 11.6kN/m. The data contained extremely high loading of approximately 47kN/m, when there was observed substantial ice jamming on the canal.

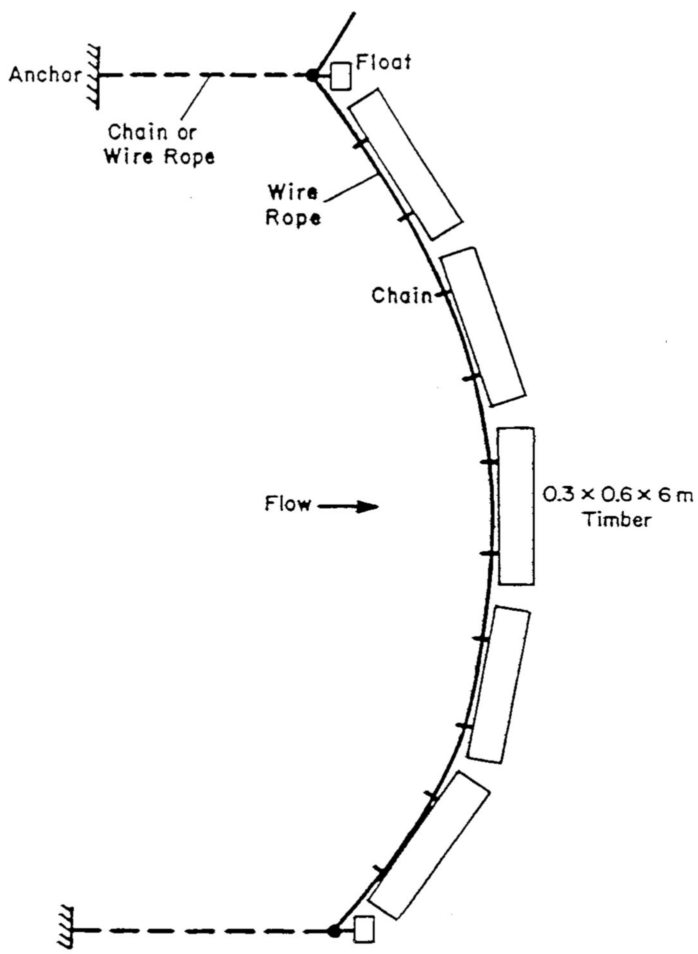

Fig. 10: Schematic of a floating ice boom [42]

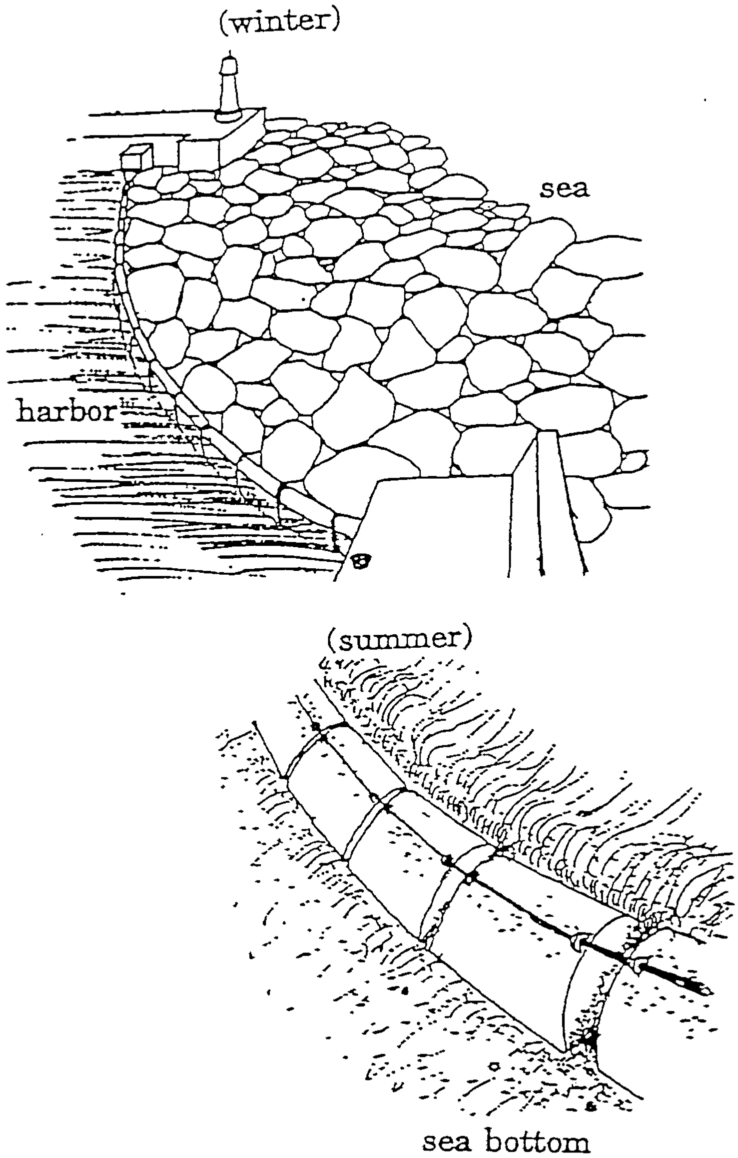

Fig. 11: Schematic of SFIB (ice boom) [44]

There have been neither data nor technical papers published on usefulness of ice boom in the NSR ports, but ice booms of much more strengthened structures, for instance such as a hinge-connected steel pontoon type, might be applicable even in the NSR ports in some cases when ice conditions are moderate enough to use such a mechanism.

4.2 Ice Boom of New Type

(1) Sink-and-float type

Ice boom has several versions, which have naturally been developed in the regions where ice conditions are moderate and economic and social activities are relatively high enough to investigate modified types of ice boom to allow year round operation of harbours. One of the examples is found in a port in the Sea of Okhotsk. An ice boom has been developed to prevent the harbour from freezing and ice floes entering into the harbour mainly due to wave actions.

Imaizumi et al.[44] reported the development of a sink-and-float type ice boom(SFIB) for ice floe control. The SFIB consists of a number of floating bodies linked tightly with steel cables and tied to piers at their ends. The SFIB can sink down to the sea bottom when the floats are filled with water and at demand it can stay at the water surface to prevent ice floes from entering the harbour while the floats are filled up with air. Basic concept of the SFIB is illustrated in Fig.11 and the features in action and storage are illustrated in Fig.12.

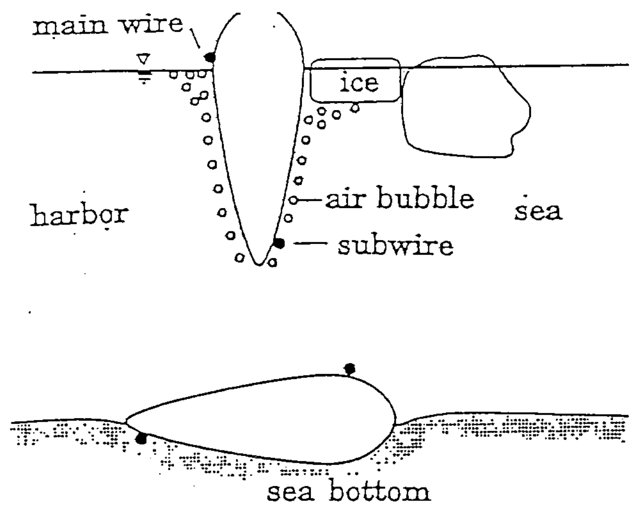

Fig. 12: SFIB (ice boom) in action and in storage [44]

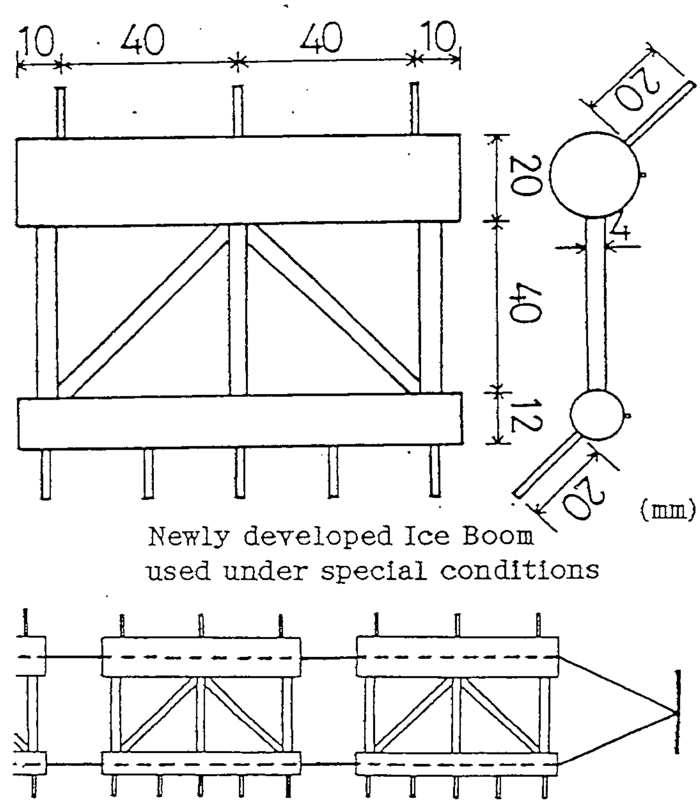

Fig. 13 Wire-net type ice boom [45]

Basic information of the SFIB for the design was investigated. They showed a main factor of the SFIB design as a function of ice thickness, incident wave height, incident wave length, size of ice cover and height of the SFIB floats.

For progressive waves, the height of the SFIB floats is a key factor for its effectiveness. However, there should be a certain limitation of the height of the SFIB floats due to structural strength and operation of the total system with a sense of economy. For standing waves in a harbour, when the SFIB float height to wave height rate is larger than 0.3, the system is applicable and it was found that the SFIB could be effective when the standing wave height is lower than 5 m.

There would be a defect of this system. The sunken SFIB floats in a storage state would be threatened to be deeply or slightly buried in drifted sand or mud due to wave and current actions, particularly outside of the harbours. The system would then be much more applicable inside the harbours, where weaker ice and moderate wave actions are to be expected.

(2) Wire-net type

Ice booms which have been developed and applied in rivers and harbours in Canada and U.S.A. are of simple float type. It is found, however, that they could not trap moving ice floes successfully, because considerable portions of ice floes submerge and pass away through the ice boom, when ice floes run at relatively high speed.

Kunimatsu et al.[45] then developed a modified type of ice boom with a wire curtain or net hanging underside of the floats. Schematic is shown in Fig.13. They examined the ice boom in the Saroma Lagoon adjacent to the Sea of Okhotsk with two inlets.

4.3 Alternative methods

Flow developers, akin to air curtains, can be aimed to control moving ice floes. Deflector structures and pile clusters are also utilized in lakes and rivers where the ice floe movement has a predominant direction or its direction is predictable.

To protect some structures from ice forces, ice piers, drift deflector, barges, or other alternative devices were widely applied. They will be designed in some cases as supplementary devices for a total ice managing system.

Ordinary floating ice boom will have a difficulty in adjusting the anchoring devices in the locations where the water level changes to great extent. To deflect ice floes or prevent ice movement in the undesired direction, moored or even self-propelled vessels, icebreaking or ice-strengthened, could be applicable. The icebreaker maneuvered with her engine and rudder to keep the moving ice floes from pressing her stern against the shore.

Ice-strengthened vessels, which usually their main propulsion engines will not be in operation and moored, could be used for storage vessels and/or ice floe deflecters in the NSR ports.

4.4 Ice Flushing and Melting Method

Water surface flow control is one of the basic concepts of removing ice from undesirable locations. The technical problem pivots on how to efficiently generate appropriate water surface flow. Air bubbler curtains and submerged water pumps are of the most successful means to generate a desired surface flow, which have been studied also for damping water waves at entrances of ports and harbours or inside of them.

4.4.1 Air Bubbler System

(1) System

Air curtains induce flow by releasing air at a certain depth; and the induced water flow flushes ice away from problem areas, as illustrated in Fig.14[46]. The induced water surface flow is dependent on intensity of provided air flow, where considerably high intensity of air flux is required to move and flush out ice. A schematic example of air curtain applied to flush ice from a navigation lock is shown in Fig.15[46].

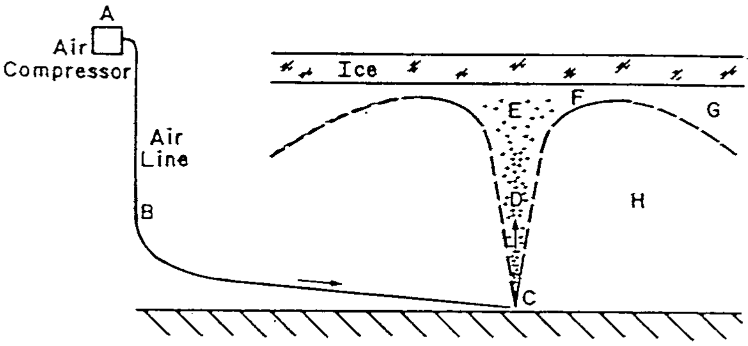

Fig. 14: Schematic of a bubbler system [46]

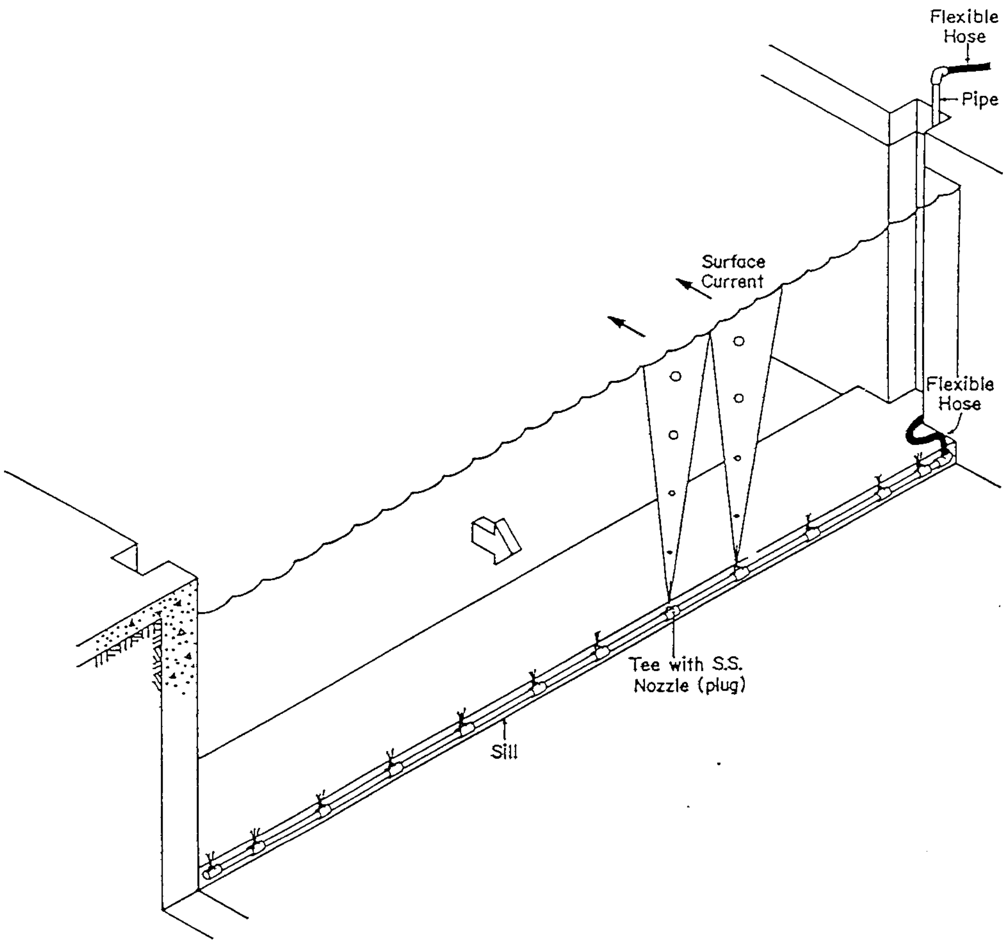

Fig. 15: Air curtain used to flush ice from a navigation lock [46]

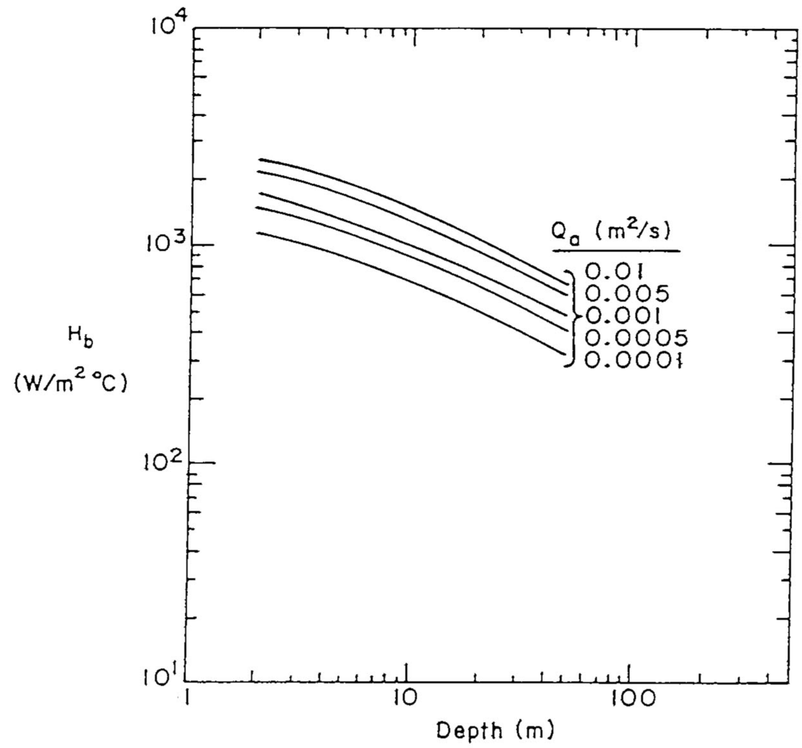

Fig. 16: Heat transfer coefficient at distance as a function of diffuser submergence depth and air discharge rate [47]

Ashton prepared a monograph on air bubbler systems[46] and reported on laboratory experiments on line-source bubbler system heat-transfer coefficients[47]. Fig.16 gives heat transfer coefficient at distance as a function of diffuser submergence depth and air discharge rate.

Air is compressed by a compressor, which will be installed indoors or outdoors in a protected space. A few compressors will be installed and interconnected through a discharge manifold piping system. The piping system is usually laid on the harbour bottom and in some cases at a certain depth of water. Air runs through the manifold piping to perforated diffuser lines, or the manifold itself may have diffuser orifice ports that emit air. The air at the orifices, warmed up during compression, is normally cooled down by the time it reaches the diffuser. The air must have enough pressure at the diffuser to overcome the depth of water hydrostatic pressure and in most cases some additional pressure to generate satisfactory air bubbling emitting velocity which can induce upward water flow.

The discharge air expands and cools to some extent on leaving the orifices. If it expands too quickly, an icing condition can be produced, and the discharge air must remain in proper pressure level. The air bubbles entrain ambient waters in the upward plume. The volume of entrained water depends on size of the air bubbles, where the tinier ones are more efficient. The air bubbles themselves will not add an effective contribution to melting of the underside of the ice cover. Flushing away of ice floes and melting of the underside of the ice are performed by relatively warm water moved upward induced by the air bubble flux.

The volume of water necessary for melting of a cubic foot of ice close to melting temperature depends naturally on the temperature of the water, unit weights of both water and ice, the specific heat capacity of water, and the heat of fusion of ice. The buoyant plume spreads as it encounters the ice cover or mass of ice floes, or reaches open water. When an ice cover exists, the mixed flow of bubbles and entrained water hit an underside of the ice and move laterally, melting the ice primarily by convection. This heat loss results in a cooling of the mixed flow and the velocity of the flow decreases as it spreads out, which causes a rapid decay in the heat transfer rate between the ice and the flow. The air bubbles or the mixed flow of the plume induces a net circulation on the water, which draws warm water up to the surface from distant lateral directions.

If the water depth is too shallow or total volume of water is limited as in a swimming pool, the air bubbler system can not work well. Bengstsson's measurement[48], for instance, will confirm the minimum water depth at which the air bubble system can be applied effectively, and it is said that a six feet water depth is required to operate an air bubbler system effectively.

To keep floating ice floes away from the undesired location, for instance, cargo handling piers, docking facilities and out of navigation locks, 100 psi air was supplied to a 2.5 inch manifold and supply line system, which had nozzles of 0.4 inches in diameter with 10 feet apart spacing. No expansion freezing was experienced. The elevation of water surface was observed as high as a foot, and no ice floe could pass across the hump.

(2) Design parameters

The parameters to be discussed in the design of air curtain system will be as follows;

- geographical features of the site,
- water level; mean and variation,
- current velocity and predominant direction,
- waves; incident, attenuation and predominant direction
- air and water temperature; mean and variation,
- area required for ice control,
- depth of nozzle submergence,
- air supply line sizes and total length,
- manifold sizes and length,
- orifice nozzle sizes and spacing,
- air supply rate and pressure, including range of pressure,
- power supply facilities.

In the case of an installation in a navigation lock, as shown in Fig.15, typical air discharge rates for air curtains are approximately of 0.01~0.02 m^3/s per meter of air line.

The air pressure must be sufficient to overcome both the hydrostatic pressure at the submergence depth of the nozzles, which will vary with the water level change, and the total losses in supply line. When relatively high air pressure is to be provided, the losses in supply line will increase.

The amount of water induced and entrained by the air flow increases with the distance above the nozzle line. There have been several papers published on the rate of vertical water flow as a function of depth, air flow rate and type of air source, i.e., point or line source. Kobus[49], for instance showed some empirical results on the relation of the nozzle depth and the induced water flow. In the NSR ports in future, further investigations are required for application of the air bubbler system, as the induced water flow will be expected to be much higher than those of Kobus' or other empirical studies, under the much more severe ice and natural conditions of the NSR ports.

(3) Installation and maintenance

Air bubbler system requires careful installation, maintenance and monitoring as well. Occurrence of failure of the system will always have high possibility in winter season, as real ice condition is statistical and will happen to overcome the design loads of the system. In any case changes in the bottom contours due to currents, waves, sediments, or even ice blocks should be carefully checked.

(4) Operating costs

Operating costs will vary widely because of differing weather, water temperatures, utility rates, equipment specified, etc. The costs also vary from year to year, including maintenance cost variations and repairing costs increase.

Operating costs can be estimated from system parameters.

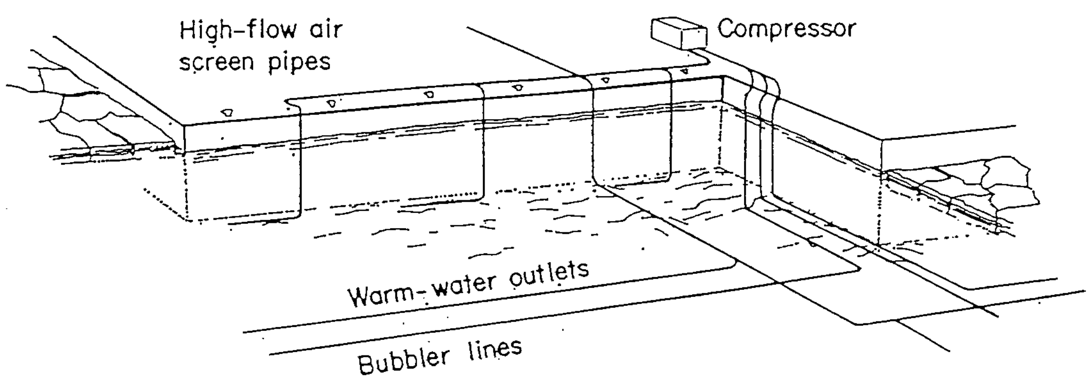

Fig. 17: Combination of ice control methods [50]

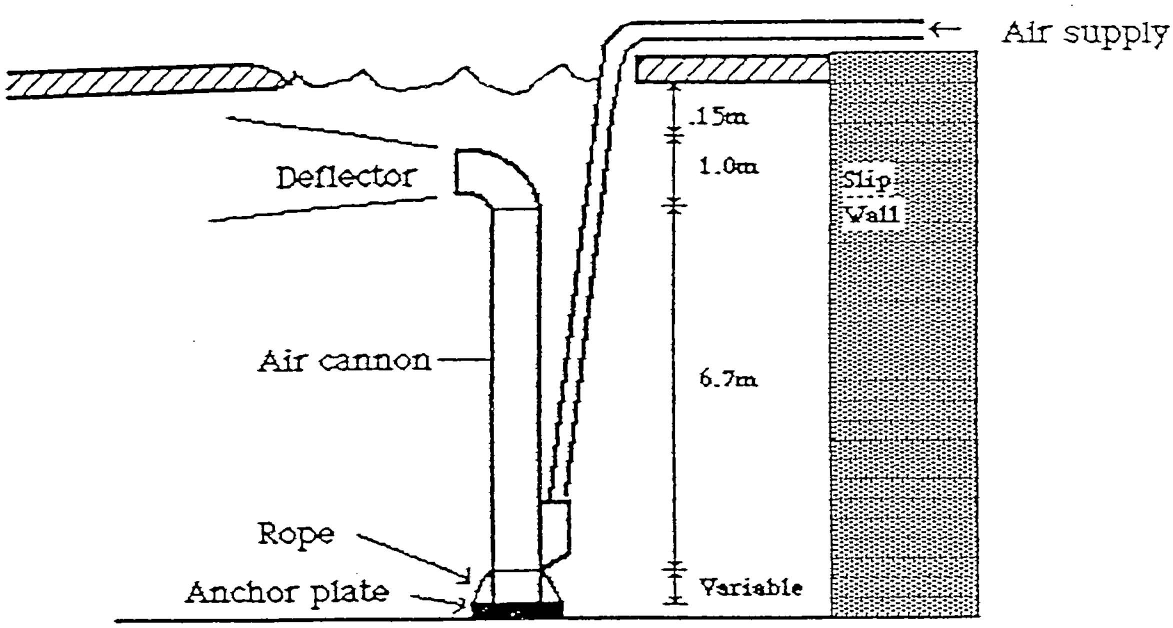

Fig. 18: Atara Air Cannon Bubbler with deflector [51]

4.4.2 Combination of Ice Control Methods

There have been examined various combinations of different ice control methods. One of them is shown in Fig.17[50]. In this case warm water is distributed to critical areas and air bubbler is utilized to circulate the thermal energy to the underside of the brash ice cover. The air is directed to air curtain line and pumped at a certain rate to generate a water flow that pushes the loose ice blocks away from the berthing area.

The "Atara Air Cannon Bubbler", developed in Canada, is another type of the air bubbler[51]. The schematic is shown in Fig.18. The device propels fluid by means of a rising piston of air. A bubble generator located at the base of the tube emits a large air bubble.The bubble rises in the tube drawing replacement fluid into the tube behind it and exits from the top of the tube entraining an increasingly larger volume of fluid as it ascends to the surface. The air and water flow produced by the apparatus impinges on the ice cover, resulting in the thermal erosion of the ice. The ice management experiments with this device were conducted at Thunder Bay with satisfactory results.

4.4.3 Submerged pump

Submerged pump systems can generate a strong upward water flux, which delivers warm water against the ice and suppresses ice covers. There are several slightly different units developed, such as flow developer, propeller unit, deicer, velocity system and water agitator, but they are almost the same in principle. The submerged pump system resembles the air bubbler system in mechanism of the action, in particular, in the case of the submerged pump system having manifold and nozzle line units. Contrary to the water flow induced by air bubbles, however, the induced water velocity by a submerged pump decays inversely with distance from the pump outlet The submerged pump should therefore be positioned close to the ice. The submerged pump units have been used mainly for local ice suppression, for instance, in pier side. Eranti et al.[50] reported the utilization of submerged pump units in Finnish harbours. The ice-free areas were found to vary considerably, naturally depending on the local water temperatures and ice conditions.

4.4.4 Other Techniques

There have been various kinds of techniques developed and some of them have been tested or installed successfully in harbours.

(1) Heating

As most ice-associated problems can be solved and prevented by heating the surface adhered with ice, by making use of various ways of heating, such as electric resistance heating, steam or warm water, warm pipes heated by steam, water, or oil, embedded in the surface.

In water supply systems in cold regions, intake trash racks are extremely susceptible to blockage due to deposition of frazil ice on the bars of the racks. Removal of trash racks is hazardous during frazil runs, and heating units have long been used to the trash rack bars. Electric heating is the most popular solution. Gevay-Erith[52] presented a detailed description of the design and performance of electric heating units for trash racks in central Labrador. Primary objective of the heating is not to melt the frazil but to prevent the frazil from adhering to the trash rack elements. The effectiveness of the heating units depends on the spaces between bars, which should not be too small.

(2) Warm Water Supply

Another technique will be a supply of warm water to the ice, which is available in numerous instances. If relatively warm ground water is available, there can be a warm water supply unit of low cost utilized. When warm water originated from any source is planned to use, its environmental effect should widely be investigated.

(3) Water Jet

Water jets with high nozzle pressure were tried to use for rapidly cutting ice, as the jet cutting methods have been utilized in other fields of industry. Calkins-Mellor[53] reported that water jet cutting was feasible for lock wall deicing. Useful technical data are presented by Coveney[54] based on a series of test results using small and moderate scale water jets into freshwater ice.

(4) Mechanical Methods

Mechanical methods for breaking and moving the ice, such as by blasting, by using pneumatic devices, or by using draglines, clamshell buckets, endloaders, backhoes and bulldozers, have also been developed.

(5) Surface Coating

Studies on ice-phobic materials have eagerly been conducted, examining their adhesive or bond strengths to ice. Of the various formulations tested, the most promising was found to be a solution of a block copolymer, silicone oil and toluene, and a recent study[55] found that the effect of surface coating varied considerably according to inclination of the coated surface. . Any coated surface cannot stand abrasion and weathering effects, which implies a necessity of repeated re-coatings or re-paintings of the surface.

4.5 Icebreaker

As before-mentioned in section 4.3, icebreakers are effective for deflection of ice into desired direction. Those vessels can be much more widely applied to ice control in harbours. Breaking of ice sheets, pushing ice floes into favourable direction due to displacement effect of ships, creating open water channels, particularly for small harbour boats, will be major actions made by icebreakers. Strong induced flow by ship propellers is another means of moving ice, especially when the ship has a powerful propulsion device. Ducted propellers or nozzle propeller will be preferable.

Aircushion vehicles can be operated to break ice sheets. Moving downward pressure of aircushion vehicles can be more effectively applied to breaking ice, when ice has relatively low salinity.

5. ABRASION OF CONCRETE STRUCTURES DUE TO ICE

Abrasion in the concrete occurs when a moving ice sheet or block breaks against a structure. The field observations indicated that ice abraded the concrete structures significantly. Abrasion mechanism depends on various factors, such as surface condition of concrete, mechanical properties of concrete, size and protrusion of concrete aggregate particles, moving direction of ice and velocity, magnitude of ice force, ice properties, air and water temperature. The abrasion problem of concrete marine structures has been investigated by laboratory abrasion tests and field tests on icebreakers and lighthouses. It is found that the most dominant factors in the abrasion of concrete are temperature of ice, stress intensity of ice against a concrete surface, strength of concrete and durability of strength during freeze-thaw cycles[56],[57].

The lighthouse abrasion in Helsinki was measured to be almost 300 mm over 30 years[56]. The abrasion mechanism is complex but abrasion depth of concrete in the arctic condition could be estimated through empirical diagrams or laboratory tests.

6. ICE AND SNOW ACCRETION

Ice and snow accretion on structures exposed to the atmosphere or marine environment is of importance in the NSR harbours, as this may lead to the failure of the structures and their function. In aircraft and marine icing incidents, endangering of human life and the loss of industrial resources could be expected to happen. Even today tragic accidents have occasionally taken place in aircraft due to icing on main wings or other key units for control. Marine icing, one of the typical spray icing has resulted in losing many human lives and their vessels due to capsizing. Faults on an overhead transmission line grid system are other typical incidents due to ice and snow accretion.

Except for the NSR vessels in service, ice and snow accretion may not be serious incidents for structures and marine facilities in the NSR harbours. Icing and snow accretion on structures and transmission lines should be discussed and prevented through technical considerations in their design stage.

The term ice accretion is usually employed to describe the process of ice growth on a surface exposed to the atmosphere. The rate of growth of ice is primarily dependent on the rate of impaction of the icing particles, ice and snow, airflow, local thermal conditions on the surface of a structure, and geometry of the structure. Icing particles may exist as supercooled water droplets, ice crystals agglomerated in the form of snowflakes. When the ambient temperature and the surface of a structure are cold enough, water droplets should be taken into account.

As Brown-Krishnasamy[58] notes, essentially there are four types of frozen deposit which can be accumulated on a surface of a structure. They are rime, glaze, frost and snow(wet). Rime is an ice deposit caused by the impaction of supercooled droplets and their freezing on a substrate of which temperature is lower than 0? ? in most cases, associated with freezing fog. Glaze ice will form when the droplet freezes slowly enough for a film of water to cover the accreting surface. This will occur when the heat loss from the surface is less than the latent heat of fusion liberated by the freezing droplets. Frost is generated when water vapour in the air subliminates on a substrate below 0?b. It forms ice crystals which will vary in form, commonly known as hoar-frost. Wet snow exists in different forms, as an agglomeration of flakes, either bonded or isolated, and a mixture of ice, water and air. The other types of solid precipitation are snow grains, pellets, hail and graupel. The features of ice and snow accretion are largely dependent on geophysical, meteorological environmental condition and thermal and geometrical condition of the surface.

Icing on pavement will be the most familiar type of icing in cold regions. This event causes extremely hazardous driving and working conditions on roads. A comprehensive analysis of the event is given by Jumikis[59]. Various anti-icing and deicing devices and techniques have been developed. Apart from fuel consumption or working expenses and maintenance cost, there can be found effective deicing techniques for pavement icing.

Spray icing in marine environment has a different feature. A combined action of wind and wave are predominant in addition to meteorological condition. Waves easily form a clapotis at a pier, quay wall, groin and an impermeable breakwater, which will generate a flux of sea water spray by wind. The spray flux carried by wind impacts a surface of a structure, which is cooled down into supercooled state in the air. Such a spray icing on marine structures and facilities will cause a hindrance to various activities in the area.

Marked progress has been made in understanding the physical process involved during ice and snow accretion on structures, through the continuous field measurement of ice load and wind on ice load, together with the simultaneous measurement of meteorological variables, model experiments in an icing wind tunnel, construction of mathematical and computational icing models and simulation studies.

As for atmospheric icing, the state of the art is well summarized in the text book written by Poots[60], and a great deal of data and information of ice and snow accretion in general can be found in the proceedings of the International Workshop on the Atmospheric Icing of Structures, whose first workshop was held in 1982 in Hanover, U.S.A.

Various techniques have been developed for anti-icing, deicing, snow removal and ice control. Among them, artificial heating such as heat pipe, use of chemicals and abrasives, air and water jet, mechanical removal, and forced vibration techniques will be often tested and utilized(for example, Gray-Male[61]).

For removal of ice which has already grown to some thickness, there will be two ways which seem to be the most practical and effective in marine environment, heating and pneumatic deicing. One of the most common techniques of deicing is undoubtedly an artificial heating. It is found, however, that the necessary heat supply for keeping a surface ice-free during extreme marine icing conditions is about 5 kW/m^2 for a vertical cylinder and 7 kW/m^2 for a vertical flat plate. A method of reducing this energy input has been proposed by using intermittent heating. Small amount of water is then allowed to freeze and the heat of fusion will automatically bring the water temperature up to the freezing temperature. It is shown that it may be sufficient with as little as half the energy supply used in the continuous heating case.

A pneumatic de-icer consists of a series of inflatable tubes built into a rubber mat. When the tubes are filled with air the expansion may cause fracture in the ice on the outer side. Such de-icer boots have long been used on the loading edge of aircraft wings. Stallabrass[62] compared the effectiveness of different mechanical and chemical deicing methods, such as pneumatic deicing, plastic foam, adhesive reducing paint and freezing point depressant. He found that the pneumatic one was most effective both on masts and flat surfaces. He also pointed out some disadvantages of the pneumatic deicing method as follows; cost, probability of damage to the de-icer, and need for removal of the shed ice from the decks when reduction of the total weight is to be achieved.

7. EQUIPMENT FOR OPERATIONS IN HARBOUR

There should be numerous operating, supporting, maintenance and rescue services units provided in a harbour.

Harbour lights, beacons, danger marks, other navigation aids in port, harbour icebreakers, dredging ships, harbour tugs, pilot or guard ships, rescue ships, fire-extinguishing boats, most of them would be required to dispose in the NSR harbours. As they can withstand ice-infested harbour conditions, they follow rigid specifications in their strength, performance and workability.

Autonomous unmanned or manned submersibles will be useful for underwater inspection and repairing while the water surface is covered with relatively thick ice. Together with marked development in sensing technology, controlling techniques and related software, autonomous unmanned vehicles could be put into service. A small long-range vehicle could enjoy a closed cycle diesel, CCD, as a prime mover, which can realize an air-independent submerged operation range of longer than 1,000nm[63]. An example of an underwater vehicle is illustrated in Fig.19.

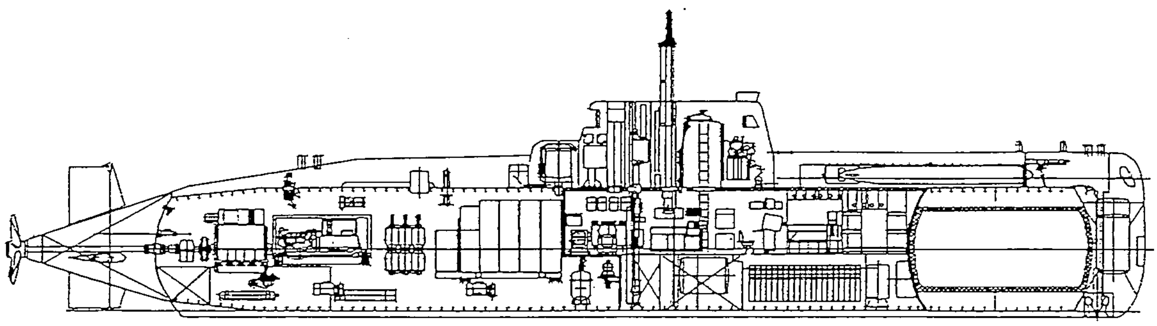

Fig. 19: An underwater vehicle [63]

Currently available ROVs carry the advantages in their capabilities for real-time observations and data transmission, and for the moment, have much more reliability in operation below ice cover than autonomous submersibles.

In the early stage, one-man tethered submersibles had successfully been in service. The Mantis, for instance, carried out supporting services of drilling or associated operations with the rig supply vessel Balder Cabot in the seas off Nova Scotia and Labrador. ROVs have extensively been investigated and various types of ROV have been developed suitable for particular missions of operation.

Submarine might be another type of vehicles suitable for operation below the ice-cap under extremely severe ice conditions for a long time, provided the submarine has an energy source that does not require surfacing and modern underwater navigation system.

8. HARBOUR STRUCTURES

8.1 General Features

In any ice-free waters, in order to assure the safety levels all through execution, transportation, installation and operation all stages of structure configurations have to be covered during the design process. Because of the special environmental conditions in the arctic regions, engineering should adopt adequate principles and solutions ranging from material selection to general design and from construction methods to strategies in project execution, as well as maintenance scenario. In the case of a concrete floating platform for a harbour, for instance, the construction sequences to be taken into design for a concrete structure represent the complete execution history, from start casting in dock or similar facility, through slip forming at sea, mating of topside, towout to site, installation and lastly short or long term operation.

Snow loads and heavy icing have caused structural collapses. Icing and blowing snow may cause significant maintenance problems and decrease workability in a harbour area. Frost problems are mostly encountered in foundation design and earthworks. In most cases soils are frost-susceptible. Foundations have to extend below the active layer to avoid frost damage and the thermal regime of the ground should be maintained to prevent thaw settlements in permafrost areas. Frost action also demands extensive annual maintenance efforts and expenses.

Concrete construction in the arctic regions has brought up special problems in comparison with ordinary winter construction in the subarctic regions and in the sites of moderate climate. Long-distance transportation in the arctic occurs mainly through air and water routes, and water transportation is the prime mover of freight. Working conditions will be uncomfortable and hazardous in the arctic winter, and the extent of operations is much limited. Inefficiency of working in the arctic circumstances is illustrated in Fig.20, being based on temperature, lighting, and precipitation[64]. Precast concrete elements are undoubtedly most appropriate in arctic conditions, which will be transported and erected at the site, as the strengthening of concrete at extremely low temperature and durability of concrete are among the most common problems difficult to solve.

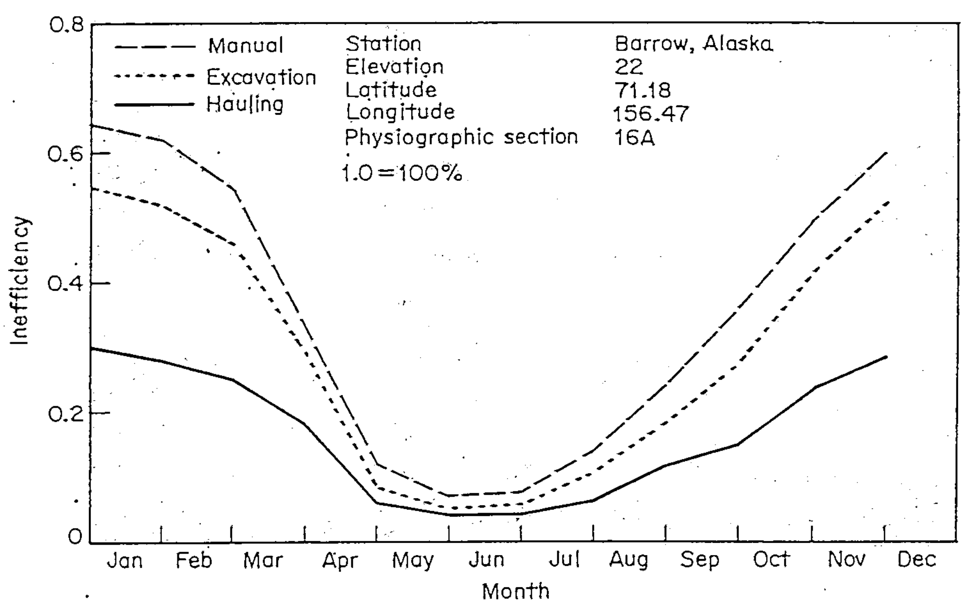

Fig. 20: Example of Arctic earthwork inefficiency [64]

Structures of concrete or other porous materials tend to deteriorate when they are subjected to consecutive freeze-thaw cycles in the presence of moisture. Air-entrained or fine-filament-entrained concrete with low slump rate have been utilized in cold conditions. In concrete structures, an application of effective joint seals in building or pavement joints in cold climates is an important issue to ensure a design life or to elongate the life of seals. They should respond with elastic or viscoelastic behaviour over a reasonable design life to any movement of the joints without adhesive or cohesive failure. To meet this desirable response feature, lower modulus, rubber-based, elastomeric materials have been formulated as joint sealants. It should be noted that the modulus of elasticity, dependent on temperature and loading rate, increases with a reduction in temperature and an increase in loading rate, and that the seal stiffness will mostly depend upon the material modulus and the shape of the seal [64].

The use of open caisson for the construction of harbour protection, breakers, watch towers, etc. is often impractical or uneconomic because of the temporary work necessary . The problem can be avoided, however, with the box caisson, which is constructed as a floating vessel on dry land or in a dry dock, or in a temporary shore facility. The box caisson, of any desired shape, is subsequently floated into position and sunk on to its foundation. The box caisson also carries the advantage in the work phase in construction in the arctic. A full structural and stability analysis should be undertaken at the design stage of at least about three major phases, launching, transporting and sinking phases. A gravel or crushed rock bed usually provides a suitable foundation. A piled foundation will be more appropriate, but it demands due regard to permafrost.

Work phases in construction, particularly in welding, painting, roofing and concrete pouring cannot be performed without careful protective measures. Various other special aspects should be considered in harbour design in the arctic, including thermal insulation, condensation, and fire safety in the long winter. In the arctic, engineering always requires in various respects a new and rational approach, innovative design, careful planning, special construction methods, utilization of update effective materials, and tight project control.

As the harbour facilities become older and more maintenance is required, the effectiveness of the present design, construction techniques, and remedial methods should be reassessed, and appropriate maintenance cost analysis should be conducted.

The design working life, usually the assumed period for which the structure is to be used for its intended purpose, should be carefully determined, taking repairing actions into account. The requirement on durability of the structure takes care of the structure remaining fit for use throughout its intended working life, being given appropriate maintenance. The process of anticipated inspection and maintenance should become part of design input, as actions consequent on expected deterioration in design.

Marine concrete structures in the arctic are exposed to ice actions and the cold climate. Resin grouts, for example, will be required and used for the underwater crack injection of damaged concrete piers, footing and underwater marine structures. Present resin grouts, such as blended silica fume cement, microfine cement, welan gum and cellulose-based anti-washout admixtures, are not reliable in their application to the underwater structures in the arctic. Reliable alternatives should be developed, with the results of laboratory evaluation and field repair, particularly on fluidity, viscosity, stability, penetrability, rate of setting, strength, corrosion strength, aging properties, re-injection workability and quality controllability under arctic conditions. A grout optimization study should be conducted.

New authorized documents which indicate the categorization of structures according to their design working life are indispensable.

8.2 Prevention of Aqueous Corrosion

Handicaps in maintenance, repairing and renewal of the marine structures in the NSR ports and harbours should be offset by strengthening in the prevention of corrosion. Prevention of corrosion is one of the most important subjects to take into account in every phase from planning to repairing.

In an environment facilitated by dry-heated and weather-tight buildings, even bare unprotected steel will not corrode seriously, while that subjected to condensation will face varying degrees of corrosion. Marine environment with high air-borne salt level and frequent presence of condensation accelerates the risk of corrosion significantly. In protecting against corrosion, the importance of good design cannot be over-emphasized, as this would minimize contact with corrosive medium. When debris is allowed to accumulate in contact with the member of the structure, corrosion will be accelerated. It is important to sweep or hose off the dirt frequently, and regular cleaning and inspection are more effective than painting.

Prevention of aqueous corrosion will adequately be fulfilled by

(1) good and functional design,
(2) reasonable modification of the materials,
(3) proper modification of the environment of structures,
(4) utilization of protective coatings; metallic, inorganic and organic,
(5) application of cathodic protection,
(5) keeping the surface of structures clean.

Adequate considerations should also be taken to atmospheric corrosion and corrosion in soil.

9. MOBILITY OF VEHICLES

Major operations in human society rely largely on the use of automotive and construction equipment. In extremely inhospitable environment as in the arctic, special and careful provision is required to assure reliable operation of the equipment without damage and danger to both human activities and structures. In a harbour area, the operations often involve risk of collapse of the equipment involving human bodies being cast into the water or ice cover, due to the extremely adverse and slippery working conditions.

At low temperatures, the performance of the elements of the engine and associated systems easily deteriorate. Thickening of lubricant, stiffening of seals, loss of battery power, and ice forming in fuel lines and carburetor have frequently been reported. Furthermore, particularly under construction of the structures and facilities, freezing thawing ground can cause difficult conditions for vehicle mobility.

To introducing improvement in mobility of vehicles, extensive studies have been made of materials for earth and road construction. Use of blast-furnace slag, as thermal insulation material, was examined in earth and road construction, and technical guidelines were proposed. An example of the guidelines is shown in Fig.21[66].

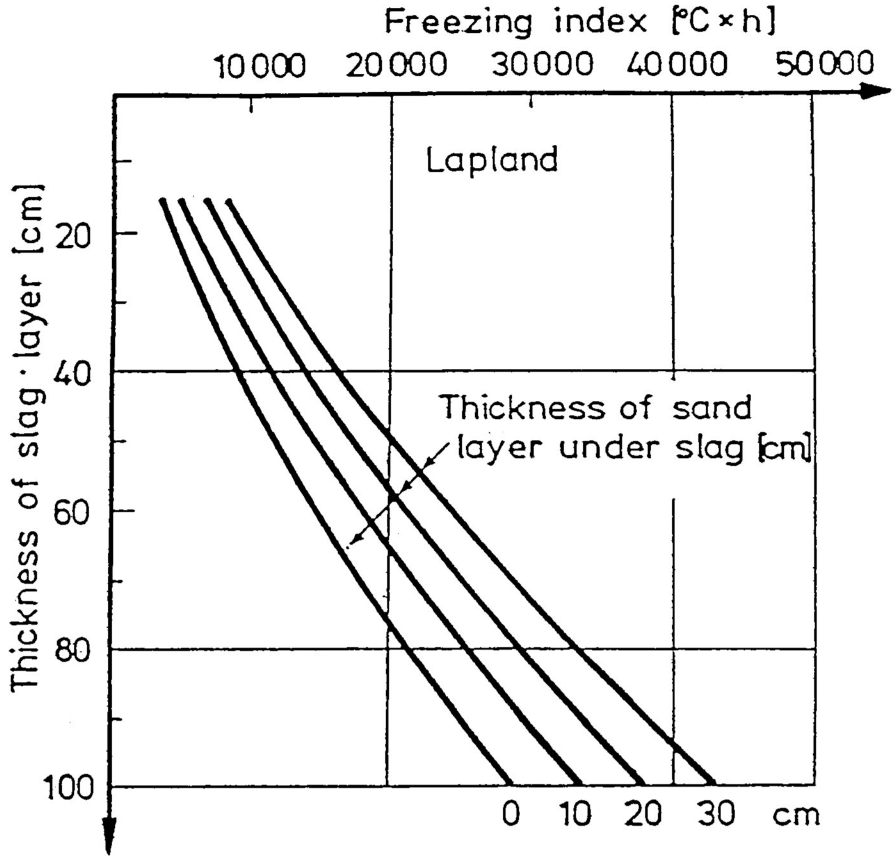

Fig. 21: Design chart for frost-safe road structure by using crushed air-cooled slag [66]

10. ENVIRONMENTAL ISSUES

Construction of ports and harbours necessitates construction of adjacent and connecting roads, at least for supporting harbour activities. Needless to say, environmental assessment of each port and harbour along the NSR should carefully be conducted. Short and long term research programmes should also be carried out to evaluate the performance of the roads and to assess changes in the adjacent environment associated with the roads, for instance, through determination of the rate and magnitude of thaw penetration subsidence under and adjacent to the roads, surveying the rate of change in plant communities, vegetation, soil fauna, and soils due to natural and man-made surface disturbances, collecting data on loss of topsoil and organics, and acquisition of knowledge to enhance restoration by native plant species.

A large body of information exists applicable to the design and construction of the arctic ports and harbours, though no definite and reliable information exists relative to damage assessment and repair of the arctic harbour facilities. Moreover, in future, some ports could enjoy exporting energy resources such as oil and natural gas, which would suggest subsea arctic pipelines. Permafrost, strudel scour, and ice gouging are surely the most significant factors of forces acting on the subsea portion of the pipeline. The effects of ice on the pipeline will naturally decrease with the depth of laying and the depth of water, while the contrary is the case of the laying cost. Although a potential pipeline oil spill would be limited in volume, which is largely dependent on leak-detection capability, pipeline diameter and total length, low leak rate spill could hardly be detected until visual inspection or a discrepancy in mass balance between production and sales was identified.

Clean-up technology of spilled oil developed under arctic conditions will be enhanced in the ports where ice conditions are stable for relatively long periods. Contrary to the ice condition, complex features of ports and vessels would lessen the effect of the clean-up techniques.

The life span of wastes will be long in the arctic environments because of the slow biological and chemical decomposition processes. Harbour construction and associated vehicular activity in particular on the tundra may cause long-lasting terrain disturbances in the environment, which may lead to damage to vegetation and serious changes in drainage patterns and the permafrost conditions. It is extremely important that the environmental impacts and risks of development be assessed and considered in the planning and design as well as construction.

11. CONCLUDING REMARKS

To meet the requirements for the Northern Sea Route establishment in the near future, well organized ports and harbours should be newly constructed along the NSR. Under the hostile geophysical and meteorological condition with the fragile environment in the arctic, every man-made facility associated with the harbours should be designed and constructed with due consideration for any minor influence on the environment and total cost including maintenance and repair. Ice management in the NSR harbours will ensure the vessels in service against suffering from various threats and accidents in ice-covered harbours. There have been numerous techniques to avoid or decrease troubles induced by ice and snow. Most of them, which have been primarily developed for the subarctic regions, should be reassessed, in particular, as to their global cost performance and should be updated by systematic investigations.

Technical guidelines validated with sufficient field, in-situ experiences should be provided, and through them rational design of new ports and harbours along the NSR could be achieved.

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Review of INSROP report I.6.4 "Some Aspects of Port and Harbour Managament of Ports along the Northern Sea Route" by Kitagawa, Izumiyama and Ozeki.

Review by Professor Lewis Shapiro,
Geophysical Institute, University of Alaska Fairbanks

Wednesday 29 April 1998

Dear Mr. Ragner;

I have read the paper by Kitagawa, Izumiyama and Ozeki as you requested. It was understandable, but will require rather extensive editing to put it into good english. In additon, there are instances where the meaning of a sentence is simply not clear because of the choice of words. I think the editor will require some technical expertise to recognize these and determine what the authors were trying to express. An example is the first sentence in the paragraph on page 6 which begins with "The presence of sea ice..." Incidentally, I do not mean these comments as criticisms; the author's ability to use english is impressive and is infinitely better than I could ever hope to achieve in their language.

I'm not quite sure what the objective of this paper is. Project I.6.4 refers to ice management, but the title of the paper mentions "...Port and Harbor Management..." The technical content of the paper is broad; about one third is directly related to ice management, but the rest covers a variety of issues including ice loads on structures, vehicle mobility, and environmental problems which, while important, do not bear on the problem of ice management.

I think that the authors review of some of the ice management methods is good. However, I would like to see some comments on the range of conditions under which these methods could be expected to be effective. I doubt if any of them will be generally useful under the Arctic conditions that exist along most of the NSR, so I think that some discussion of their applicability is needed. Incidentally, icebreakers receive little mention in the paper, but they are a major tool in ice management in some harbors and for offshore operations as well. There are problems with their use in harbors though (such as the rapid increase in ice volume by the growth of new ice on broken fragments) so some review of icebreaker use should probably be included in the paper.

If the rest of the subjects are to remain in the paper, then I think the coverage them need to be extended. For example, the coverage of ice loads on structures is directed at the large structures used for offshore petroleum exploration, but there are papers available on ice loads on harbor and navigational structures which the authors should be able to locate. There are also reports in the literature on the design and construction of a harbor at Nome, Alaska, on problems of constucting harbors in the Canadian Arctic, and on transportation of ore from northern mines by bulk cargo carriers. I think the authors would find these useful. They are scattered in the literature in various symposium volumes, but can easily be located with one of the extensive bibliographies on the polar regions which are available on compact disc. Finally, I wonder why the authors chose to make specific mention of AUV's (including one with a possible range of about 1000 nm) in connection with inspections of harbor installations. Currently available ROV's can do what is required for such applications. They are also likely to be more useful for such work than AUV's in the future, because of their capabilities for real-time observations and data transmission.

In summary, I think that the issues I note here need to be addressed before the paper is published. However, I encourage the authors to continue with the task, since the resulting review should be useful.

Sincerely, Lewis Shapiro

Prof. L. Shapiro
Geophysical Institute
University of Alaska

Dear Prof. Shapiro

I sincerely appreciate your kind and careful review of our INSROP paper.

I am afraid that you were irritated by our paper in barely understandable English. English of our paper is to be modified by an expert in Norway.

There have been published and will be published several INSROP papers on the similar topics, such as;

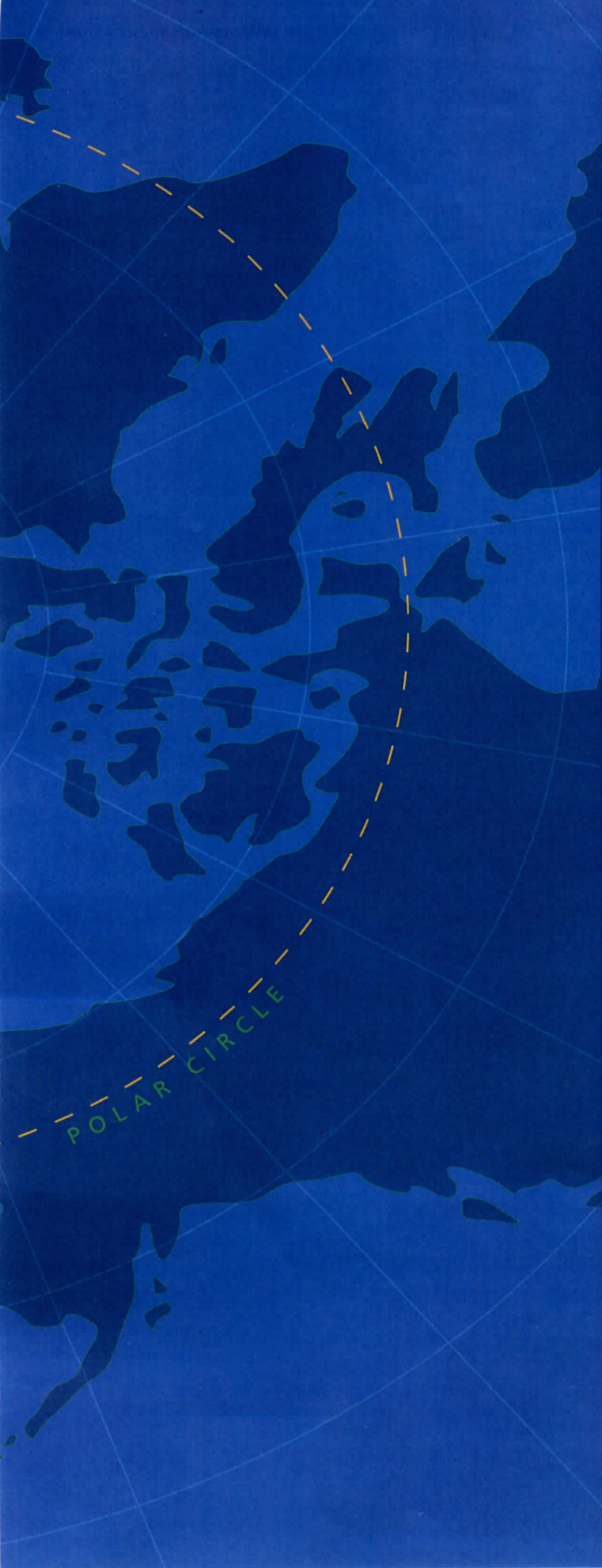
A.V. Ierusalimsky, et al, "New concept of removing ice", INSROP Paper 21,
A.V. Ierusalimsky, et al, "New concept of removing ice", INSROP Paper 62,
G. Semanov, et al, "Requirements to NSR shore reception facilities", INSROP Paper 64,
M. Lensu, et al, "Ice environment and ship hull loading along the NSR", INSROP Paper 66,
L. Tsoy, et al, "Environmental and structural safety of ships", INSROP Paper 70,
N. Isakov, et al, "Regional port development along the NSR", INSROP Paper 87.

We had planned to carry out a similar work as those done by Dr. Ierusalimsky at the beginning of the INSROP. At the 2nd INSROP Joint Research Committee meeting, however, we found that the projects similar to us were conducted in Russia. We decided that our paper would be a supplementary to them, avoiding unnecessary duplication of survey work. I am sure that the topics and subjects suggested in your review of our paper are discussed in the above-mentioned papers, even repeatedly on some topics.
As you rightly noted, there are found several terminologies on morphodynamics unfamiliar to you in our paper. Professors on morphodynamics at Hokkaido University had kindly checked them. I will ask them again about the terminologies.

I should refer to ROVs, except for icebreakers and their role in ice management, which were already discussed by Russian researchers.
In Japan, R&D projects have mostly been conducted on AUVs. Research funds for AUVs have been available more easily than for AUVs. Monitoring of seismic and volcanic activities of the sea bed is crucial for improvement in accuracy of forecasts of earthquakes. The study on algorisms for AUVs has fashionably been performed at universities and industries in Japan. I am sure that AUVs have to anticipate difficulty in existence of sea ice in the Arctic. I would like to add a brief description of ROVs.

Once again I thank you very much for your peer review of our paper.

H. Kitagawa



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 stockholding 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 multidisciplinary approach, entailing extensive cooperation with other research institutions both at home and abroad. The INSROP Secretariat is located at FNI.