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APPLICATION OF ICE BOOMS FOR OIL-SPILL CLEANUP IN ICE INFESTED WATERS

FINAL REPORT

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EXECUTIVE SUMMARY

This report provides the results of a study to assess the applicability of ice boom technology to aid or extend oil spill cleanup capabilities in broken ice. The technology has been developed and used successfully at several locations to control the ice. For oil spill cleanup in broken ice, booms have the potential in a number of ways, such as:

(a) preventing ice ingress into the spill area, thereby providing an ice-free area where conventional oil spill equipment can operate; and,

(b) providing a means to assist in separating the oil from the ice.

Ice booms may have the potential to assist in many of the scenarios defined in the Alaska Clean Seas Technical Manual.

Ice booms, in combination with the available support vessels on the North Slope, are expected to be applicable to oil cleanup in moderate broken ice conditions of up to about 50%. Booms are also expected to be applicable for some cases in higher ice concentrations of up to 70%. However, larger vessels with more power, such as icebreakers, would be required for a wide operating envelope.

Prototype tests should be carried out in the Alaskan Beaufort Sea as the next step in advancing this technology for reliable usage in oil spill cleanup situations in broken ice in the Arctic. It is believed that quite conservative assumptions were made in this project in establishing the loads on the boom, particularly with respect to the under-ice currents at the boom, and their colinearity with the winds. This was necessary because very little data are available for this case. Field measurements would be valuable to improve the estimates made here.

A field deployment should be conducted offshore of Prudhoe Bay using a boom of limited size. A boom with two 500 ft (150 m) spans should be built and deployed using the available support vessels in the chevron and catenary configurations.

This work should be accompanied with numerical analyses that build upon the results of the field tests and the work done here.

ACKNOWLEDGMENTS

The oil spill scenarios used in this study were taken directly from those developed by Alaska Clean Seas, which are reported in the Alaska Clean Seas Technical Manual.

The project benefited from extensive research and field deployments regarding ice boom technology, which have been carried out over the past seven years by, or on behalf of, the following organizations:

- New York Power Authority
- Ontario Power Generation
- Hydro-Quebec
- Canadian Coast Guard

These programs produced an extensive knowledge base to define all aspects of ice boom performance and they led to the development of numerical models to design an ice boom.

Joseph Mullin of the Minerals Management Service of the United States Department of the Interior was the Contract Office Technical Representative (COTR) for this project.

DISCLAIMER

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1 INTRODUCTION AND PROJECT OBJECTIVES

1.1 Introduction and Background

It is generally recognized that current capabilities for cleaning up oil spills in pack ice are very limited (e.g., S.L. Ross et al, 1998). The reasons for this include the fact that pack ice conditions tend to disperse the spilled oil widely into thin films or droplets that may coat the pack ice pieces or be located between them, on them, or below them (Figure 1.1). These films or droplets are expected to be too thin to burn, or to clean up efficiently using mechanical equipment.

Depending upon the geographical location and the time of year, oil may be released into an environment ranging from open water to broken ice conditions (i.e., ice floes with varying sizes and concentrations) to sheet ice conditions. Consequently, a number of scenarios are possible (Figure 1.1), such as:

(a) floating oil getting mixed between and on the sides of individual ice floes;
(b) oil submerged under the ice floes;
(c) oil encapsulated under the ice floes;
(d) oil mixed in with slush.

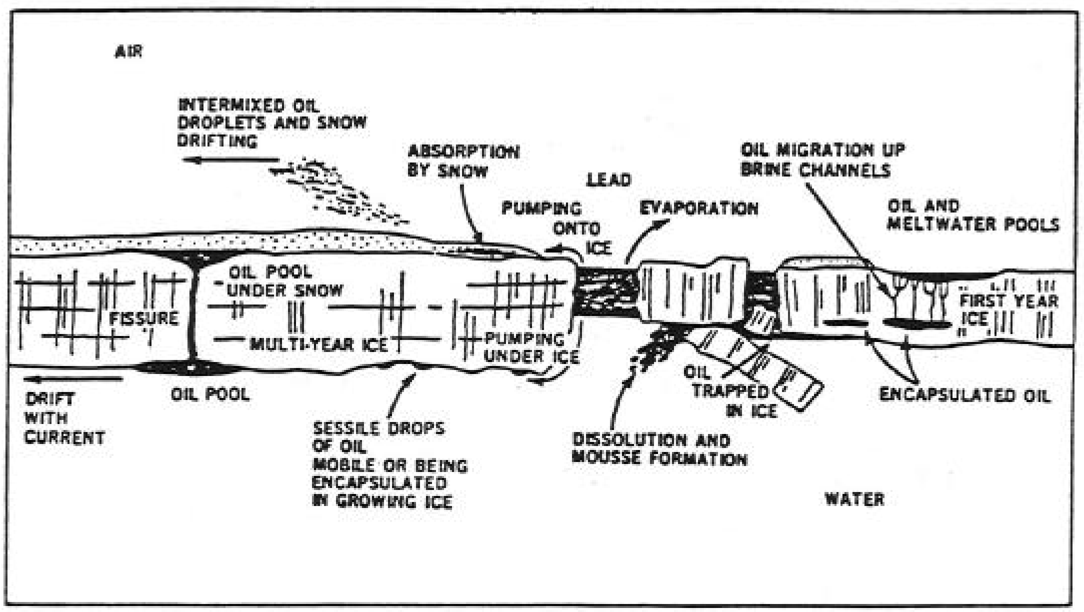


Figure 1.1: Oil Behavior and Fate in Broken Ice (after Bobra and Fingas, 1986)

The oil spill cleanup scenario also depends on the source of the spilled oil, which could include:

(a) a batch spill resulting from an oil tanker accident;
(b) a blowout of an exploration or production well;
(c) damage to an underwater pipeline.

However, whatever the source of the spill, it is generally recognized that presently available mechanical oil-spill recovery devices cannot operate efficiently in waters containing significant ice concentrations. This is due to a number of reasons including:

(a) the ice, and its pressure, disperses the oil widely into thin films or droplets. This significantly reduces the oil recovery efficiency by preventing conventional skimmers from operating in thick oil pools.
(b) the ice prevents the skimmer from accessing the oil easily.
(c) the oil spill cleanup equipment may be damaged by the ice.

1.2 Project Objectives

The overall objective of this project was to investigate the potential application of ice control booms for oil spill cleanup efforts in broken ice. Ice control booms may aid oil spill cleanup efforts in a number of ways, such as:

(a) prevention of ice ingress into the oiled area - this would have the potential to improve or extend the capabilities of current mechanical equipment by allowing it to operate in conditions that are ice-free or significantly reduced in ice severity.

(b) providing containment of the spilled oil – this might be achieved, for example, by surrounding an oiled area that contained ice pieces with a boom. This would aid cleanup efforts by preventing widespread dispersion of the spilled oil.

(c) improving current capabilities to separate the oil from the ice – this might be achieved, for example, by towing an oiled ice area with a boom and support vessels at speeds high enough that the oil is removed from the ice.

The project had a number of sub-objectives (listed below) that were necessary in order to evaluate the applicability of ice control booms for oil spill cleanup:

(a) define the most likely scenarios where an ice boom could be used for effectively recovering oil from ice or for preventing the ice from drifting toward an oil spilled area

(b) investigate the operating windows in which an ice boom can be deployed in a broken ice field. This included a review of the expected ice forces on an ice boom deployed in various ice concentrations, the resistance capacity of a boom to retain ice, the bollard pull of a typical icebreakers and tugboats required to keep the boom in place during the oil recovery operations.

2 TECHNOLOGY REVIEW

2.1 Ice-Capable Mechanical Oil Spill Cleanup Equipment

Mechanical equipment for the efficient recovery of oil in significant pack ice concentrations is presently unavailable, despite the fact that a significant amount of research has been conducted to date. Some of the previous technology development efforts include:

(a) Purves et al., 1977, proposed a circular net for collecting oil from an Arctic oil well blowout. At that time, information regarding pack ice pressure and its behaviour was scarce and thus, its effect on an ice boom was also poorly understood. This lack of fundamental knowledge severely hampered the design efforts.

(b) Abdelnour et al, 1985, conducted laboratory tests of an oil-skimming bow. These tests showed that the oil-skimming bow, even with the use of a water jet to herd the oil and move it toward the skimmer, had poor oil recovery efficiency, especially for high ice concentrations of close to 10/10. The study also showed that the approach would be difficult to apply under Arctic conditions.

(c) Loset et al, 1992, investigated the concept of using a flexible boom for collecting ice upstream of a well blowout. These model test experiments showed that significant research was still required. Field tests were also carried out. Although no published information was obtained regarding these tests, the work did not result in a commercially available product.

(d) the current MORICE project – this project is aimed at developing an ice-capable skimmer (Jensen, 2000). Small scale, preliminary testing has been carried out in the laboratory and in the field. However, considerable work remains to develop this into a commercial usable product.

Despite this work, mechanical equipment for reliable oil spill cleanup in pack ice is not available. The problems encountered may be broadly classified as follows:

(a) containment – pack ice conditions tend to prevent the occurrence of thick oil pools by dispersing the spilled oil, which results in low oil cleanup efficiencies. Containment is required for thick oil pools to develop.

(b) separation – it is well known that the oil will tend to be widely dispersed and mixed into the pack ice. It is necessary to separate the oil from the ice in order to conduct cleanup operations.

(c) damage due to interaction with ice pieces

(d) access – in many cases, the pack ice would prevent the mechanical equipment from accessing the spilled oil.

2.2 Ice Boom Technology

2.2.1 Historical Perspective and General Objectives for Booms

Ice booms have been used for more than 40 years upstream of water intakes at hydroelectric power plants and in river channels used for navigation for two general purposes, depending on the particular site being considered:

(a) to prevent ice ingress into an area – Figure 2.1 shows a boom deployed annually in Lake Erie, at the mouth of the Niagara River by the New York Power Authority (NYPA) and Ontario Power Generation (OPG). The ice boom is to prevent ice floes and fragments in Lake Erie from being driven into the Niagara River, which can cause blockage at their water intakes and results in operation losses.

Figure 2.1: Lake Erie Niagara River Ice Boom

Note to Figure 2.1: This boom consists of 22 spans; is 2.6 km long; and has been deployed annually in the northeast end of Lake Erie by the NYPA/OPG since 1963.

(b) to accelerate the formation of a stable ice cover – in this case, the boom's purpose is often to minimize the formation of frazil ice, along with the trashrack or water intake clogging problems that are often associated with frazil ice. In other cases, the boom may be placed to reduce the total ice volume generated in the river.

Booms developed to meet objective (a) above are of most interest for this study as this is one of the methods by which ice control booms might aid oil spill cleanup efforts in ice.

2.2.2 Typical General Arrangement for a Boom

It should be noted that ice booms with many different types of general arrangements have been used to date. However, it is generally recognized that ice booms need to be designed with the capability to relieve the ice load should it become too great. This is necessary to avoid damage and/or excessive costs. This capability is achieved by constructing the booms such that the flotation elements (i.e., pontoons – Figure 2.2) will submerge individually which allows the ice to over-run the boom in severe conditions.

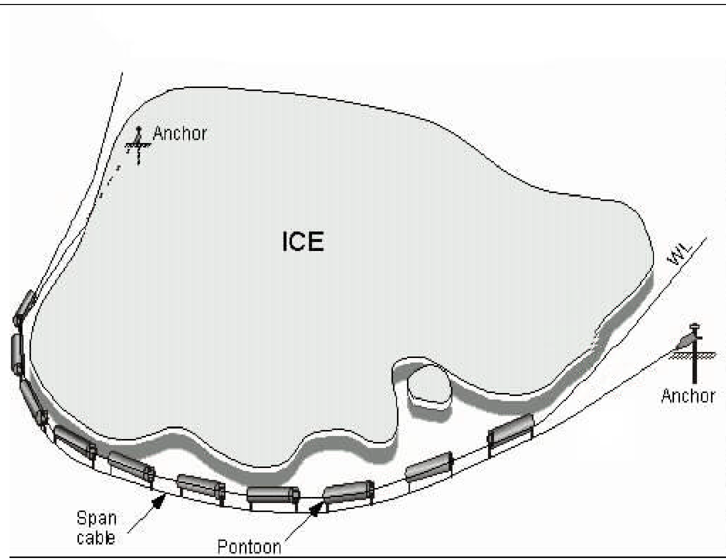


Figure 2.2: Ice Boom Schematic

A typical ice boom section consists of one span cable (as shown in Figures 2.2 and 2.3) or more span cables. (22 spans are shown in Figure 2.1). The span cable is attached at each end to an anchor cable or to an anchor placed in the riverbed. Each span has pontoons attached to the cable with chains, one at each end of the pontoon. These chains maintain the cable at about 1 m below the water surface. The pontoons are typically about 10 m long and the gap between each two pontoons is between 2 and 7 m. Buoys are used to facilitate the removal and the deployment of the boom.

The ice-retention capacity of the boom is directly related to its buoyancy. When the ice load exceeds the pontoon resistance capacity, it submerges and the ice drifts over the pontoon. This limits the load on the boom, and reduces the probability of ice damage. The pontoon's buoyancy varies with its size and should be selected based on the desired ice retention capacity of the boom.

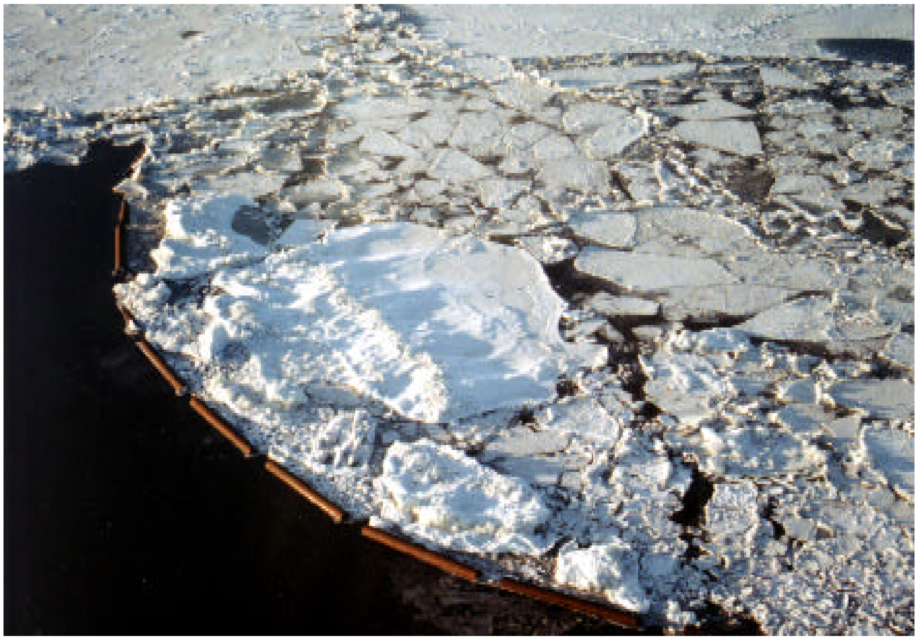


Figure 2.3: Lavaltrie Ice Boom

Note: This is a close-up view of one 120 m wide span of the 1 km long Lavaltrie Ice Boom. The current velocity at this location is 0.8 m/sec

2.2.3 Recent Boom Technology Developments: the Lake Erie Niagara River Boom

Traditionally, wooden timbers have been used for the pontoons of an ice control boom. This led to a number of problems (listed below) that limited the boom's ice retention capability and performance:

(a) the wooden timbers had little reserve buoyancy, particularly when they were water-logged, which allowed ice to over-run the boom easily;

(b) the wooden timbers tended to deteriorate and to be damaged easily.

In 1992, the New York Power Authority (NYPA) and Ontario Power Generation (OPG) initiated a study to assess and improve the performance of the Lake Erie Niagara River Ice Boom, which had been comprised of wooden timbers up to then. The wooden timber ice boom had relatively poor ice retention capacity and allowed a significant volume of ice to over-run the boom. This caused ice to drift into the Upper Niagara River and forced NYPA/OPG to use large amounts of water to flush the ice over Niagara Falls. The revenue losses resulting from this lost power exceeded $750,000 U.S. per year.

Significant research and development was carried out over the 1992-97 period to better understand the main factors affecting ice boom performance, and to develop an improved boom. An analytical assessment of the "old" timber boom was first carried out. This study concluded that the Lake Erie Niagara River ice boom would be much more effective if the pontoons had more buoyancy to provide more ice retention capacity.

The study also pointed out that the pontoons were being submerged when the loads on the anchors and the span cables holding the pontoons were less than 5% of their design load, which showed that the cables and the anchoring system had a large reserve capacity.

The “old” timber boom was next instrumented during the winter of 1993-94 (Abdelnour et al, 1995). This provided useful data for evaluating the boom’s performance and also for the calibration of numerical models. These models produced the basis for the design of reliable and efficient ice booms that led to overall improved performance.

The field data confirmed the earlier performance assessment. The ice submerged and over-ran the boom when the ice load was well below the capability of the boom anchor and span cables. A recommendation was made in July 1994 to replace the timber pontoons with larger and more buoyant steel pontoons. These pontoons were expected to increase the boom’s ice resistance by up to 5 times, compared to the timber pontoons. The steel pontoons were selected based on model tests, analyses, and field deployments made by the Canadian Coast Guard (CCG) in the St. Lawrence River (who undertook development efforts in parallel – described in the next section).

NYPA/OPG next built a prototype ice boom that contained five spans with steel 30” diameter pontoons (Figure 2.4).

Figure 2.4: Prototype Lake Erie Niagara River Ice Boom

Note: This figure shows the prototype ice boom that was tested. The pontoons in five of the 22 spans were replaced with steel pontoons for this prototype.

The prototype ice boom was instrumented and observed. The new steel pontoons proved to be significantly better in resisting the ice than the timber pontoons (Figure 2.4). This prompted the

NYPA/OPG to proceed with the replacement of all the timber pontoons with steel pontoons during the fall of 1997 (Cowper et al, 1997).

It has operated successfully since that that time. Based on the cost savings associated with reduced power generation losses, reduced repair costs for the boom, and reduced icebreaker time, NYPA/OPG determined that the benefit/cost ratio for the "new" boom was 5.5.

2.2.4 Recent Boom Technology Developments: the Canadian Coast Guard Booms

During the same period that NYPA/OPG were undertaking development work, the Canadian Coast Guard (CCG) embarked on a plan to improve the reliability of winter transportation through the St. Lawrence River System. This was precipitated by an ice-related event that interrupted navigation for a long period of time during the 1993 winter.

Laboratory tests were carried out to compare various ice boom pontoons. This was followed by the use of analytical models to design a boom capable of retaining the ice in 0.8 m/sec currents. A cylindrical pipe pontoon, with 0.61 m (24") diameter, was proposed to resist the driving forces expected for the Lavaltrie site (Abdelnour et al., 1995).

The CCG then built and deployed "new" steel pontoon ice booms in the St. Lawrence River near: (a) Lavaltrie; (b) Lanoraie, and; (c) Lac St. Pierre. Each of these booms was built with the purpose of preventing ice ingress into the main areas of the navigation channel.

The Lavaltrie and Lanoraie booms were re-engineered in 1993. The Lac St. Pierre boom, which was 2.5 km long, was constructed in 1994 to retain the ice along the North East side of Lac St. Pierre at Yamachiche (See Figure 2.5). The new Yamachiche ice boom resulted in improved navigation in the St. Lawrence River channel due to significantly less ice obstruction.

Figure 2.5: Yamachiche Ice Boom

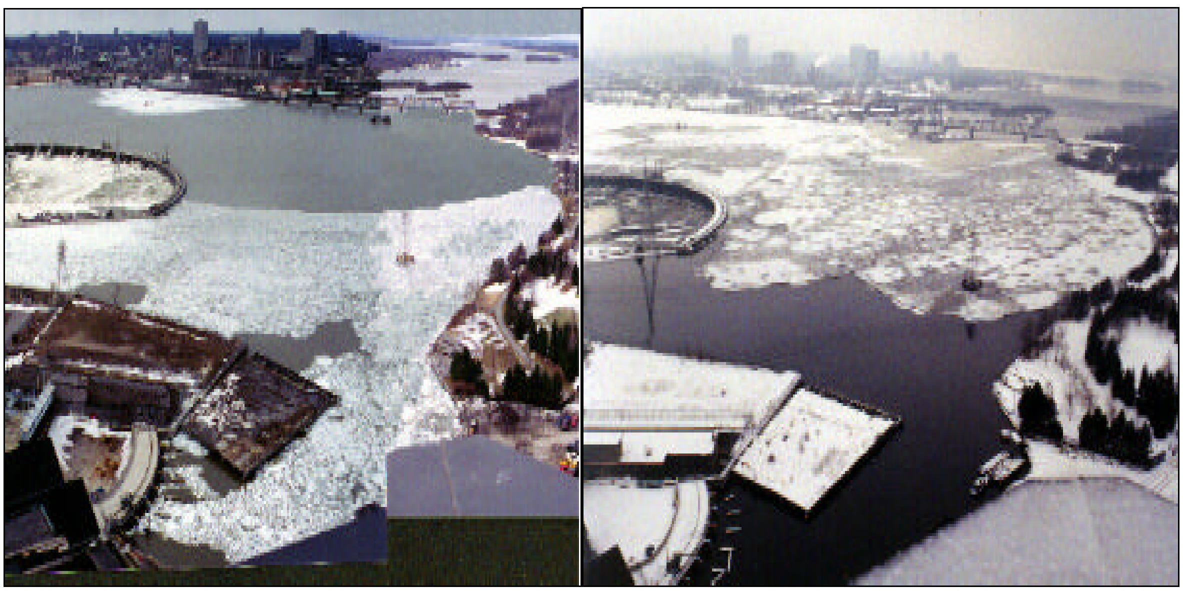
Note: The Yamachiche Ice Boom has 22 spans; is 2.6 km long; and has been deployed in the northeast end of Lac St. Pierre since 1994.

2.2.5 Boom Technology Developments: Other Booms

The experience gained since 1997 from the NYPA/OPG studies, and the feedback obtained from the CCG ice booms, led to the development of a robust ice boom design procedure that has been used for the conceptual design, detailed design, fabrication and deployment of several new ice booms, including:

(a) the Hull2-E.B. Eddy Ice Boom – This boom was designed and built in 1997 (Figure 2.6). The site was selected based on field observations carried out during the previous winter, of 1996/97 (Abdelnour et al, 1998). This boom was primarily built to accelerate the formation of a stable ice cover, and to minimize frazil ice production. However, it was also successful in preventing ice ingress into the trashracks of the two power plants (Figure 2.6).

The boom was deployed to protect two hydroelectric power plants; one owned by Hydro-Quebec and the other by E.B. Eddy Forest Product Limited. The boom was placed about 200 m upstream of the two intakes and spanned 225 m across the entire channel width.



Ice Cover Without a Boom   Ice Cover After the Boom Was Deployed

Figure 2.6: Ice Cover at the Hull 2 and EB Eddy Power Plants: Before and After the Boom Was Installed

Notes:
1. These power plants are located on the Ottawa River.
2. The boom was placed to accelerate the formation of a stable ice cover upstream of the two power plants to reduce power generation losses. The production losses decreased by 80% in 1997, which was the first year that the boom was installed. The reduction in power generation losses was sufficient to pay for the cost of the boom in two years.

(b) one on the Rideau River in Ottawa, upstream of Strathcona Rapids - The Strathcona boom was deployed to minimize the production of ice in the Rideau River, thus reducing the cost for ice clearing in the spring. This boom has one span and is about 100 m wide.

(c) one on the Rivière Rouge, upstream of the Chute Bell Hydroelectric Plant, near Montebello, Quebec. The Chute Bell Boom was designed to protect the hydroelectric power plant from ice. This boom also has one span and is about 100 m wide.

(d) Pickering Nuclear Generating Station - In February 1999, an ice boom was installed at the Pickering Nuclear Generating Station (Figure 2.7). This boom was built to prevent ice ingress into the cooling water channel for the power plant. It is exposed to waves up to about 4m high. The experience base built up with booms allowed this boom to be built, designed, and installed in 4 weeks.

Figure 2.7: Ice Boom Deployed at the Pickering Nuclear Generating Station Ice Boom, in February 1999

(e) Wakefield Boom – This boom was deployed on the Gatineau River, 3 km upstream from Wakefield, Quebec (Figure 2.8) in November 1999. The boom is designed to accelerate the formation of an ice cover early in winter and to hold the broken ice during the spring break-up. This boom performed extremely well in forming the ice and was left in place during the break-up.

Figure 2.8: The Wakefield Ice Boom,
(installed in November 1999)

2.2.6 Summary

Improved ice control booms have been developed that provide much better ice retention capacity. Steel pontoon booms have been built at many sites to date. Robust design procedures have been developed to apply the new booms. This shows that booms are a mature technology.

3 ICE BOOM APPLICABILITY FOR OIL SPILL CLEANUP

3.1 Overview

All presently available oil-spill recovery devices cannot operate efficiently in waters containing significant ice concentrations. The ice, and its in-plane pressure, significantly reduces the oil recovery efficiency by preventing conventional skimmers from operating in thick oil pools. Furthermore, the ice prevents the skimmer from accessing the oil easily. Also, the ice exposes the skimmer to potential structural damage.

The overall intent of this report is to investigate the application of ice boom technology for recovering oil in ice infested waters. An ice boom may be useful in a number of types of cleanup applications as follows:

1) provide a means to prevent broken ice from drifting into the oil-spill area, thereby:

   (i) allowing conventional equipment to operate;
   (ii) allowing in-situ burning;
   (iii) maximizing the operating window.

2) surrounding the contaminated area, thereby preventing dispersion of the spilled oil;

3) providing a means of separating the oil from the ice, in combination with support vessels, thereby aiding oil recovery by conventional equipment.

3.2 Oil Spill Recovery Scenarios

The oil-spill scenarios are well described in the Alaska Clean Sea Technical Manual, 1999 (termed Manual subsequently). This Manual was prepared for contingency planning in the event of an oil spill at the exploration sites offshore Alaska. Based on the Alaska Clean Seas Technical Manual, 1999, six specific scenarios were defined for which the ice boom could be applied, as follows.

3.2.1 Scenario 1: Oil-Spill from an Offshore Structure

Oil spills can occur in several ways from an offshore structure. Two main cases were depicted in the Manual:

(a) The first case is when the oil is being released, either continuously, or as a batch spill, from an island placed in relatively shallow water and where the prevailing wind direction, and hence ice drift direction, is relatively constant. The boom could be deployed in a Chevron shape, and anchored at least one hundred meters upstream of the structure (depending on the size of the island, the type of spill, and other factors), as shown in Figure 3.1.

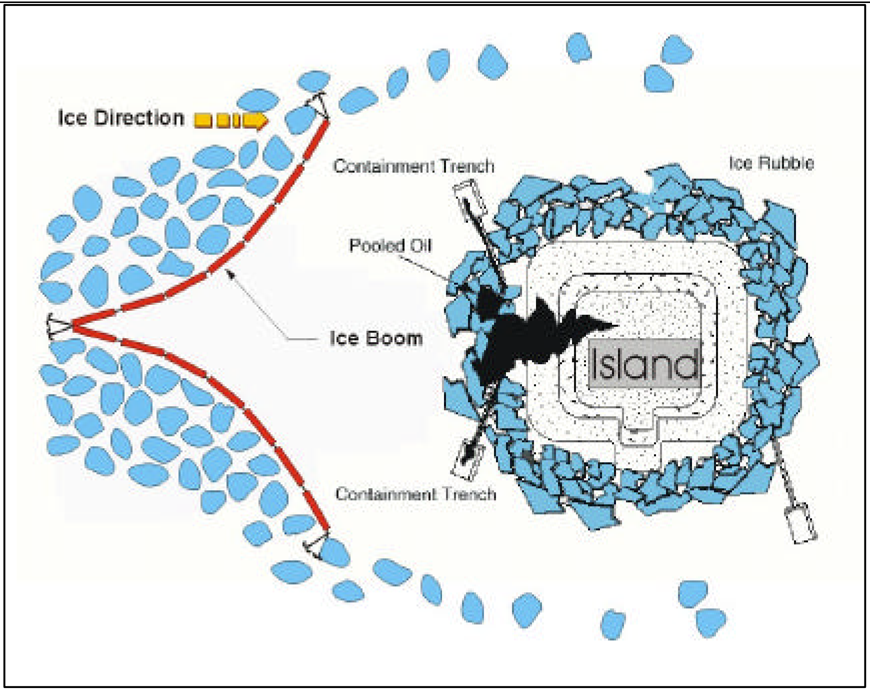


Figure 3.1: Scenario 1a: Oil-Spill from an Offshore Structure

(b) The second case is where the structure is in deeper water and where wind direction changes, and ice drift direction variations, are relatively frequent. The oil could either be released continuously, as in the case of a blowout, or as a batch spill. In this case, the boom will have to be continuously realigned with the wind using supply vessels and the distance of the boom upstream from the structure will be significantly more than 100 m upstream (Figure 3.2).

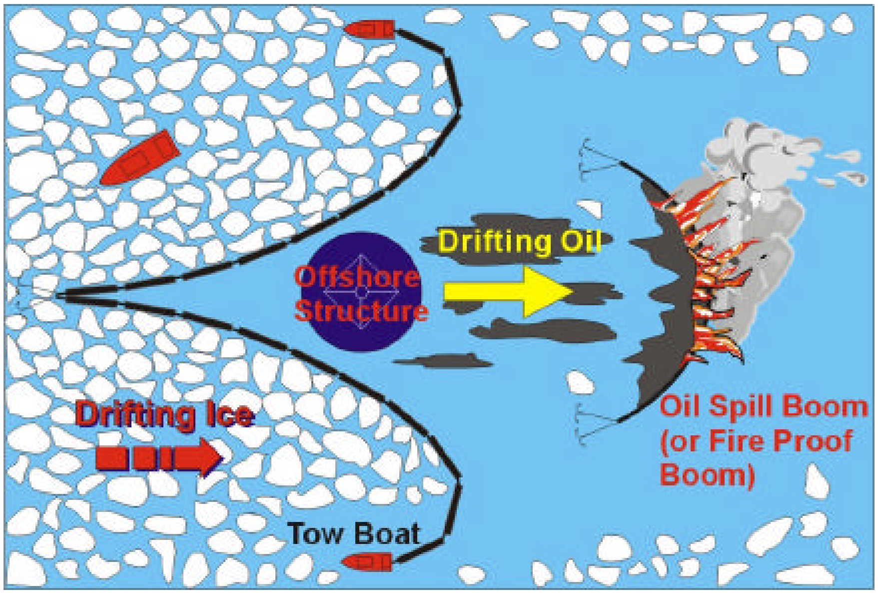


Figure 3.2: Scenario 1b: Oil-Spill From An Offshore Structure

In either of the above two cases, the boom would provide an ice-free area in its lee where drifting oil can either be recovered using conventional oil spill recovery equipment (Figure 3.1) or burned after being contained in a fire proof boom (Figure 3.2).

3.2.2 Scenario 2: Batch Spill From an Oil Tanker

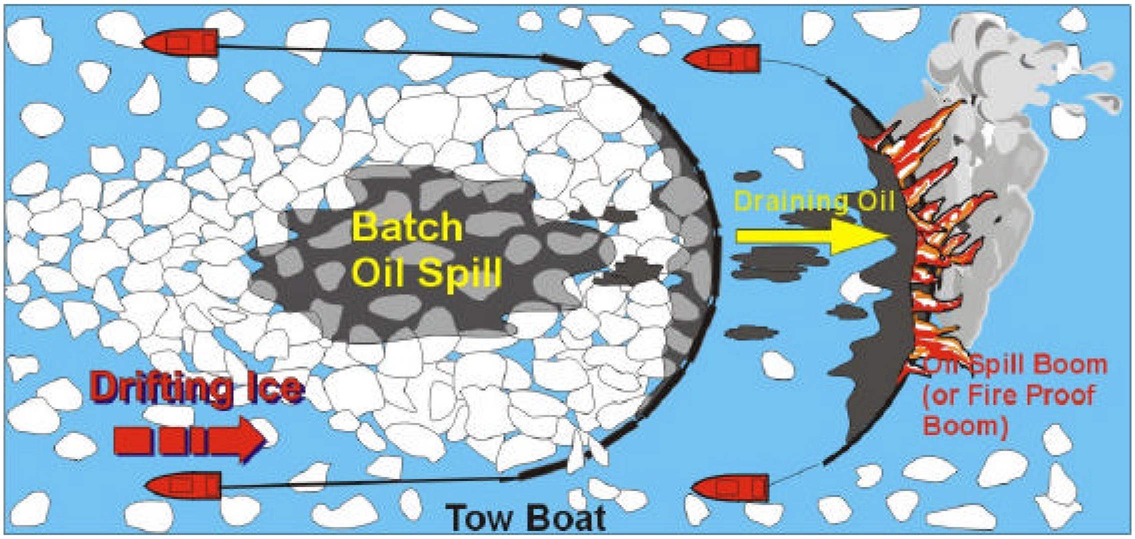


Figure 3.3: Scenario 2a: A Batch Spill from a Tanker

A batch spill from a tanker (or a pipeline burst) can cause a large ice area to be oiled. In this case, a supply vessel could tow the boom and surround the contaminated area.

Depending on the ice conditions, the oil spill spreading and the area where the oil is spilled, the following options are available:

(a) Oil-Ice Separation at Spill Site - For this scenario, the boom would be towed by two supply vessels through the ice to surround the contaminated area (Figures 3.3 and 3.4) to help separate the oil from the ice in higher ice concentrations. Oil-ice separation is expected to occur to some extent as the boom is not a continuous structure. Rather, it consists of steel pontoons with gaps between them, with the pontoons being connected to a submerged span cable (Section 2.2). Thus, the boom will contain ice pieces, but it will be incapable of containing the oil. Hence, when it is towed through the ice by the ships, it may help to separate the oil from the ice.

The oil can either be burned after being contained in a fireproof boom as shown in Figure 3.3 or it can be collected using conventional oil spill recovery equipment as shown in Figure 3.4.

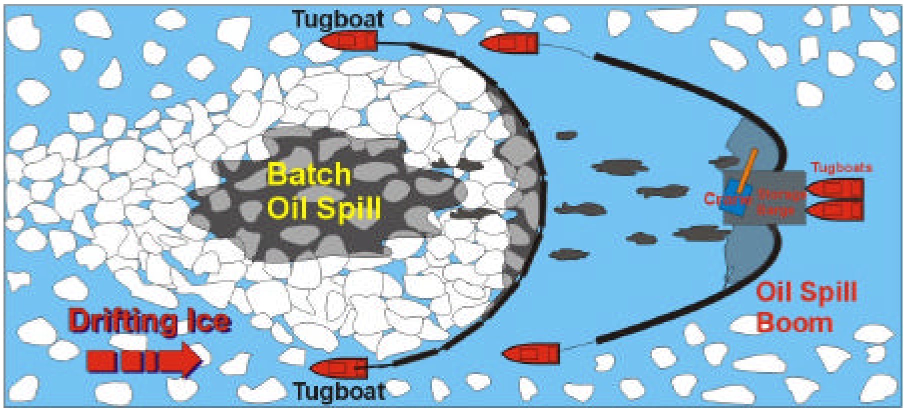


Figure 3.4: Scenario 2b: A Batch Spill from a Tanker

To achieve oil-ice separation, the relative towing speed should be higher than the current velocity required forcing the oil droplets to move under and between the ice floes. Laboratory tests in a flume with a level ice sheet (by Cox et al, 1980 and Free et al, 1981) showed that oil movement would occur under the sheet when the water velocity exceeds about 0.13 ft/s (4 cm/s).

The oil slick movement rate increased substantially when the current exceeded about 0.3 knots (0.5 ft/s; 15.6 cm/s). See Figure 3.5. This shows that oil-ice separation using a boom would likely be most successful if the towing rate exceeded about 0.3 knots (0.5 ft/s)

(b) <u>Removal of the Oiled Ice to a Cleanup Site</u> - The contaminated ice could also be towed to an inlet where the currents are negligible where the ice is less likely to disperse in the surrounding pack. In this case, the oil recovery logistics become less difficult and can be completed over longer periods of time.

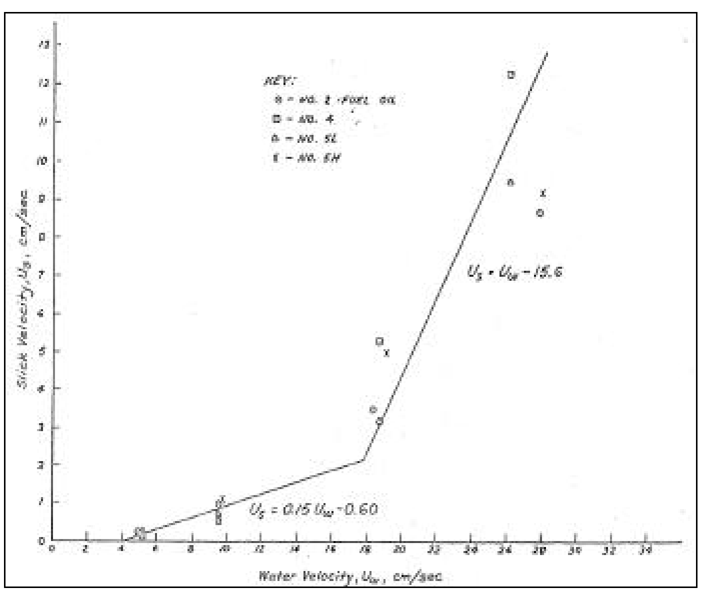


Figure 3.5: Oil Slick Velocity Versus The Current Velocity (after Cox et al, 1980)

3.2.3 Scenario 3: Continuous Spill from a Punctured Offshore Pipeline

An oil spill from an underwater pipeline can cause the oil to disperse under the ice without being easily seen or without it surfacing on the water.

Oil recovery in drifting pack ice of significant concentration would be impossible in this situation with currently available equipment. A boom deployed in a Chevron shape (Figure 3.6), could assist in this situation by diverting the ice away from the spill area. This mode of deployment will reduce the amount of contaminated ice and provide an ice-free area where conventional containment and recovery equipment could be deployed.

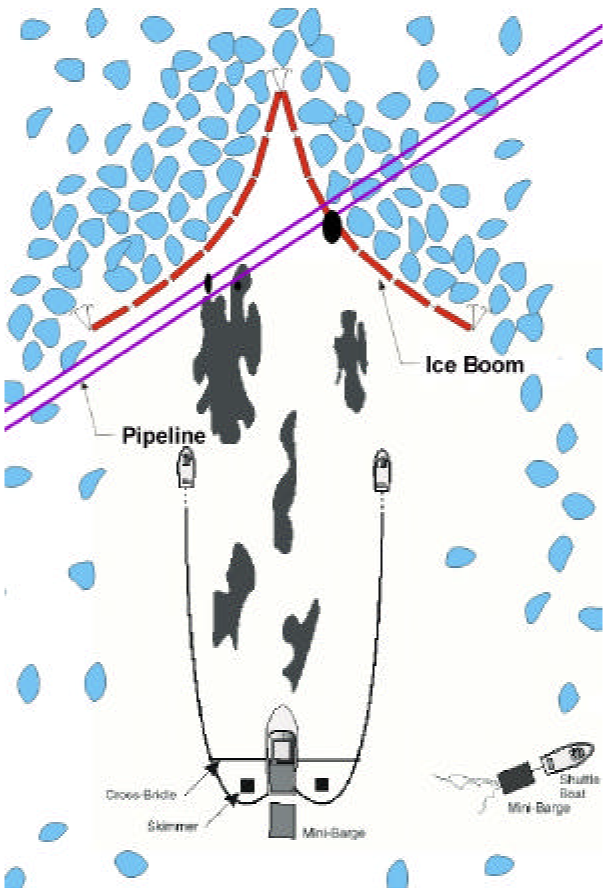


Figure 3.6: Scenario 3: Continuous Spill from a Punctured Offshore Pipeline

3.2.4 Scenario 4: Continuous Spill from a Reservoir

Ice can cause significant problems for a spill from a reservoir located on an inlet, a river or a shoreline, when the ice is drifting. An ice boom could assist in this scenario by ‘shielding” conventional cleanup equipment and/or containment booms from the moving ice (Figure 3.7).

In this case, the ice boom would divert the ice and ensure little mixing between the ice and the spilled oil. The boom would also provide an open water area for the oil spill recovery equipment to operate effectively.

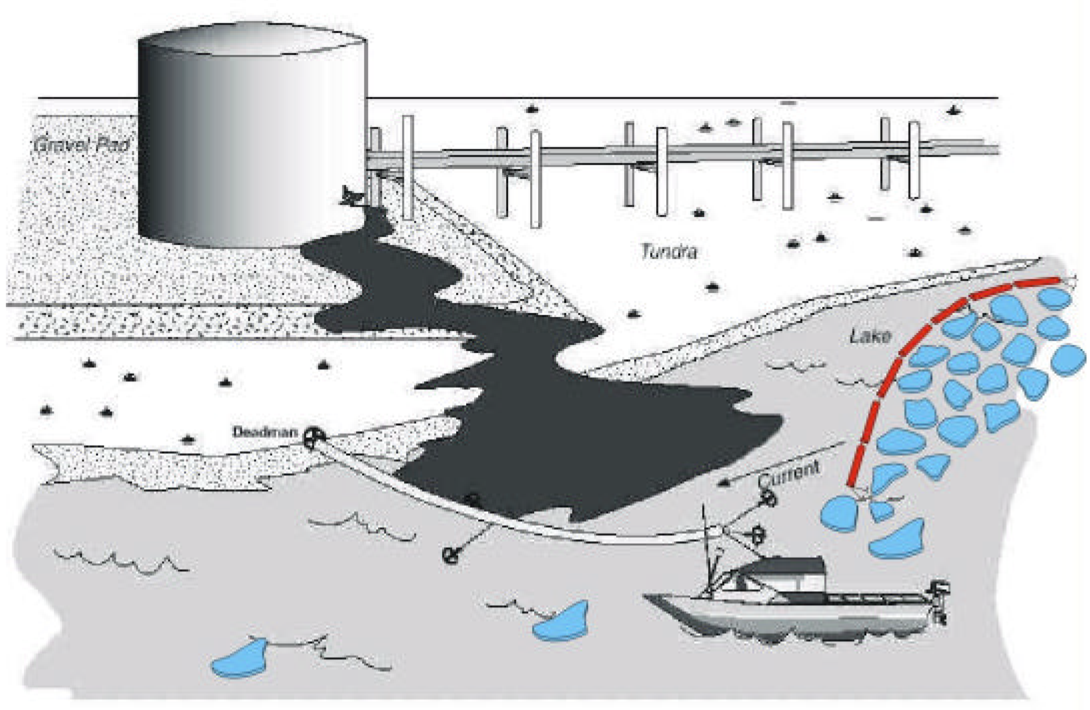


Figure 3.7: Continuous Spill from a Reservoir

3.2.5 Scenario 5: Oil Drifting in a River

The recommended response for this scenario in the Manual is to deploy booms across the river, and to use conventional oil spill cleanup equipment (Figure 3.8). However, this response technique would be ineffective if large amounts of ice were drifting downstream in the river. Ice booms could assist here by retaining the drifting ice while allowing the oil to drift downstream to be later collected by a conventional ice boom (Figure 3.8).

To evaluate the applicability of this approach, it is necessary to consider the currents and ice drift rates at the site. The ice drift rate should be lower than about 2.6 ft/sec (80 cm/sec), which is about the maximum current velocity at which ice can be effectively retained by a boom.

Only laboratory test data are available to estimate the relative currents required to achieve effective oil-ice separation, as described in Section 3.2.2. These data suggest that currents of more than about 0.5 ft/. sec would be required to achieve extensive oil slick movements under the ice (Figure 3.5)

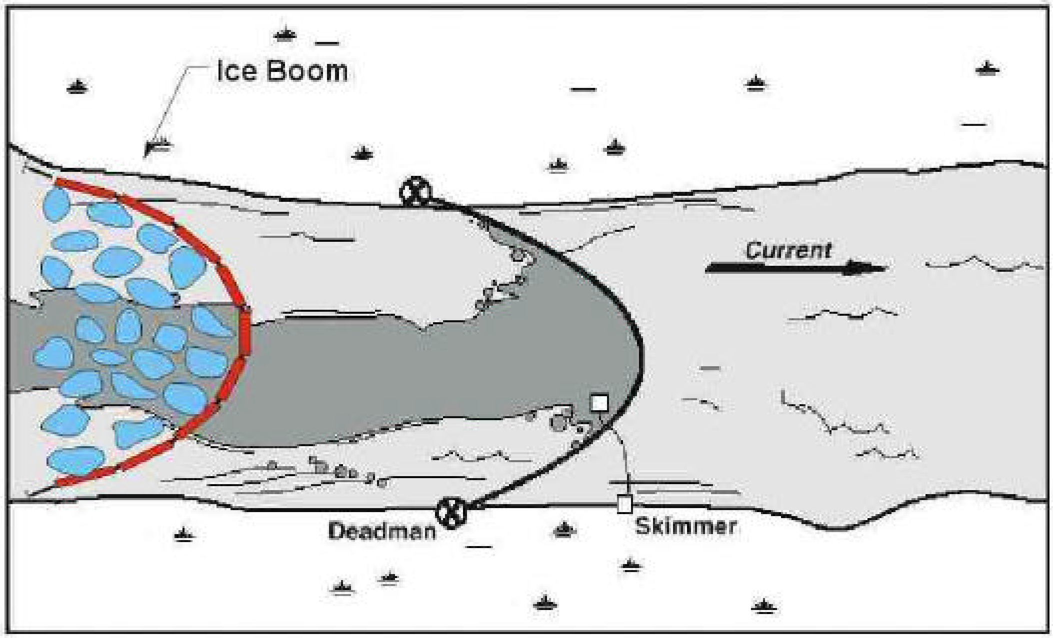


Figure 3.8: Scenario 5: Oil Drift in a River

4 ICE LOADS ON THE BOOM

4.1 Ice Loading Scenario

The expected ice loads are a very important issue as they will control the operating envelope for the boom, in combination with the capabilities of the available logistical support platforms. It is important to note that because the boom is designed to submerge and allow the ice to pass over it when ice forces become too large (described previously), the boom is not expected to be damaged should more severe ice conditions (than the design ones) be encountered. However, this would temporarily render the boom ineffective for oil spill containment or for protecting oil spill cleanup equipment behind the boom.

The ice loads on the boom will depend on the ice conditions in which the boom is deployed. The important issues include:

(a) whether the boom will be used in “open sea” conditions or in a channel (termed “river ice” conditions). This is an important distinction as the shorelines in a “river ice” condition provide confinement which affect the loads exerted on the boom. Compare Figures 4.1 and 4.2. Although the equivalent apex angle is typically much less for “river ice” situations, which would theoretically result in higher drag loads on the boom, the shorelines provide load relief to the boom as load is transferred to them. The net result, for a 10/10 ice pack, the ice loads tend to be considerably less for “river ice” conditions. However, for 3/10 to 7/10 ice pack, the ice load can be considerably less for a boom in an open sea.

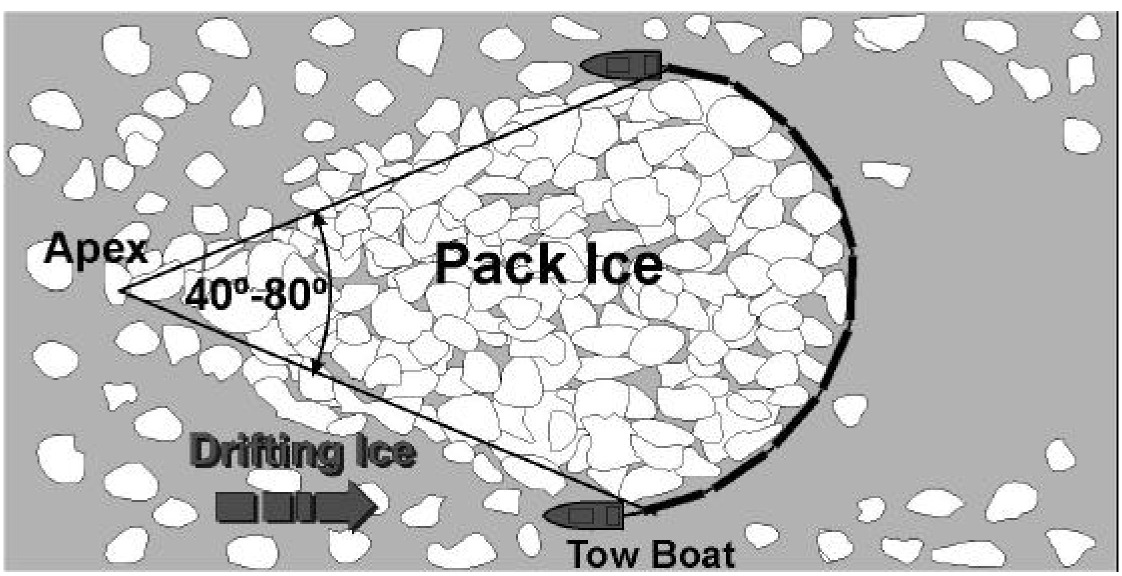


Figure 4.1: “Dead Wedge” Formed Upstream of a Boom in an Open Sea

(b) The type of ice conditions - loads have been evaluated for a boom in pack ice conditions. Figures 4.3 and 4.4 illustrate the expected ice loading process for this case. Generally, the interaction will proceed in two steps.

First, the boom will fill with ice pieces. Then, ice fragments will be diverted past, or shear past (depending on the ice concentration and pressure), the ice wedge. Clearly, the maximum ice loads will be developed by the steady-state conditions produced after the boom has become filled with pack ice fragments and subsequent ice floes are diverted past the wedge that is formed (Figures 4.3 and 4.4).

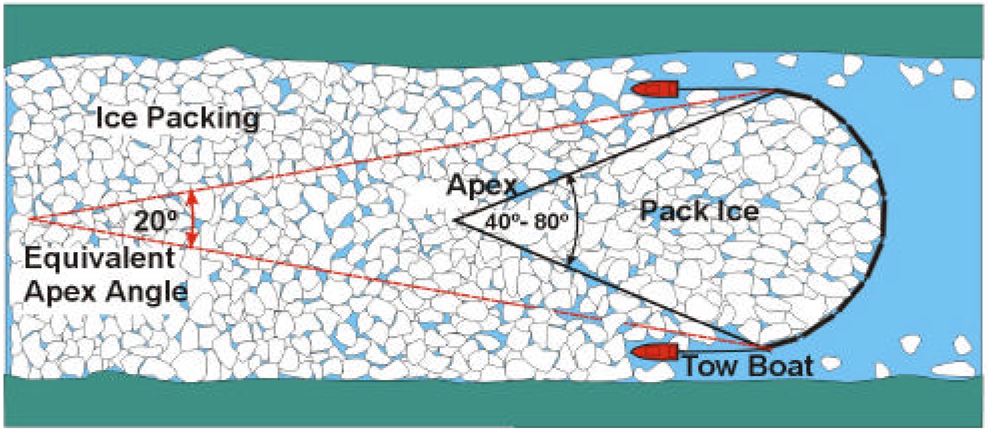


Figure 4.2: "Dead Wedge" Formed Upstream of a Boom in a Channel

The total force on the boom (F_{tot}) is comprised of two general components as described in equation 4.1.

$$F_{tot} = F_{drag} + F_{ice} \quad [4.1]$$

where: F_{drag} = the force due to wind and current drag
F_{ice}= the pack ice force due to the mechanisms in Figures 4.3 and 4.4

Drag forces and pack ice loads are discussed in Sections 4.2 and 4.3 respectively.

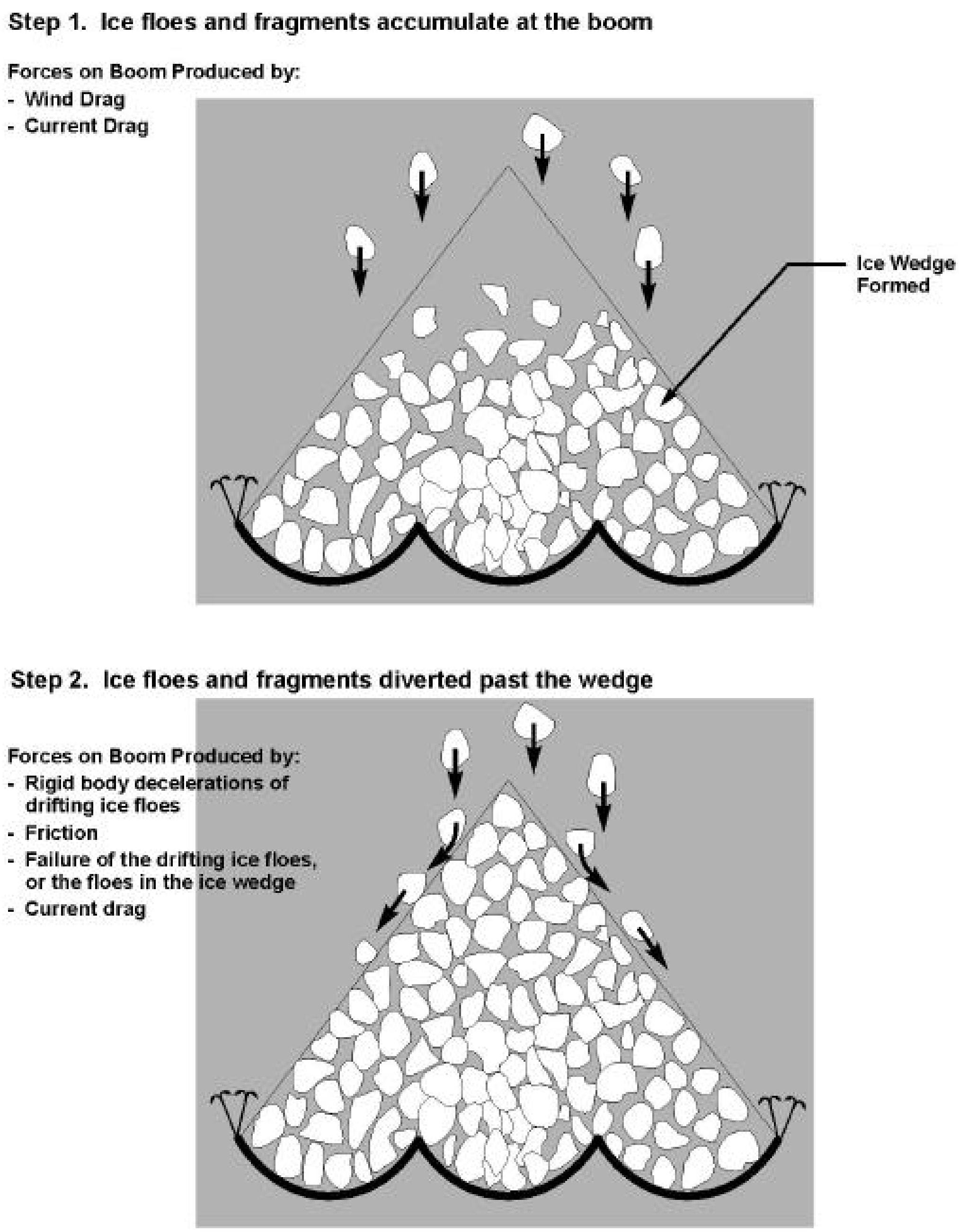


Figure 4.3 Ice Accumulation and Loading Process in Pack Ice Concentrations up to about 8/10ths

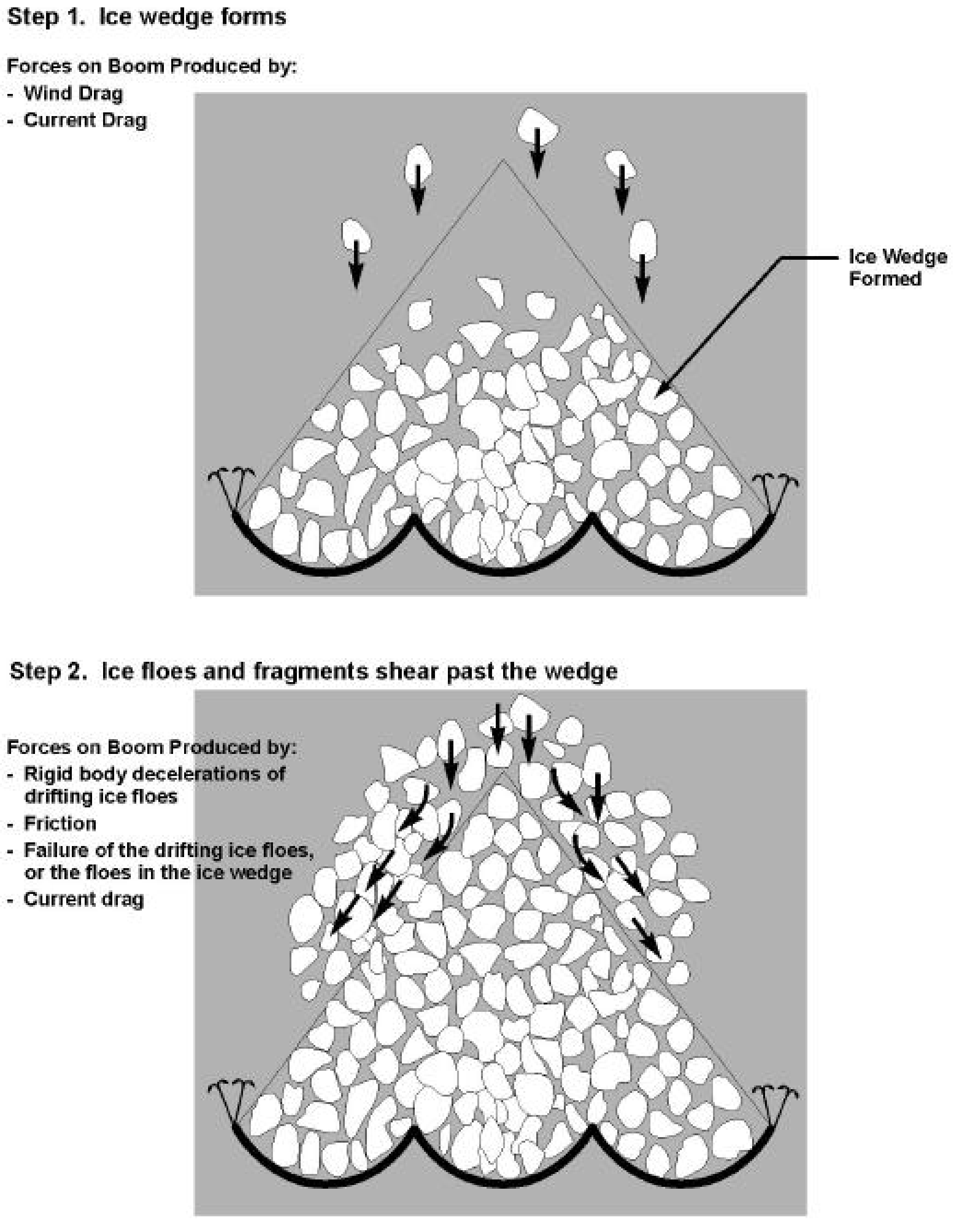


Figure 4.4: Ice Accumulation and Loading Process in High Pack Ice Concentrations (7-9/10ths)

4.2 Calculating Wind and Current Drag Forces

The total drag forces, F_{drag}, can be determined as follows:

$F_{drag} = F_{current} + F_{wind} = (\tau_c + \tau_w)\ A$ [4.2]
Wind drag shear stress, τ_w: $\tau_w = \rho_\omega C_{dw} V_w^2$ [4.3]
Current drag shear stress, τ_c: $\tau_c = \rho_c C_{dc} V_c^2$ [4.4]

where:
F_{wind} = wind drag force on the ice
$F_{current}$= current drag force on the ice
A = the effective area of the ice cover affected by the current and wind (termed the "dead wedge", and illustrated in Figures 4.1 to 4.4)
C_d = drag coefficient at air-ice interface (C_{dw}) or at ice/water interface (C_{dc}).
ρ = specific gravity of water (ρ_c) or air (ρ_w).
V = wind speed (V_w) or current speed (V_c).

The effective area of the "dead wedge" was defined for the "open sea" conditions analyzed in this study (Figure 5.1) by assuming that a triangular-shaped ice accumulation is formed. This selection is based on past observations that showed a wedge will form with an apex angle ranging from about 40° to 80° (e.g., Figure 4.5). The apex angle will be governed by the frictional properties of the ice fragments in the wedge, and by the lateral confinement. The apex angle will be reduced as the lateral confinement is increased.

Figure 4.5: Triangular-Shaped Ice Accumulation Upstream of the Boom Placed in Lac St. Pierre (in the St. Lawrence River)

Because booms will be most applicable to relatively open pack ice concentrations for the case being analyzed here (described subsequently), the apex angle used for these analyses was determined from analyses of the frictional properties of the ice fragments in the “dead wedge”. An investigation into the behavior and properties of pack ice fragments that accumulated in front of the Offshore Structure, the Kulluk was made (Barker et al, 2000). Gulf Canada Resources used the structure for oil exploration in the Canadian Beaufort Sea during the 1980’s (see Figure 4.6).

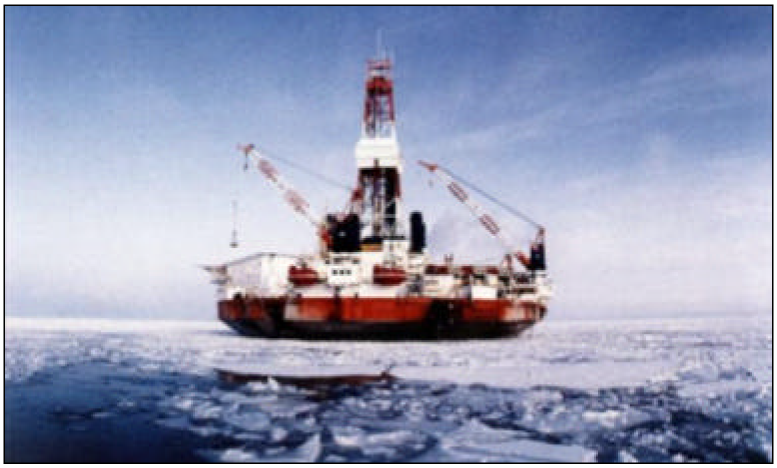


Figure 4.6: The Offshore Structure, the Kulluk used for oil exploration in the Canadian Beaufort Sea during the 1980’s.

The Kulluk was a moored, 70 m diameter (at the waterline) conical-shaped drilling structure used in the Canadian Beaufort Sea. It was held on station with a mooring system comprised of up to 12, 3.5” diameter mooring lines. See (Wright, 1999) for description. (Barker et al, 2000) found that a value of 27° for φ (the internal friction angle of the pack ice material) produced the best correlation between the measured and predicted ice loads. Assuming that Coulomb’s friction law is applicable, the apex angle (θ) of the “dead wedge” can be calculated as follows:

$$\theta = 2 * (45 - \varphi /2) \qquad [4.5]$$

Equation 4.5 yields a value of 63° for the apex angle for an internal friction angle of 27°. This value was used for evaluating the area of the “dead wedge” for all subsequent drag force calculations.

Values of 0.0033 and 0.020 were used for the air/ice surface drag coefficient (i.e., C_{dw}) and the water/ice surface drag coefficient (i.e., C_{dc}) respectively, as these are typical values for a relatively rough broken ice cover. It is recognized that these values are not constants, and they vary with both time and ice conditions. However, because several conservative assumptions were made in determining the drag forces (described subsequently), efforts to account for the expected variations in drag coefficient (within the range of commonly-used values) were not considered to be useful.

4.3 Calculating Pack Ice Forces

The loads produced by pack ice in an "open sea" condition (Figure 4.1) depend on many factors including:

(a) the pack ice concentration;
(b) the thickness of the pack ice fragments;
(c) the type of features in the pack ice (e.g., ridges), and whether or not ice management operations are carried out;
(d) whether or not the ice is under pressure.

Extensive reference was made in this project to full-scale data collected with the Kulluk for a number of reasons, which are listed below.

(a) Loading Scenario - the loading scenario was similar to that expected for the ice control boom. Compare Figure 4.7 with Figures 4.1, 4.3, and 4.4.

(b) Ice Conditions - the Kulluk data were obtained in pack ice conditions in the Canadian Beaufort Sea. The Kulluk typically operated in the June to December period.

(c) Width of loading – the Kulluk was a wide structure that allows the measured forces to be applied (on a line load basis) to other wide structures with confidence. Although it is well known that ice loads decrease with the loaded area, and with the width of loading or aspect ratio, the Kulluk is wide enough that a direct application of the measured line loads to other loading widths will involve very little error.

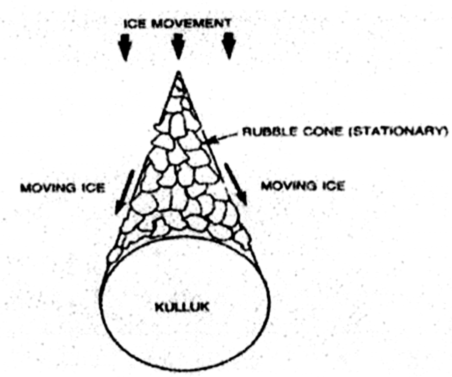


Figure 5.21 The upper photo provides a representative example of poor ice clearance in "tight" pack ice conditions around the Kulluk. In this situation, the managed ice fragments are not clearing well, and a "rubble wedge" can be seen updrift of the Kulluk. The lower figure is a schematic illustration of this situation.

Figure 4.7: Ice Loading Schematic for the Kulluk (after Wright, 1999)

(Note: the photo referred to the figure caption from Wright, 1999 was not included because it is of poor quality)

Ice management by icebreakers is one significant difference between the Kulluk operations and those for the boom. Most often, the ice approaching the Kulluk was broken up into small floes by two CAC 2 (Canadian Arctic Class) icebreakers which reduced the loads significantly (Wright, 1999). However, as will be shown subsequently, the boom is expected to be capable of operating only in relatively low ice concentrations (up to about 50 to 70%). In this case, ice management operations become less significant.

4.3.1 Effect of Pack Ice Concentration

Previous studies (e.g., Wright, 1999; Comfort et al, 1999) have shown that this is a very important factor. A wide range of model test data in broken ice have shown that the ice loads are relatively low at ice concentrations below about 8/10ths and that they rise substantially at greater concentrations (Figure 4.8). The best-fit equation to the model test data is as follows:

$$\text{Load Ratio} = 1.13 * 10^{-5} * C^{4.94} \qquad [4.6]$$

Where:

Load Ratio = mean load at a given concentration/mean load at 10/10 concentration

C = ice concentration, in tenths

This trend has been generally confirmed by full scale data for the Kulluk (Wright, 1999), which was a moored conical-shaped drilling structure used in the Canadian Beaufort Sea.

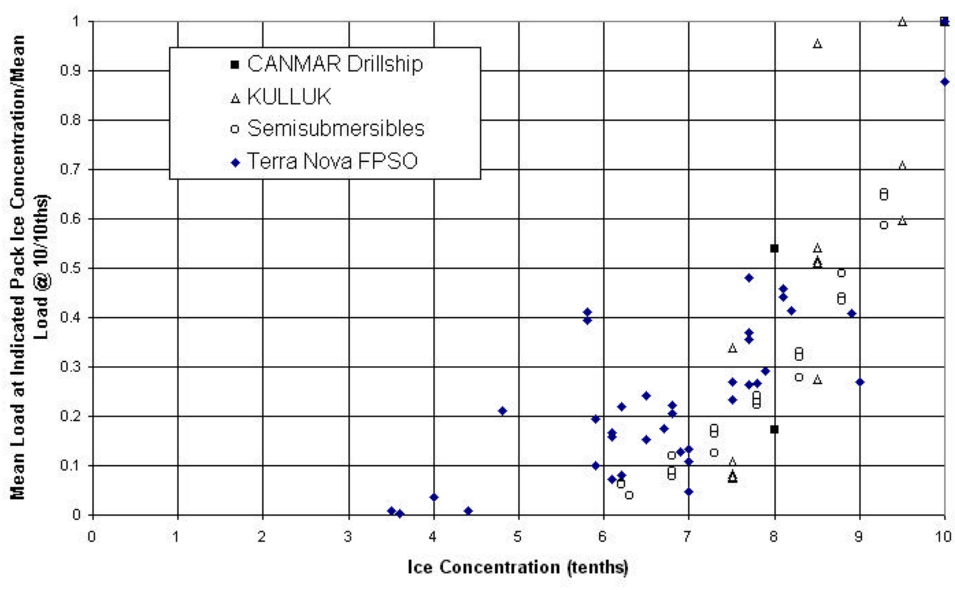


Figure 4.8: Effect of Pack Ice Concentration on Pack Ice Loads

(See Comfort et al, 1999 for supporting information)

4.3.2 Effect of Pack Ice Thickness

Full scale data for the Kulluk (Figures 4.9 and 4.10 – Wright, 1999) and model test data for a wide range of floating structures (Comfort et al, 1999) both show that the loads increase with the ice thickness. This trend reflects a number of processes including:

(a) the forces developed by rigid body decelerations of floes in low or high pack ice concentrations (Figures 4.3 and 4.4) increase with the mass of the floes;
(b) ice failure forces along the wedge boundary increase with the ice thickness;
(c) frictional forces along the wedge boundary increase with the ice thickness.

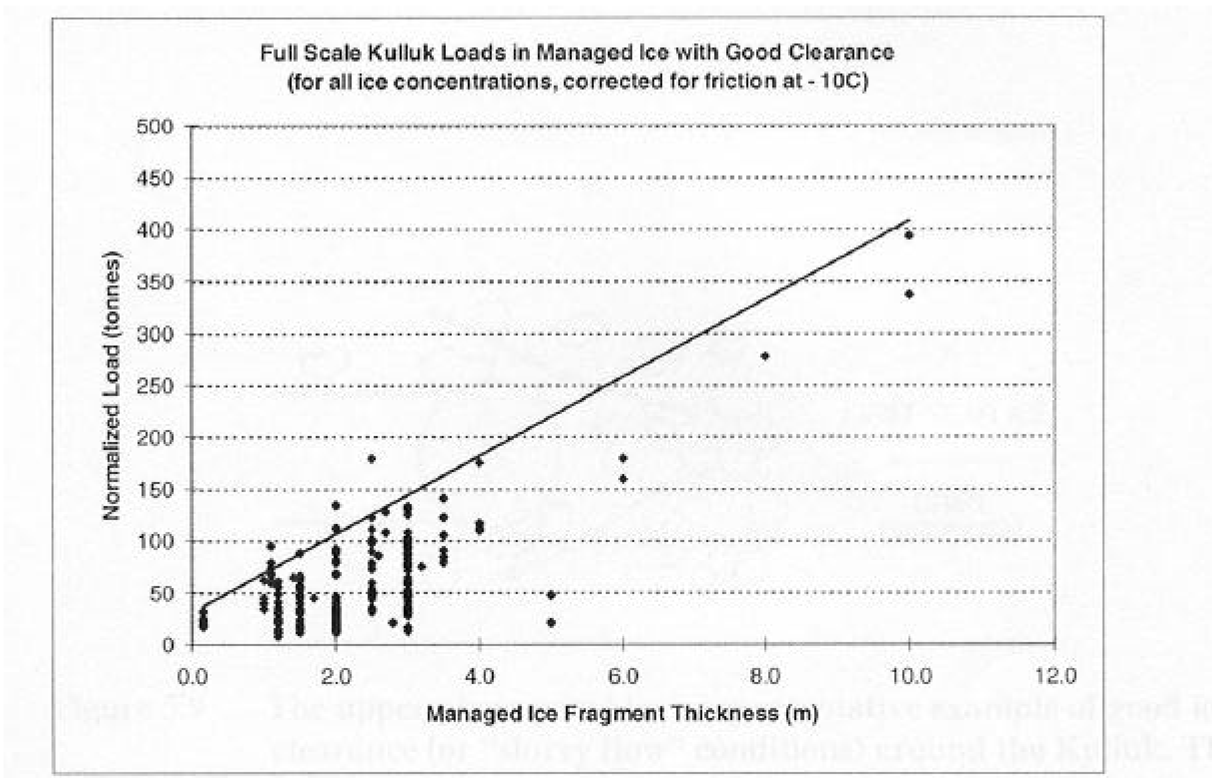


Figure 4.9: Ice Loads on the Kulluk in Managed Ice Conditions with Good Ice Clearance and No Pressure

(after Wright, 1999)

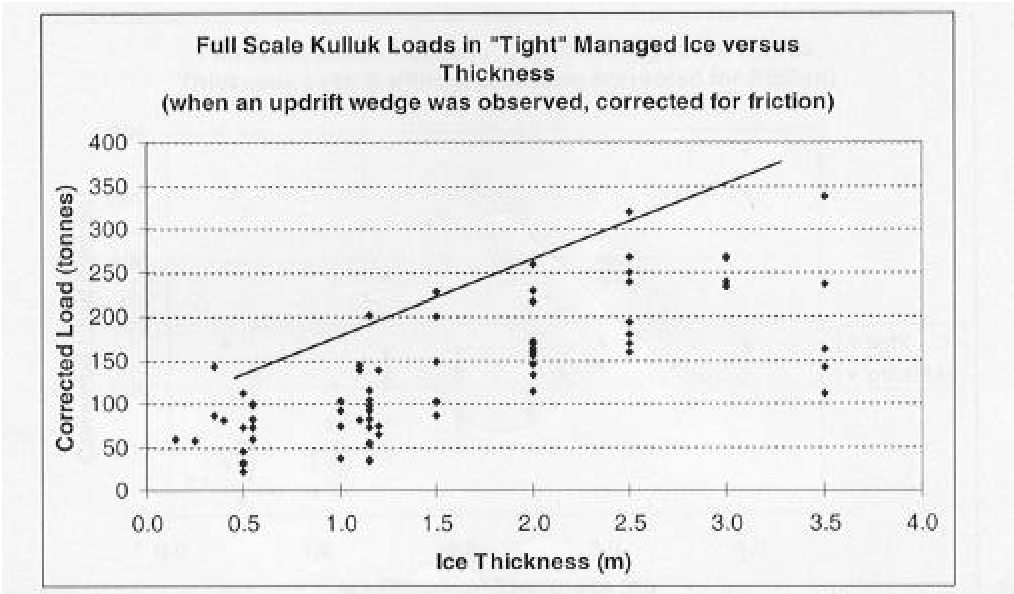


Figure 4.10: Ice Loads on the Kulluk in Tight Managed Ice Conditions with Poor Ice Clearance and No Pressure
(after Wright, 1999)

4.3.3 Effect of Pack Ice Features or Interaction Types

It is well known that pack ice is highly non-uniform. The significance of the different ice feature and interaction types that may occur is illustrated in Table 4.1.

Table 4.1: Maximum Ice Loads on the Kulluk

(Wright, 1999)

Case - Ice condition and thickness	Maximum Load		Maximum Line Load	
	(tonnes)	(lbs)	(kN/m)	(lbs/ft)
Level unbroken ice to 1.2 m	250	551000	35	2400
Small unmanaged ridges: approx. maximum thickness = 8 m	400	882000	56	3800
Managed ice with good clearance: maximum floe fragment thickness = 10 m	400	882000	56	3800
Floe fragment impacts	600	1323000	84	5700
Tight managed ice with poor clearance: maximum floe fragment thickness = 10 m	350	772000	49	3400
Tight managed ice with poor clearance and pressure: maximum floe fragment thickness = 4m	550	1213000	77	5300

The following observations can be made:

(a) effect of ice management (which refers to the operations done by Gulf Canada, who operated the Kulluk, to break up the incoming ice using icebreakers) – this greatly affected the loads. The loads in unmanaged ice were up to about 5 times higher than the comparable case for managed ice (Wright, 1999).

(b) effect of ice feature and interaction type – the highest loads were produced by floe fragment impacts.

(c) effect of ice clearance – the loads were increased when the ice was not able to clear readily past the Kulluk.

(d) effect of pressure – the loads were increased when there was pressure in the ice. This is described further in the next section.

4.3.4 Effect of Ice Pressure

It is well known that the ice may become pressurized. For the Alaskan Beaufort Sea, wind stress is the mechanism most likely to induce pressure in the ice.

However, for completeness, it is worthwhile to note that current-induced pressure has been observed in a number of other locations (e.g., the Gulf of St. Lawrence).

Ice pressure has two important effects for this project as follows:

(a) the loads are significantly increased when the ice is under pressure. Compare Figures 4.10 and 4.11.

(b) the channel or area behind the boom would be closed and become ice-covered. This would render the boom ineffective for aiding oil spill cleanup operations.

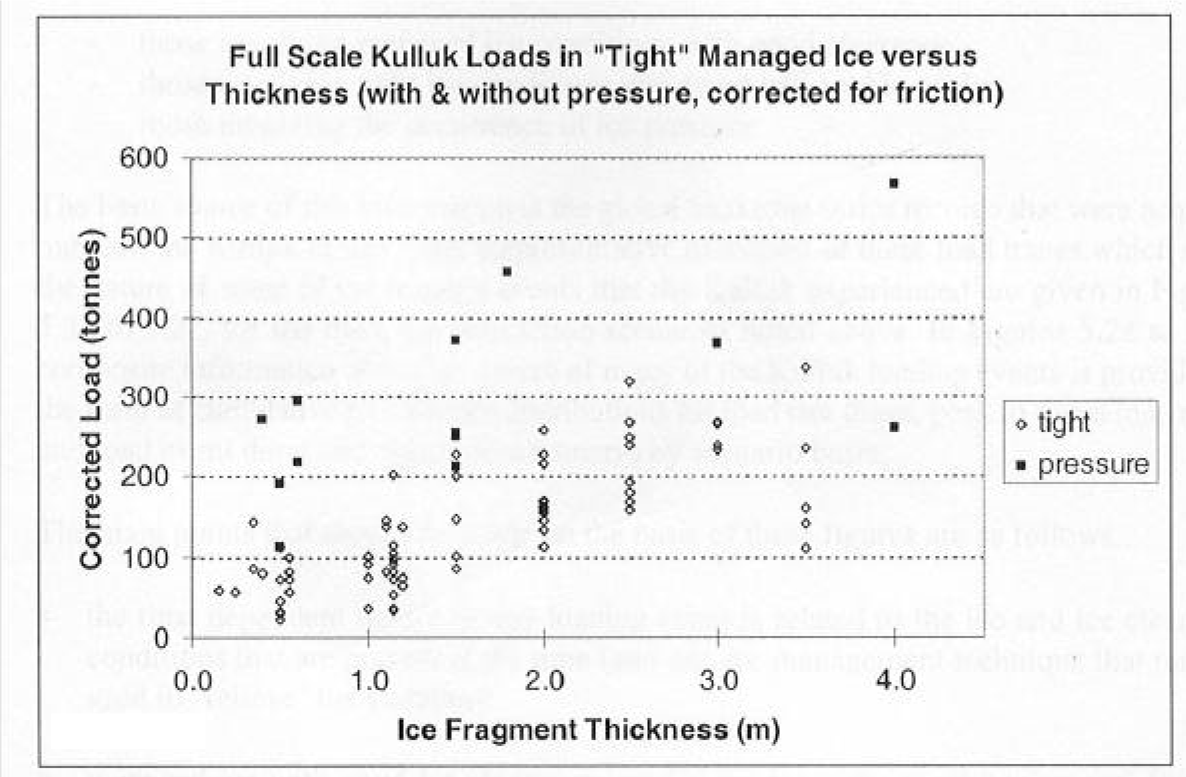


Figure 4.11: Effect of Pressure on the Loads Exerted on the Kulluk

(after Wright, 1999)

4.4 Loads on the Boom

4.4.1 Wind and Current Drag Forces: Inputs Used and Cases Considered

Wind and current drag forces were calculated by assuming that these two forces are collinear which errs conservatively.

Table 4.2 lists the input values used. Upper range values were used for the wind and current speed to add further conservatism.

Table 4.2: Drag Force Calculation Inputs

	Wind Drag Forces	Current Drag Forces
Ice wedge apex angle	63°	63°
Wind or current speed	100 km/hr	0.30 m/s
Air or water density	1.293 kg/m^3	1000 kg/m^3
Air or water drag coefficient	0.0033	0.020

Line loads due to drag forces were calculated for boom widths ranging from 230 ft (70 m) to 2500 ft (750 m). As expected, the line loads applied by drag forces increase with the boom width, as a larger boom width results in a larger ice wedge area.

Ice forces were calculated for the case where there was no pressure in the ice as the boom will not be effective in pressured ice (described previously). The calculation involved two general steps:

(a) Define the expected ice load at 9+ to 10/10 the pack ice cover. The upper bound relation developed by Wright, 1999 for the Kulluk for "tight managed ice with poor ice clearance" (Figure 4.10) was used to establish this. This selection was made as Wright, 1999 reported that the pack ice concentration ranged from 9 to 9+/10 for this case, and the relation expressed an upper bound to the data (Figure 4.10).

(b) Define the load reduction expected for pack ice concentrations lower than 9+/10. Equation 4.6 was used to define this.

4.4.2 Calculating Ice Loads

The ice load for this case was calculated as follows:

F_{ice} (Conc) = Load ratio (defined in equation 4.6) *
Upper bound to field data (defined in Figure 4.11) [4.7]

The ice load was evaluated for ice concentrations of 30%, 50%, and 70%.

As noted in Section 4.3, higher ice loads are to be expected for higher ice concentrations, or when there is pressure in the ice. However, ice loads are not presented for these cases here as simple comparisons have shown that these ice conditions impose loads that are beyond the practical range for a boom.

4.4.3 Calculated Line Loads Acting on the Boom

Ice forces were calculated as described in Section 4.4.2. Drag forces were added to determine the total force and line load across the projected width of the boom. The calculated line loads are shown in Figures 4.12, 4.13, and 4.14 for pack ice concentrations of 30%, 50%, and 70%, respectively.

As expected, the line loads increase with the pack ice concentration.

The effect of the ice thickness depends on the pack ice concentration. At low concentrations (i.e., 30% and 50%), the line load is insensitive to the pack ice thickness (Figures 4.11 and 4.12, respectively). This reflects the fact that ice forces are a small proportion of the total force in these cases. At 70% ice concentration, the loads increase with the pack ice thickness (Figure 4.14) indicating that ice forces are becoming more significant.

For the ice thickness and boom widths considered, the line loads range from 12 to 115 lb/ft, 38 to 215 lb/ft, and 160 to 680 lb/ft for pack ice concentrations of 30%, 50%, and 70%, respectively (Figures 4.12 to 4.14).

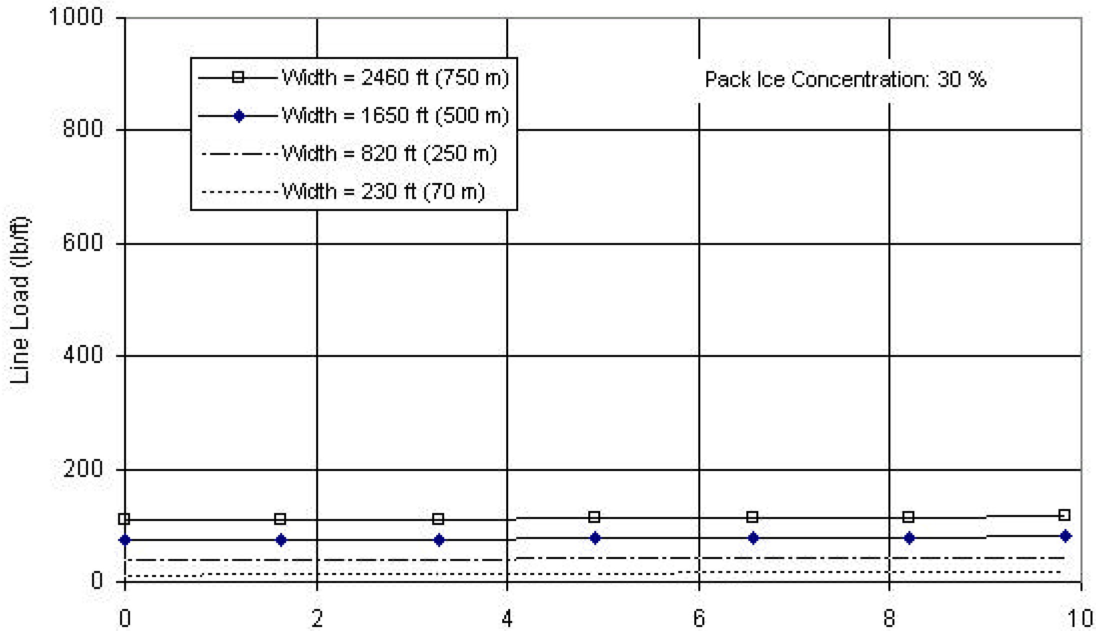


Figure 4.12: Line Loads for a Pack Ice Concentration of 30% with No Pressure

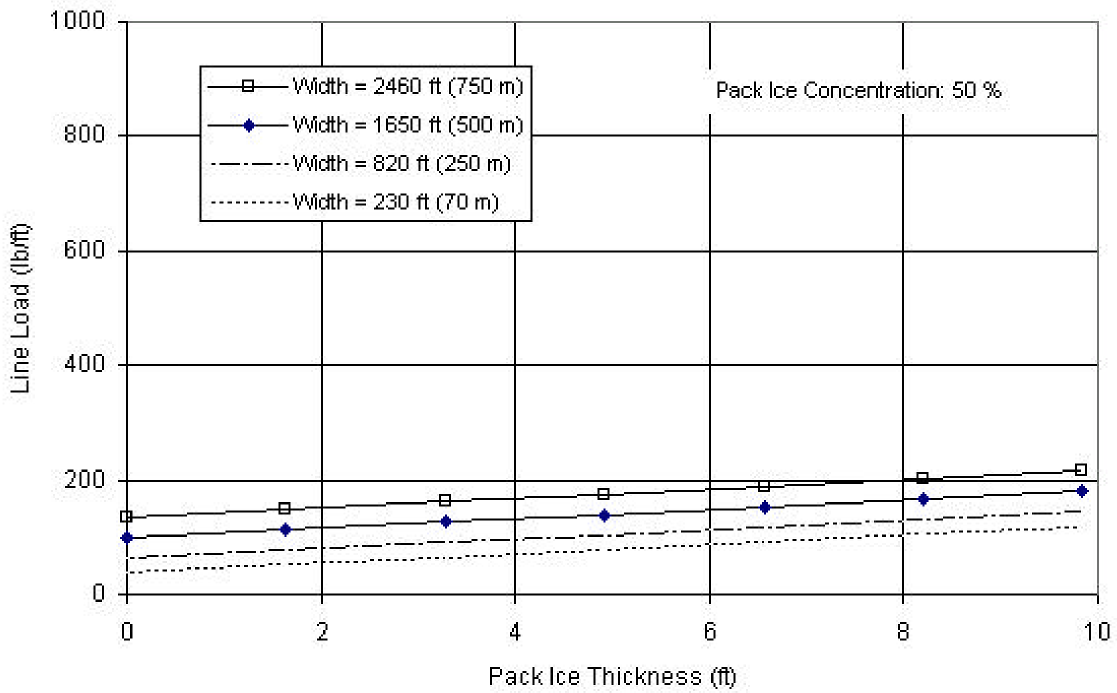


Figure 4.13: Line Loads for a Pack Ice Concentration of 50% with No Pressure

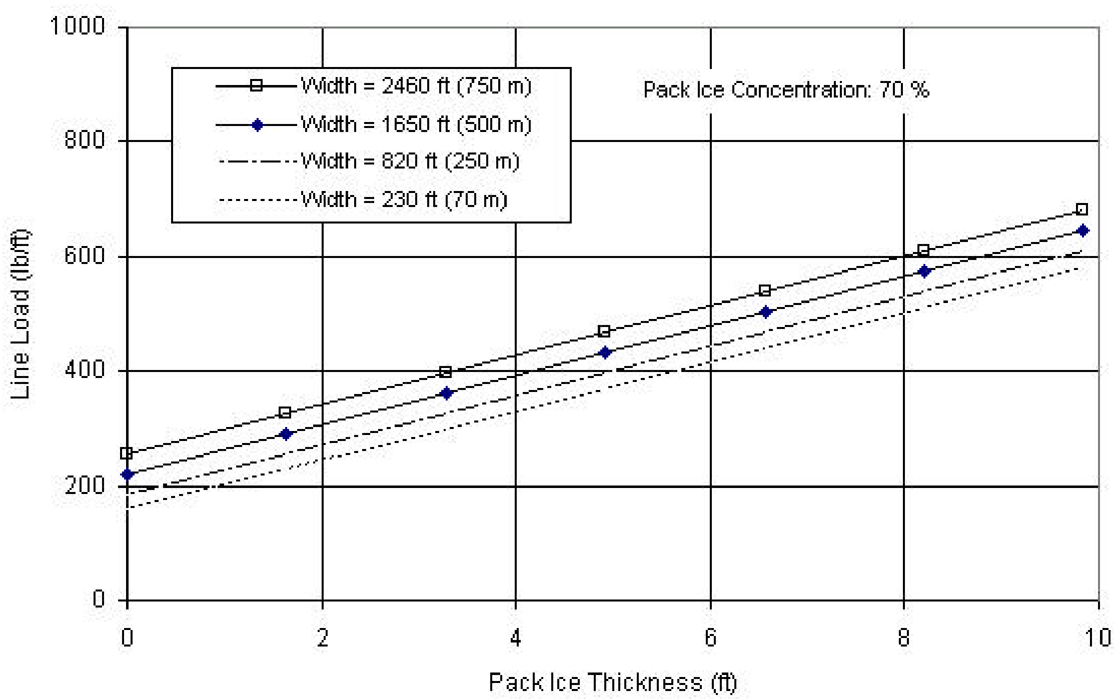


Figure 4.14: Line Loads for a Pack Ice Concentration of 70% with No Pressure

4.4.4 Anchoring or Ship Thrust Requirements for the Boom

The total anchoring requirements are shown in Figures 4.15 4.16, and 4.17 for pack ice concentrations of 30%, 50%, and 70%, respectively. It should be noted that the individual anchor requirements will depend on the number of boom spans across the boom width. This is considered further subsequently.

As expected, the anchoring requirements increase greatly with the pack ice concentration, and the projected width of the boom.

For the ice thickness and boom widths considered, the total anchoring requirements range from 1 to 142 tons, 4 to 265 tons, and 18 to 836 tons for pack ice concentrations of 30%, 50%, and 70 %, respectively (Figures 4.15 to 4.17).

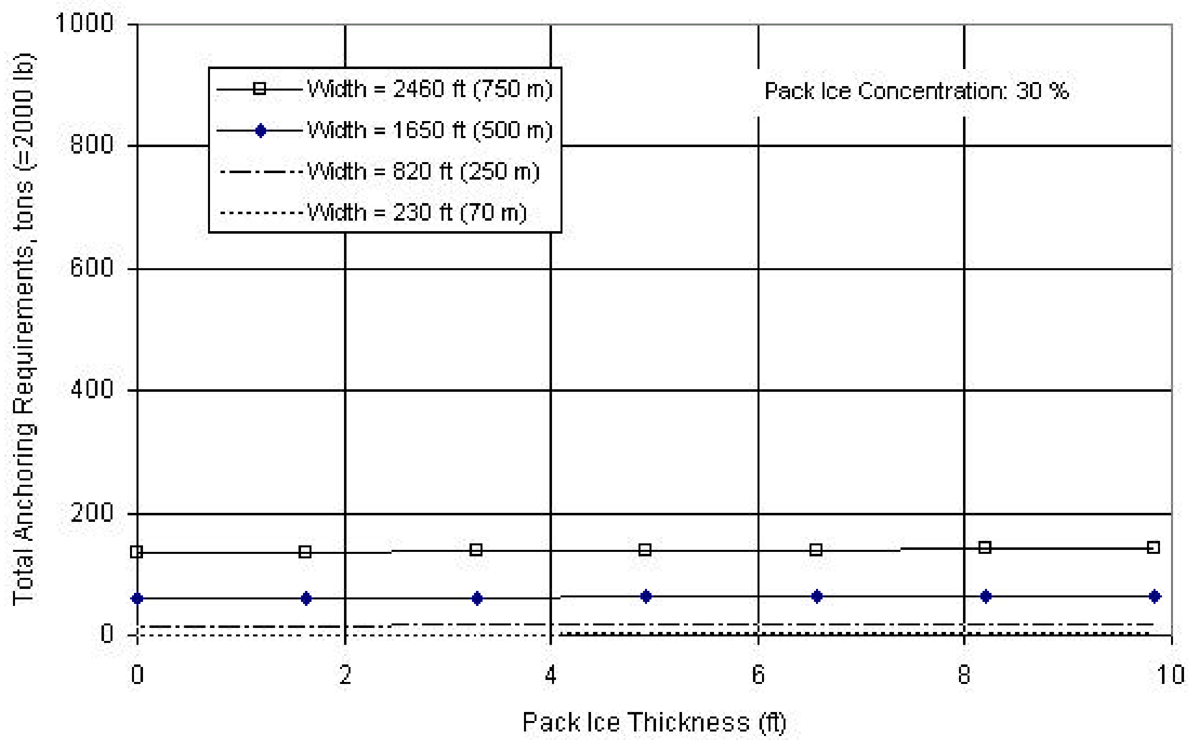


Figure 4.15: Total Anchoring Requirements for a Pack Ice Concentration of 30% With No Pressure

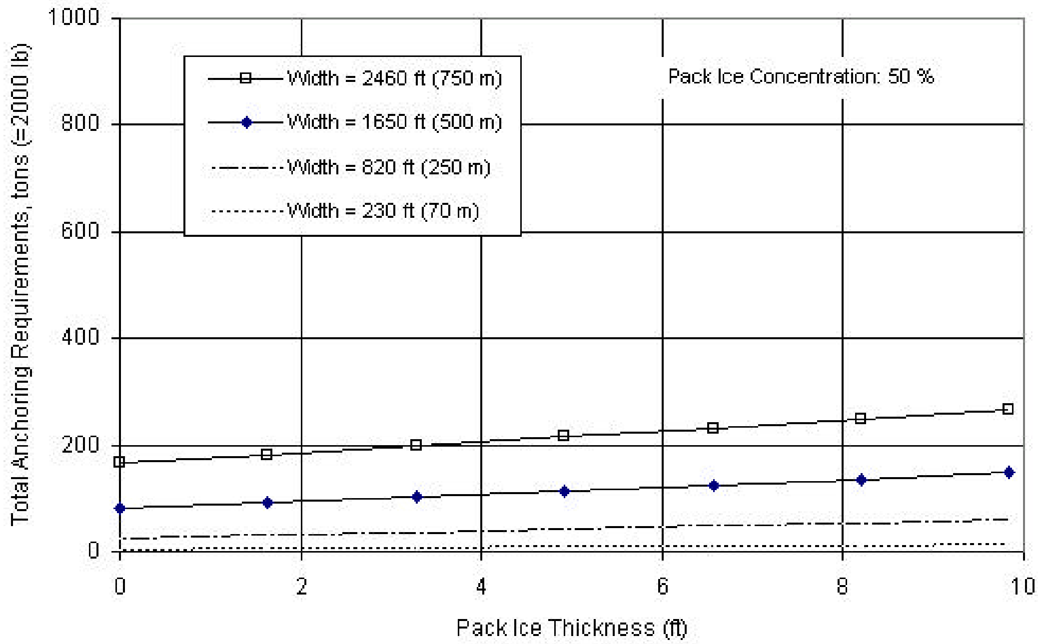


Figure 4.16: Total Anchoring Requirements for a Pack Ice Concentration of 50% With No Pressure

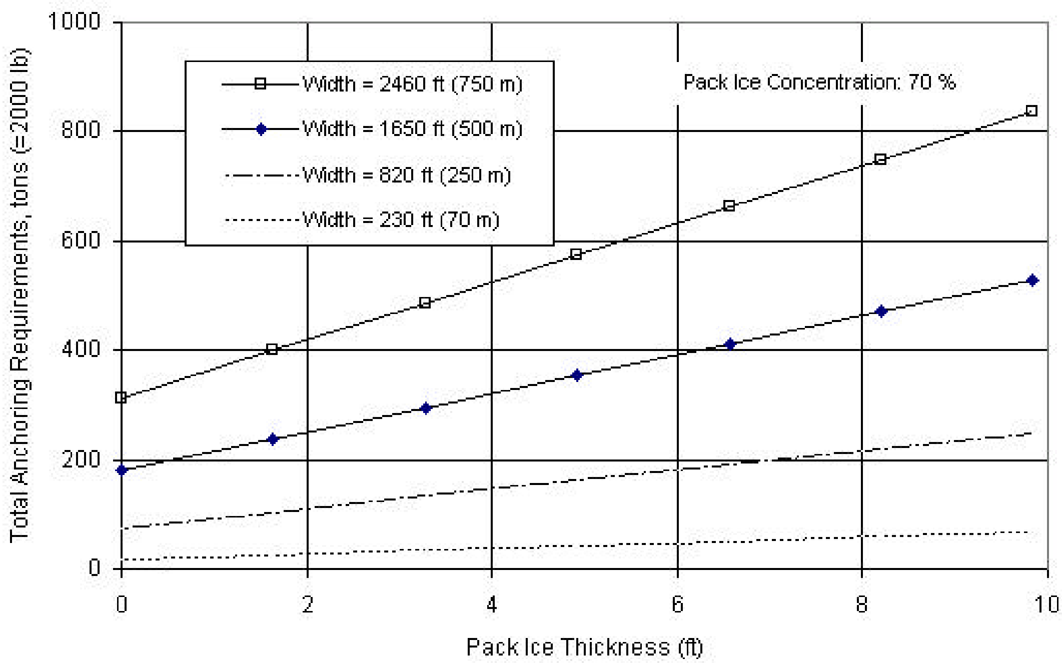


Figure 4.17: Total Anchoring Requirements for a Pack Ice Concentration of 70% With No Pressure

5 ICE BOOM CONFIGURATIONS AND DESIGN CONSIDERATIONS

This section discusses ice boom configurations and design considerations for a boom that could be used for most scenarios presented in Section 3. The considerations include the following:

(a) the ice and drag loads on the boom – These govern all aspects of the boom design. These loads are discussed in section 4.

(b) anchoring requirements and approach – in general two approaches are possible: (i) seabed anchors, and; (ii) dynamic anchoring with vessels or icebreakers.

Seabed anchors are best suited for cases where large areas need to be protected, as this would require a large boom, and hence produce large total anchoring requirements. It also offers a fast response capability should the anchors be pre-installed. The major drawback of this approach is that the boom costs will be higher, as the boom would have to be designed to provide protection against ice movements from any direction.

The second approach has the advantage that it is more flexible, and that it would be applicable to a wide range of spill scenarios. Furthermore, the boom costs will be lower, and provided that locally-available vessels could be used, the overall costs would likely be lower as well.

The most appropriate approach depends on many factors including: (i) the scenario in which the boom is deployed; (ii) the loads on the boom, and; (iii) the boom width required for it to provide a useful contribution to the oil spill cleanup effort.

(c) the ice retention capacity required – this is governed by the ice conditions and the desired operating window for the boom. At the detailed design level, the ice retention capacity is controlled by the buoyancy and number of boom pontoons. The buoyancy of a single pontoon is largely controlled by its diameter.

5.1 Environmental Conditions

The situations in which an ice boom can be used depend on the ice conditions, the environmental conditions and the available equipment used for the deployment. Two types of loadings are important:

(a) ice loadings
(b) wave loadings

5.1.1 Ice Loadings

Ice loads are described in Section 4.

It is important to note that an ice boom is designed to submerge when more severe ice conditions (than the design ones) occur. This avoids damage and the excessive costs that would be incurred if the boom were to be designed to withstand all ice conditions.

Hence, boom design at the detailed level primarily consists of a trade-off between the desired ice retention capacity and the cost or size of the boom. Anchoring requirements also influence the design process greatly.

5.1.2 Wave Loadings

Waves are an important design consideration as they can cause damage to the pontoons. Many of the damages that have occurred to date have resulted from waves causing the ends of the pontoons to impact with each other.

Obviously, the preferred approach is to prevent these loads from occurring. Rubber bumpers have also been used to minimize this problem. At the detailed design level, this is done by maximizing the “gap” (i.e., the distance between individual pontoons) so that end impacts are unlikely. The “gap” size selection is a trade-off between two objectives:

(a) to minimize the possibility of end impacts; and,
(b) to minimize the amount of ice that escapes between the pontoons. Typically, the “gap” is set at about 30-50% of the pontoon length.

5.2 Case Study

Scenario 1a in the Manual (Figure 3.1, in Section 3) was used as a case study. Two general boom arrangements are possible:

(a) Fixed Installation – in this case, the boom would be deployed around most of the full perimeter of the island (leaving only a few gaps for access in and out of the site), and held in place using seabed anchors. The seabed anchors would be pre-installed, and in the event of a spill, the boom would be deployed from either the island or shore using support vessels and/or barges. The advantages of this approach are that:

   (i) support vessels are not required on a full-time basis once the boom has been deployed which frees them up for other duties;
   (ii) this would provide a rapid response capability;
   (iii) the boom provides protection against all ice drift directions;
   (iv) ice pieces are prevented from “going around” the boom and entering the oiled area from the sides.

   The disadvantages include:

   (ii) cost - a longer boom is required, which will result in higher boom costs;
   (iii) ice ingress into the central protected area – any ice that over-runs the boom will collect inside the central protected area unless measures are taken to allow the ice to escape. This can be alleviated using approaches such as releasing one end of the boom on the “downstream” side so that this part of the boom “streams” into the ice. This approach has been used elsewhere (e.g., on the Rideau River) to allow ice passage at breakup without jamming.

(b) Ship-based Deployment – in this case, support vessels would be used to keep the boom on station. The boom would consist of one to two spans and can be deployed in different modes (Figure 5.1):

(i) 3-Ship Chevron Configuration: three supply vessels are used. One ship (or an icebreaking vessel if operations are to be carried out in more severe ice conditions, Section 6) would be used to tow the ice boom to the site. Two more vessels would be used when the boom is stationed at the oil spill site.

(ii) 2-Ship Catenary Configuration: two supply boats would be used. The boom would be towed from one end to the site while a second tugboat pulls the other end of the boom to form a catenary shape.

The advantages of this approach include:

(i) a shorter boom is required (versus a fixed installation) which will reduce costs and deployment logistics;
(ii) the boom can be maneuvered to take account of shifts in ice movement direction (Figure 5.2);
(iii) it is a flexible approach. For example, the boom could be used at many locations or in many scenarios. In this case, it could be stored at a central location and towed to the spill site. The span could also be adjusted "on-the-fly" (within limits) by maneuvering the vessels.

The disadvantages include:

(i) support vessels are tied up on a full-time basis, both for keeping the boom on station, and for maneuvering the boom to keep it perpendicular to the ice drift direction (which will change throughout the spill);
(ii) vigilance is required on the part of the operators to maneuver the boom throughout the spill in response to shifts in ice movement direction. This may be quite difficult to accomplish at all times (e.g., in fog, at night, or in other low visibility conditions);
(iii) ice pieces may "go around" the boom and enter the spill area from the sides.

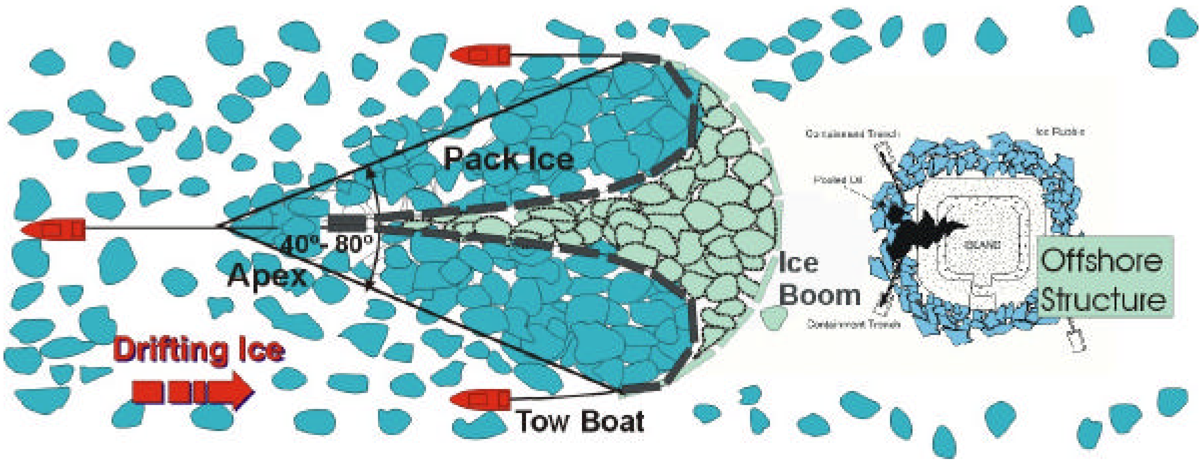


Figure 5.1: The Deployment of an Ice Boom in two Configurations (i.e., Chevron and Catenary), Upstream of an Oil-Spill from an Offshore Structure

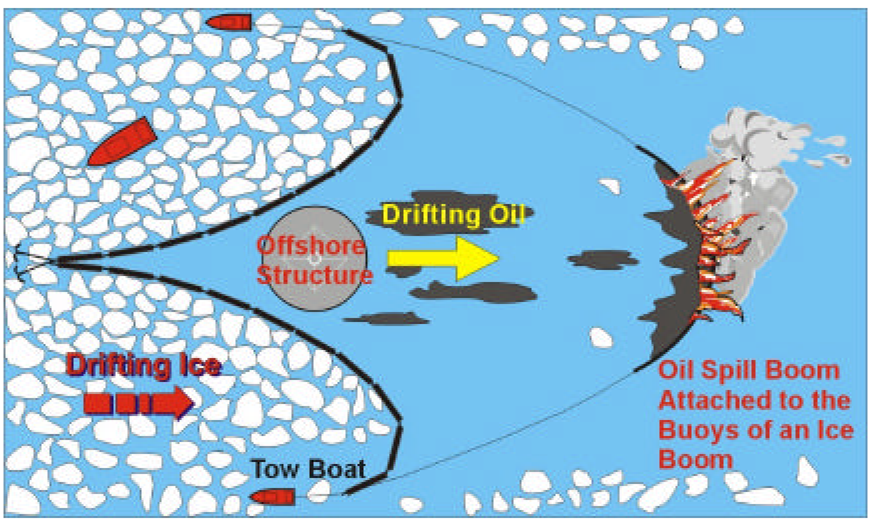


Figure 5.2: Boom Maneuvering and Attachment of an Oil Spill Boom to an Ice Boom.

In practice, some combination of the two deployment modes would probably be done, depending on the local conditions, to take advantage of the attributes of each approach. For simplicity and because the details of the scenario are difficult to specify, the two approaches were considered separately in this case study. The "ship-based boom deployment" is considered in Section 5.3 while the "fixed installation" approach is investigated in Section 5.4.

5.3 Ship-Based Boom Deployment

The boom may be deployed either in a Chevron or Catenary configuration (Figure 5.1).
The main advantages of the Chevron configuration are that:

(a) it would provide greater stationkeeping abilities by allowing three ships to hold the boom in place;
(b) it would provide improved capabilities to maneuver the boom.

Vessel requirements are presented in Section 6, along with those of available ships.

5.3.1 Design Summary

Table 5.1 summarizes the design criteria used and the boom design that was produced.

The table provides the appropriate size and the number of required pontoons and their spacing for a given ice load. Further information regarding key components and issues is provided below. Appendix A provides a set of typical ice boom drawings as a sample. These drawings were used for an ice boom deployed in Lake Ontario, where the ice retention criteria was governed by the relatively thin ice in the area.

Table 5.1: Ship-Based Deployment for Scenario 1a: Design Criteria Used and Boom Design Developed

Inputs	#	ft	m	dia in	dia mm	lb	kg
Pontoon Length		29.848	9.1				
No. of Pontoons:	22	657	200				
Cable length		1230	375.0				
Span width		984	300.0				
Gap between pontoons		24.9	7.6				
Weight of Span Cable Carried By One Pontoon:				1.5	38.1	223	101
Weight Of Chain Links Carried By One Pontoon:						200	91
Other weights (cable clamp, shackles,etc.) for One Pontoon:						200	91

English Units

Pipe dia.	Pipe radius	wall thick.	End plate thickness	Length	Steel Vol Pipe	Steel Vol Ends	Steel	Overall Pontoon	Total Weight	Bulk Density	Overall Specific	Net Buoy. Force	Span Net Buoyancy
(in)	(in)	(in)	(in)	(ft)	(in^3)	(in^3)	Wt.(lb)	Vol. (ft^3)	(lb)	lb./ft^3	Gravity	(lb)	(lb)
18''pipe	9	0.25	0.75	29.8	4993	562	1574	52.72	2197	41.66	0.67	1093	24050
24''pipe	12	0.38	0.75	29.8	9969	1156	3152	93.72	3775	40.27	0.65	2074	45622

Metric Units

Pipe dia.	Pipe radius	wall thick.	End plate thickness	Length	Steel Vol Pipe	Steel Vol Ends	Steel	Overall Pontoon	Total Weight	Bulk Density	Overall Specific	Net Buoy. Force	Span Net Buoyancy
(mm)	(mm)	(mm)	(mm)	(m)	(m^3)	(m^3)	Wt.(kg)	Vol. (m^3)]	(kg)	(kg/m^3)	Gravity	(kg)	(kg)
457	229	6.4	19	9.1	0.082	0.00921	715	1.49	998	669	0.67	494	10932
610	305	9.5	19	9.1	0.163	0.01894	1433	2.65	1716	646	0.65	938	20737

Submergence Resistance 2D Model(1)	Theoretical Resistance Corrected	Friction Resistance $\mu = 1.50$	Theoretical Resistance ωιτη Φριχτιον
(kN/m)	(kN/m)	(kN/m)	(kN/m)
0.03	0.02	0.5	0.5
0.6	0.4	1.0	1.0

Pipe dia.	Pipe dia.	Span Net Buoyancy	Actual Resistance	Force on cable	Total Force	Anchor Force	Anchor Force
(in)	(mm)	(kN)	(kN/m)	kN	Tonnes	Tonnes	Tonnes
						Catenary	Chevron
18	457	107	1.9	563	57	29	19
24	610	203	3.6	1,068	109	54	36

(1) the calculated submergence resistance for the pontoon size noted in 2 dimensions.

(a) area to be protected and required boom width – it was assumed that a 1000 ft (300 m) wide open water area would be necessary to provide a large enough area that oil spill recovery equipment could be deployed and operated. This would be about two times the expected width (or diameter) of a typical offshore production island. Two boom sections with 500 ft span (150 m) each will provide the required area.

(b) design loads on the boom – designs were developed for an applied line loads of 100 lb/ft (1.5 kN/m) and 200 lb/ft (3 kN/m) which cover the range of interest for pack ice concentrations of 30 % to 50 % (section 4).

(c) type of deployment - designs were developed for booms in either a chevron or catenary configuration (Figure 5.1).

(d) span cable – the required span cable diameter is affected by several factors including:

(i) the span to total length ratio - the total span cable length should be at least 125% longer than the desired span to avoid excessive loads.

As well, for the case where vessels are used to keep the boom on station, a shorter span cable will generate significant lateral load that will pull the boats toward the inside of the catenary. This will reduce the effective span to about 80% of the nominal value.

(ii) the span – the span cable loads and tensions increase with the span.

(iii) the anchoring or stationkeeping system used – the available anchoring capacity will impose a limit on the span that can be achieved.

For the case where vessels are used to keep the boom on station, the following spans are required to provide a total swath with of 1000 ft (see also Table 5.1):

- Catenary configuration: 1 spans @ 1000 ft – cable length per span = 1230 ft; span cable diameter = 1.25 and 1.50 inches for line loads of 127 lb/ft (1.9 kN/m) and 240 lb/ft (3.6 kN/m), respectively.

- Chevron configuration: 2 spans @ 500 ft – cable length per span = 615 ft; span cable diameter = 1.25 and 1.50 inches for line loads of 127 lb/ft (1.9 kN/m) and 240 lb/ft (3.6 kN/m), respectively.

(e) Pontoons – pontoon design is controlled by the required ice retention capacity and it involves the following important issues:

(i) the ice retention capacity of a single pontoon – this is primarily controlled by the pontoon's buoyancy and length. Typically, 30 ft (9.1 m) long pontoons have been used at the booms built to date. The ice retention capacity of a pontoon is discussed further in section 5.3.2.

(ii) the number of pontoons in a span, or per unit length - in a typical boom, 10 to 13 pontoons would used in a 500 ft (150 m) long span cable

(iii) the required gap between the pontoons to retain ice without incurring wave-induced damage (caused by the pontoon ends being slammed into each other by waves). Typically, the gap has been set at about 30-50% of the pontoon length.

The gap between two 30 ft long pontoons can be as large as 20 ft (6.1 m) without affecting the ice retention capacity of the boom, depending on the type of ice. When the boom is used in a situation where an ice cover will form, a gap of 20 ft was found to be sufficient to promote the development of an ice cover within hours when the ice consisted of thin ice and very small floes. In larger floes, a larger gap (of say 20 ft) would be acceptable as well.

In a wave environment, a smaller gap between each two pontoons will be necessary to hold the ice. To minimize the damage to the pontoons, rubber bumpers have been used at each end to prevent damage and possibly the loss of pontoon buoyancy.

For this case study, the following pontoon parameters were established (see also Table 5.1):

Table 5.2: Pontoon Parameters Established for the Case Study Design

Line Load (lb/ft)	Pontoon Length (ft)	Pontoon Diameter (in)	No. of Pontoons per 500 ft Span
100	30	18	11
200	30	24	11

(f) Attachment of the Pontoons to the Span Cable - Each pontoon would be attached to the span cable as shown in Figure 5.3. This method allows the ice to run over when the ice resistance capacity of the pontoon is exceeded. The pontoons are designed to submerge, and then resurface when the load drops. This guarantees that the impact of a large ice floe will not cause structural damages to any of the boom components. The chain should be about 50% longer than the thickness of the ice expected in the area to ensure the ice can clear the boom when the loads exceed the retention capacity of the pontoon without causing any damage to the anchor or causing the tugboat to become out of control. In thick multi-year ridges, this criterion would require that the length of the chain be about 1.5 times the ridge depth, which would be an excessive requirement. Prototype testing should be done to confirm this length.

(g) Cable Clamps Used to Ensure the Pontoon Will Not Slide Along the Cable – a ¾” fishing chain with appropriate shackles should be used to connect the cable clamp to the pontoon.

(h) Junction Plates - junction plates are used to provide an attachment point between the span cable and the anchor cable, or tow line (for ship-based deployments). See Figure 2.2, in Section 2 for schematic.

(i) The Tow Cable (for ship-based deployments) – this should be 150 to 300 ft (50 to 100 m) long to provide sufficient slack for the ice to clear from both sides of the boom without adding to the tension at the boat.

(j) Buoys - buoys are used to provide floatation to the junction plate and to allow the anchor or towing cables to be attached without the need for divers (Figure 5.4). These junction plates are held by buoys as close as possible to the water surface. The buoy can also be used to attach a conventional open water boom, should the boom be used in other scenarios (e.g., Scenarios 2a and 2b - Figures 3.3 and 3.4, respectively).

The ice boom buoys (located about 100 to 200 m apart) could also be used as anchoring points for an oil-spill containment boom (or fireproof booms) to be deployed downstream of the ice boom (as described in scenarios 2 and possibly 5). See Figure 5.2. For this case, the buoys should be equipped with a quick connect/disconnect mechanism, which is available from most oil-spill containment boom suppliers and manufacturers. The quick disconnect would make the boom easy to deploy, and to disconnect in case of emergency with less risk of an oil slick seeping outside the spill area.

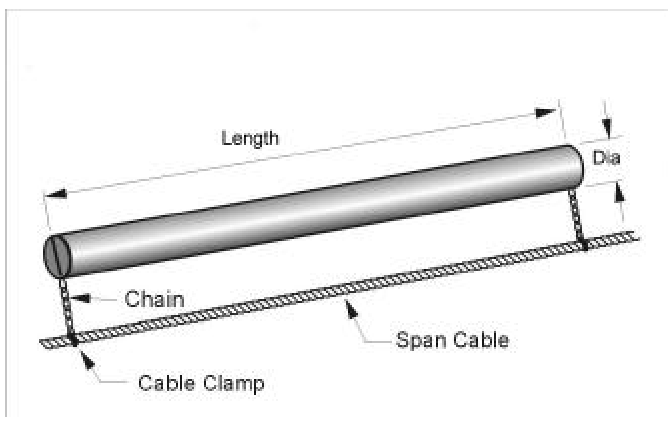


Figure 5.3: Pontoon Attached to the Span Cable to Allow Ice Over-Run when the Ice Load Exceeds the Boom's Ice Retention Capacity

Figure 5.4: Buoy Used to Connect the Tugboat or the Anchor to the Boom

5.3.2 Detailed Design: Calculation of a Pontoon's Ice Retention Capacity

Figure 5.5 describes the forces acting on a pontoon. The pontoon's ice retention capacity is governed by the force necessary to submerge it, thereby allowing ice to run over the boom. Figure 5.6 shows the measured ice retention capacity of various pontoons as well as the line load predicted by a numerical model developed by Abdelnour et al, 1995.

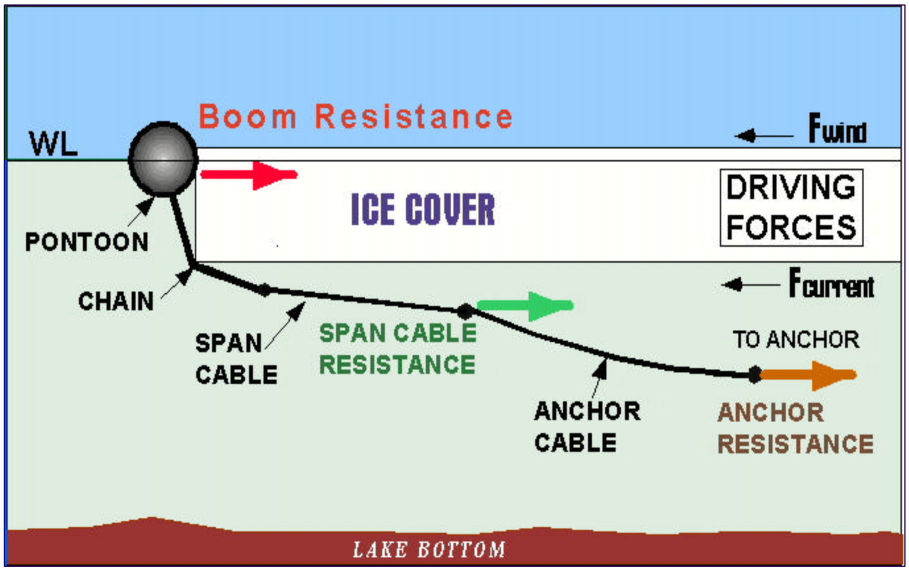


Figure 5.5: Schematic of Forces Acting on the Boom

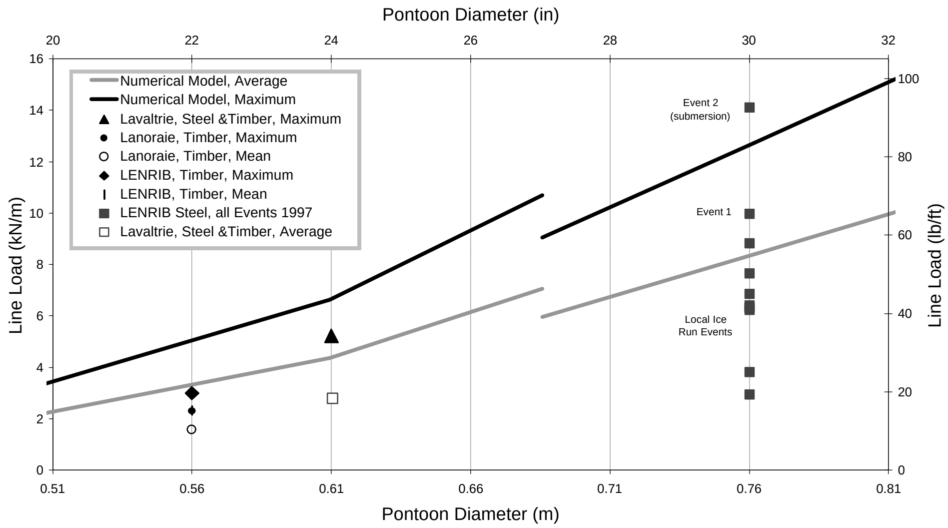


Figure 5.6: The Effect of Pontoon Diameter on a Pontoon's Ice Retention Capacity

Equilibrium is established when all the external forces and moments (Figure 5.7) reach a balance:

Total Force (F): $F = F_s + F_f$ [5.1]

Force equilibrium: $T \bullet \cos(\theta) = (B - G - W)$ [5.2]

$T \bullet \sin(\theta) = F$ [5.3]

Submergence Force: $F_s = (B \bullet D_b - G \bullet D_g + W \bullet L/2 \bullet \sin(\theta))/D_a$ [5.4]

Friction Force: $F_f = \mu * B$ [5.5]

where:

- T = tension force of the chain
- B = buoyancy force of the pontoon
- G = gravity force of the pontoon
- W = weight of the chains attached at both ends
- L = span cable length
- θ = angle formed by the chain and the vertical
- D_a = vertical distance from the water surface to the attachment point
- A_{Db}= horizontal distance between the point A (Figure 5.7) and the pontoon's center of buoyancy
- D_g = horizontal distance between the point A (Figure 5.7) and the pontoon's center of gravity
- μ =friction factor between the ice and the pontoon surface

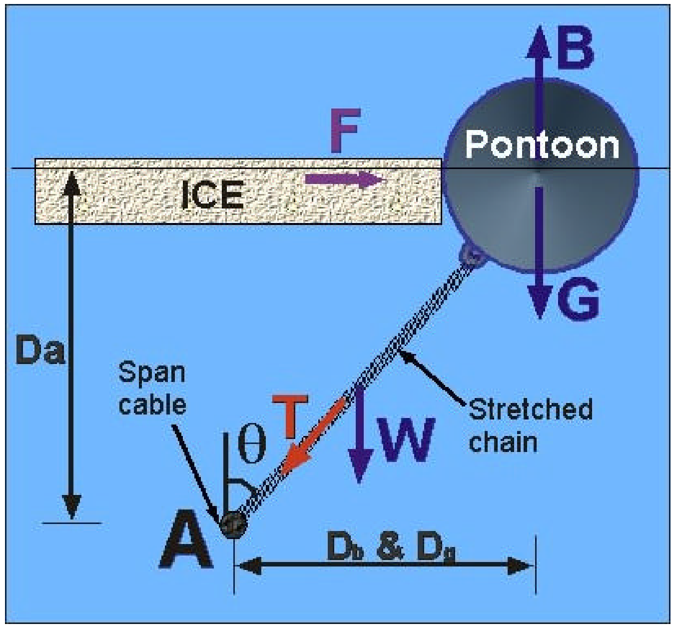


Figure 5.7: The Ice Action on the Pontoon before Submergence

The results of field measurements made in Lake Erie and in Lac St. Pierre in 1994 were used to calibrate the numerical model. Measurements made at the Lake Erie Niagara River Ice Boom in 1997, with 30” (0.76 m) diameter pontoon were used to confirm the model.

5.4 Fixed Boom Installation

Table 5.3 summarizes the design criteria used and the boom design that was produced. Most of the design issues presented in Section 5.3 for the “ship-based deployment” boom are applicable to this case as well.

Further information is presented below regarding key components and issues that differ from those for the ship-based deployment.

1. area to be protected and required boom size – a larger boom would be required (than for a ship-based deployment) because this approach does not have the capability to adjust to shifts in ice movement direction. For this case study, it was assumed that the production island was 400 ft (125 m) in size, and that the boom would need to be 150 ft (50 m) from the edge of the island on all sides to provide sufficient clear space for oil spill equipment to operate.

2. configuration: 2 spans each side @ 410 ft (125 m) each span – cable length per span = 515 ft; span cable diameter = 2 inches for line loads of 588 lb/ft (8.8 kN/m).

3. the number of pontoons in a span is 11 and the spacing 16 ft (4.9 m) as shown in Table 5.3.

4. anchoring – seabed anchors would be used in this case. Two types of anchors have been used in previous boom deployments depending on the bottom conditions:

(i) marine anchors. These are more appropriate for temporary deployment. They can be removed easily and re-deployed somewhere else.

(ii) plow anchors. They are buried few feet under the sea bottom and are expected to sink in and provide the designed pull force – see Figure 5.9

(iii) anchors drilled into rock – see Figure 5.10

Table 5.3: Fixed Installation for Scenario 1a: Design Criteria Used and Boom Design Developed

Inputs	#	ft	m	dia in	dia mm	lb	kg
Pontoon Length		29.848	**9.1**				
No. of Pontoons:	**22**	**657**	**200**				
Cable length		1025	312.5				
Span width		**820**	250.0				
Gap between pontoons		16.0	4.9				
Weight of Span Cable Carried By One Pontoon:				**2**	50.8	396	180
Weight Of Chain Links Carried By One Pontoon:						**200**	91
Other weights (cable clamp, shackles,etc.) for One Pontoon:						**200**	91

English Units

Pipe dia.	Pipe radius	wall thick.	End plate thickness	Length	Steel Vol Pipe	Steel Vol Ends	Steel	Overall Pontoon	Total Weight	Bulk Density	Overall Specific	Net Buoy. Force	Span Net Buoyancy
(in)	(in)	(in)	(in)	(ft)	(in^3)	(in^3)	Wt.(lb)	Vol. (ft^3)	(lb)	lb./ft^3	Gravity	(lb)	(lb)
30''pipe	15	0.38	0.75	29.8	12501	1816	4056	146.44	4852	33.13	0.53	4286	94292

Metric Units

Pipe dia.	Pipe radius	wall thick.	End plate thickness	Length	Steel Vol Pipe	Steel Vol Ends	Steel	Overall Pontoon	Total Weight	Bulk Density	Overall Specific	Net Buoy. Force	Span Net Buoyancy
(mm)	(mm)	(mm)	(mm)	(m)	(m^3)	(m^3)	Wt.(kg)	Vol. (m^3)]	(kg)	(kg/m^3)	Gravity	(kg)	(kg)
762	381	9.5	19	9.1	0.205	0.02975	1844	4.15	2205	532	0.53	1941	42860

Submergence Resistance 2D Model(1)	Theoretical Resistance Corrected	Friction Resistance $\mu = 1.50$	Theoretical Resistance ωιτη Φριχτιον		Pipe dia.	Pipe dia.	Span Net Buoyancy	**Actual Resistance**	Force on cable	Total Force	**Anchor Force Tonnes**	**Anchor Force Tonnes**
(kN/m)	(kN/m)	(kN/m)	(kN/m)		(in)	(mm)	(kN)	**(kN/m)**	kN	Tonnes	**Catenary**	**Chevron**
1.3	1.0	2.5	2.5		30	762	420	**8.8**	2,207	225	**113**	**75**

(1) the calculated submergence resistance for the pontoon size noted in 2 dimensions.

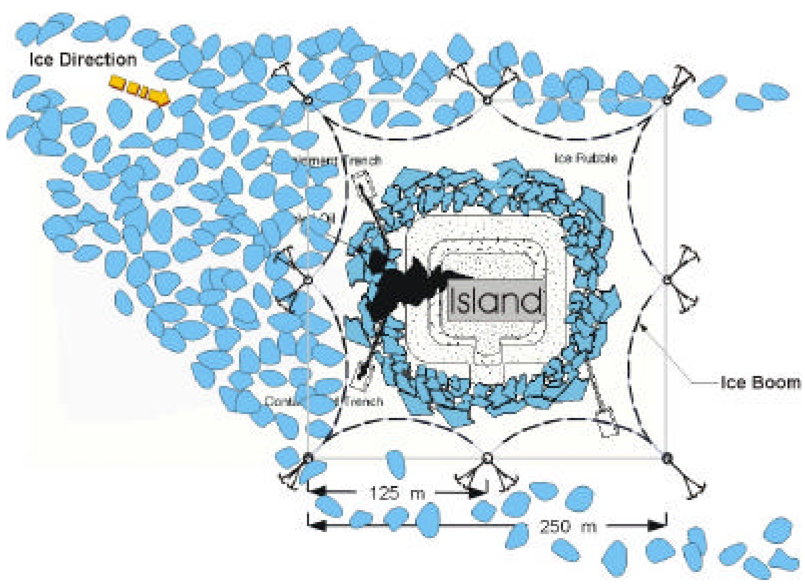


Figure 5.8: Fixed Boom Installation

Figure 5.9: Anchoring In Sandy Silt

Figure 5.10: Anchor Used for Rock Bottoms

The availability of the ice boom buoys at about 100 to 200 m distance apart will provide anchoring points for an oil-spill containment boom (or fireproof booms) to be deployed downstream of the ice boom (as described in scenarios 2 and possibly 5). These buoys can be easily equipped with a quick connect/disconnect mechanism, available from most oil-spill containment boom suppliers and manufacturers. The quick disconnect makes the boom easy to deploy in case of emergency with less risk of an oil slick seeping outside the terminal area.

6 REQUIRED SHIP PERFORMANCE

The required ship performance depends on the type of operation. This is investigated in a preliminary manner for the following types of operations:

(a) ships used in a dynamic mode to hold the boom on location;

(b) ships used to tow the boom to the site; and,

(c) ships used to maneuver the boom at the spill site.

6.1 Dynamic Positioning: Required Ship Bollard Thrust

In this case, the boom would be held on station by two to three supply vessels or icebreakers operating under their own power, as illustrated in Figure 6.1. This arrangement has the advantage that the boom's orientation can easily be changed should the ice drift direction shift (e.g., in response to a shift in wind direction).

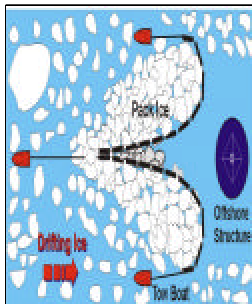


Figure 6.1: Example of Ship Maneuvering for Maintaining the Ice Boom in Position

The success of this operation will depend greatly on the powering characteristics of the ship, and the experience of the ship captain in maneuvering in similar situations. The ship bow and its hull geometry are less important for this application (where the ice concentration is less than 7/10ths) because the ship resistance in broken ice is relatively small when compared with the total load on the ice boom. The ship could also remain closer to the ice "dead wedge" accumulated upstream of the ice boom where the ice movement is negligible.

Because the vessels would be operated at low to nil speed in this case, they would be in close to a bollard condition. Table 6.1 lists the bollard thrust for several available vessels on the North Slope, and other ice breaking ships used by the US and Canadian Coast Guards.

The pull required on the ends of the ice boom depends on the load on the boom that is controlled by the drag and ice forces on it (Section 4). The operating limits are shown in Figure 6.2 for the largest vessels on the North Slope, which are clearly of most interest for this project because they offer the fastest response capability in a spill situation.

Table 6.1: Bollard Thrust of Various Vessels and Their Stationkeeping Capabilities With the Boom

Icebreaker Name	Bollard Thrust (lb)	Boom width (ft)	Allowable Line Load for two ships (lb/ft)	Boom width (ft)	Allowable Line Load for two ships (lb/ft)	Boom width (ft)	Allowable Line Load for two ships (lb/ft)
US Icebreakers							
Polar Class	1005400	300	6703	600	3351	1200	1676
Mackinaw	206800	300	1379	600	689	1200	345
Juniper	125400	300	836	600	418	1200	209
Bay class	48400	300	323	600	161	1200	81
Canadian Icebreakers							
Louis St. Laurent	444400	300	2963	600	1481	1200	741
Terry Fox	418000	300	2787	600	1393	1200	697
Henry Larsen	264000	300	1760	600	880	1200	440
R-Class	253000	300	1687	600	843	1200	422
Type 1100	143000	300	953	600	477	1200	238
Type 1050	171600	300	1144	600	572	1200	286
J.E Bernier	88000	300	587	600	293	1200	147
Sr. H. Gilbert	88000	300	587	600	293	1200	147
Griffon	88000	300	587	600	293	1200	147

Available Tugs in the area	Bollard Thrust (lb)	Boom width (ft)	Allowable Line Load for two ships (lb/ft)	Boom width (ft)	Allowable Line Load for two ships (lb/ft)	Boom width (ft)	Allowable Line Load for two ships (lb/ft)
Pt. Barrow	47000	300	313	600	157	1200	78
Pt. Thompson	47000	300	313	600	157	1200	78
Arctic Bear	51000	300	340	600	170	1200	85
Sag River	22000	300	147	600	73	1200	37
Toolike River	22000	300	147	600	73	1200	37
Kavik River	22000	300	147	600	73	1200	37
Arctic Tern	20000	300	133	600	67	1200	33

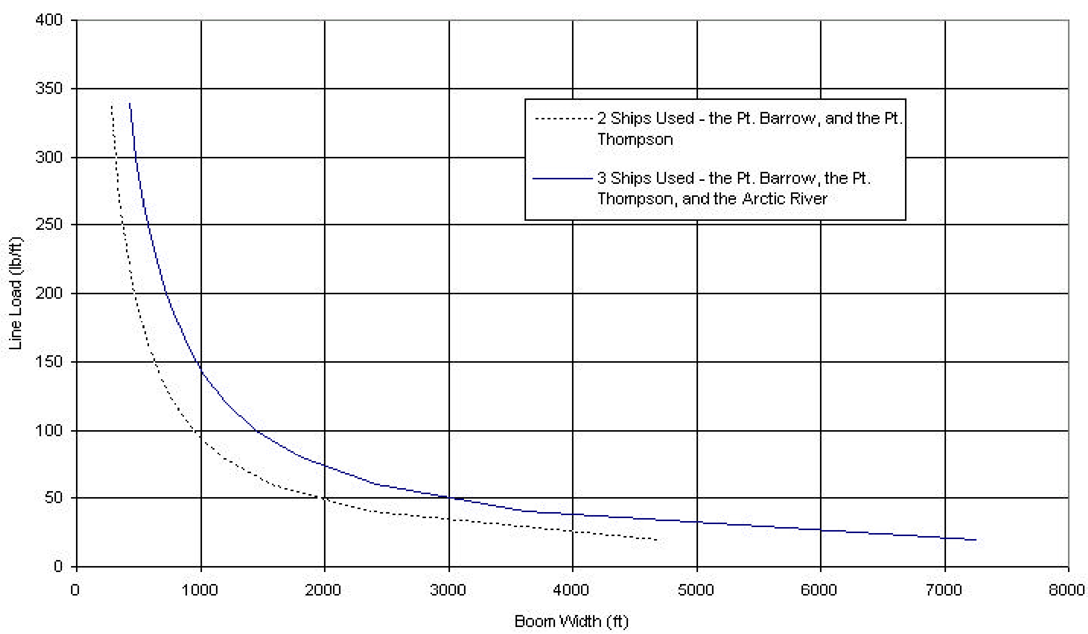


Figure 6.2: Operating Limits for the Largest Vessels on the North Slope

The stationkeeping capabilities of the three largest vessels on the North Slope for boom deployments are further investigated in Table 6.2.

Table 6.2: Stationkeeping Capabilities of the Largest Vessels on the North Slope for Boom Deployments

Pack Ice Concentration and Maximum Line Load for Range of Inputs Considered (Section 4)	Type of Deployment 3 Ships Used – the Pt. Barrow, the Pt. Thompson, and the Arctic River	Type of Deployment 2 Ships Used – the Pt. Barrow and the Pt. Thompson
30 % ; 115 lb/ft (1.7 kN/m)	Maximum Boom Width Allowed: 1260 ft	Maximum Boom Width Allowed: 820 ft
50 % ; 215 lb/ ft (3.1 kN/m)	Maximum Boom Width Allowed: 670 ft	Maximum Boom Width Allowed: 440 ft
70 % ; 680 lb/ft (9.9 kN/m)	Maximum Boom Width Allowed: 210 ft	Maximum Boom Width Allowed: 140 ft

It is clear that the available vessels on the North Slope would provide adequate stationkeeping capabilities for a useful range of boom widths in ice concentrations of 30% and 50%.

The allowable boom width in 70% ice concentration is much lower because the ice loads are increased significantly. This shows that the available vessels on the North Slope would have limited capabilities for keeping the boom on station in this ice concentration. Larger vessels, such as icebreakers would be required in this case.

6.2 Ship Transit to the Spill Site and Maneuvering at the Spill Site

The power required to tow the ice boom in ice-covered waters depends on the ice conditions and the ice boom length. Because the boom will be most applicable for ice concentrations of 50% or less (with the available vessels on the North Slope – Section 6.1), the ice resistance is expected to be relatively low relative to the main requirement (i.e., maintaining station at the spill site). Furthermore, it is expected that the boom would be streamed from the ship(s) that would further reduce towing requirements.

It is recognized that a situation may arise where the boom may need to be towed through more severe ice conditions to reach the spill site. This has not been investigated here because a wide range of cases is possible, and this was beyond the scope of the project. This would need to be evaluated on a case-by-case basis.

In most cases, manoeuvring at the spill site is expected to be feasible with the available vessels on the North Slope as again, the stationkeeping requirements will generally exceed those for manoeuvring. However, again, a wide range of cases are possible, and extreme situations, such as a local pack ice intrusion which temporarily brings a large amount of ice into the spill site, would impose more severe requirements. This would need to be evaluated on a case-by-case basis.

6.3 Summary

The available vessels have been investigated in a preliminary manner. For pack ice concentrations less than about 50%, the largest vessels presently located on the North Slope would be capable of keeping the boom on station for a wide range of useful cases (e.g., 2 or 3-ship deployments, boom widths, ice thicknesses, wind and current speeds).

At higher pack ice concentrations, the stationkeeping capabilities of the vessels would be reduced. Deployments with the available vessels on the North Slope would likely require that the boom width be reduced. Vessels with higher power, such as icebreakers, would be required to provide a wide operating envelope.

Transit to and from the site will not likely impose the design requirement as these loads (in ice concentrations of less than 50%) are expected to be less than those during stationkeeping. The same comment applies regarding manoeuvring at the spill site.

Although more severe cases could arise, they are expected to occur relatively infrequently. These would need to be evaluated on a case-by-case basis, and have not been considered here because this is beyond the scope of the project.

7 CONCLUSIONS

Improved ice boom technology has been developed and used successfully at several locations. Ice booms have the potential to aid or extend oil spill cleanup capabilities in broken ice in a number of ways, such as:

(a) preventing ice ingress into the spill area, thereby providing an ice-free area where conventional oil spill equipment can operate; and,

(b) providing a means to assist in separating the oil from the ice.

Ice booms have the potential to assist in many of the scenarios defined in the Alaska Clean Seas Technical Manual.

Ice booms, in combination with the available support vessels on the North Slope, are expected to be applicable to oil cleanup in moderate broken ice conditions of up to about 50%. Booms are also expected to be applicable for some cases in higher ice concentrations of up to 70%. However, larger vessels with more power such as icebreakers would be required for a wide operating envelope.

Prototype tests should be carried out in the Alaskan Beaufort Sea as the next step in advancing this technology for reliable usage in oil spill cleanup situations in broken ice in the Arctic.

8 RECOMMENDATIONS

8.1 Issues Requiring Further Investigation

While the results of this investigation are promising, a number of issues require further investigation before definitive assessments can be made. The most important issues are considered to be:

(a) ice interactions with the boom – more information is needed to confirm the boom's performance in severe ice conditions such as ice ridges, and large floes which may drift into it.

The amount of ice infill that occurs behind the boom during pack ice movements is another issue that warrants further investigation. Ice pieces deflected along the length of the ice wedge are expected to eventually infill behind the boom. This problem will be exacerbated by any pressure in the ice, although it is expected to occur even without pressure. As a result, the ice cover is expected to be restored eventually to the upstream concentration at some distance behind the boom.

(b) the ability to operate the boom using support vessels – testing is required to define capabilities such as the ability to maneuver the boom, to keep it on station, and to tow it to the site. Operational strategies need to be developed for possibilities such as the drift of a solitary large floe that may force the vessels to disconnect or to "collapse" the boom so that the floe(s) can pass.

(c) operational envelope – only a preliminary assessment was possible in this project, partly because a wide range of cases are possible and many assumptions would be required to evaluate them. This should be followed up with more detailed analyses, in combination with field testing which is necessary to move the technology forward for this application.

It is believed that quite conservative assumptions were made in this project in establishing the loads on the boom, particularly with respect to the under-ice currents at the boom, and their colinearity with the winds. This was necessary because very little data re available for this case. Field measurements would be valuable to improve the estimates made here.

The effect of local high concentrations of ice should be investigated. "Strips and patches" of ice are known to occur and they have the potential to over-run the boom even though the boom might be capable of controlling the prevailing ice, on average.

8.2 Recommendations

A field deployment should be conducted offshore of Prudhoe Bay using a boom of limited size. A boom with two 500 ft (150 m) spans should be built and deployed using the available support vessels in the chevron and catenary configurations.

This work should be accompanied with numerical analyses that build upon the results of the field tests and the work done here.

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[12] Loset, S., and Timco, G.W., 1992, "Laboratory Testing of a Flexible Boom for Ice Management", The American Society of Mechanical Engineers, 11th International OMAE Conference.

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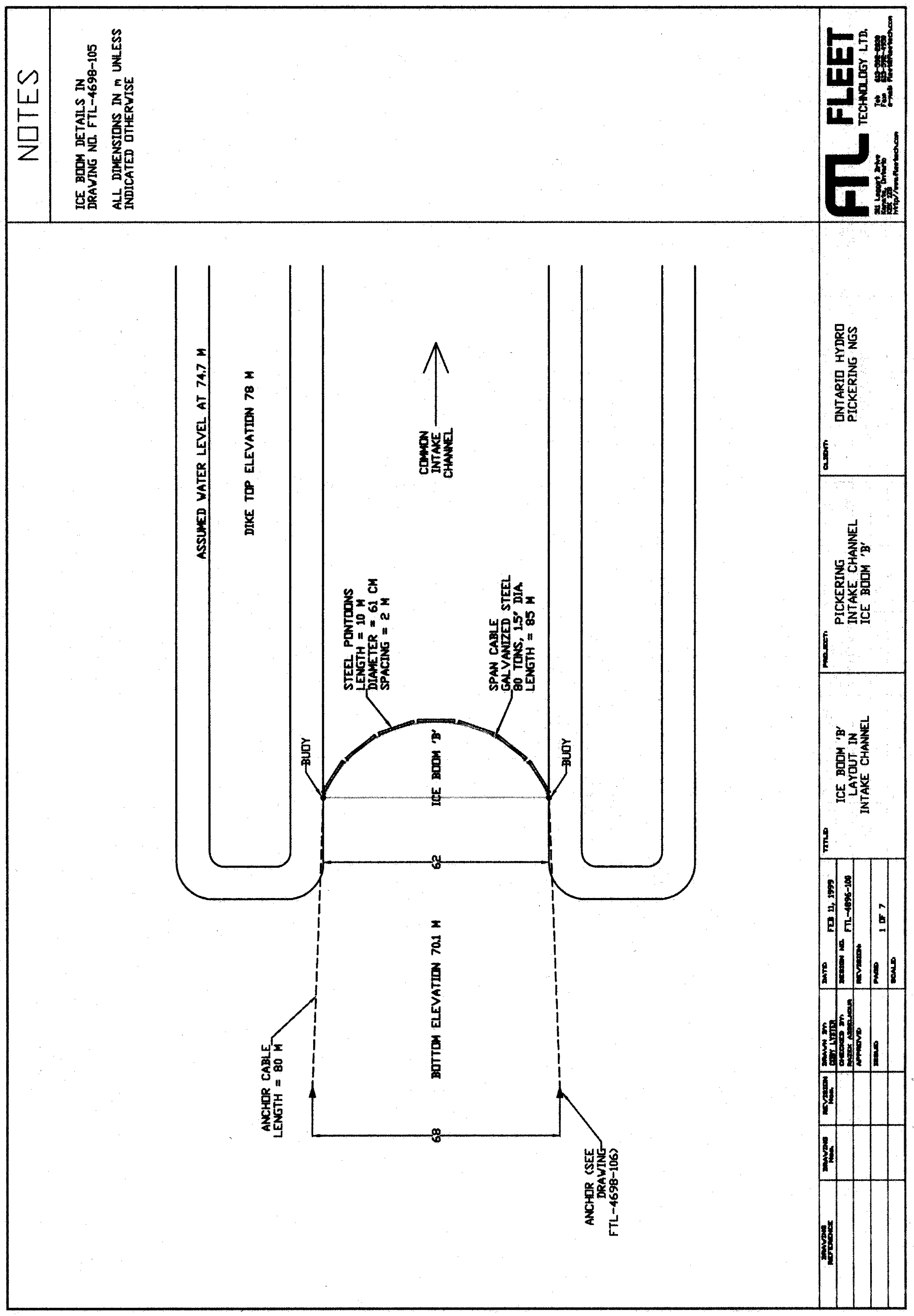
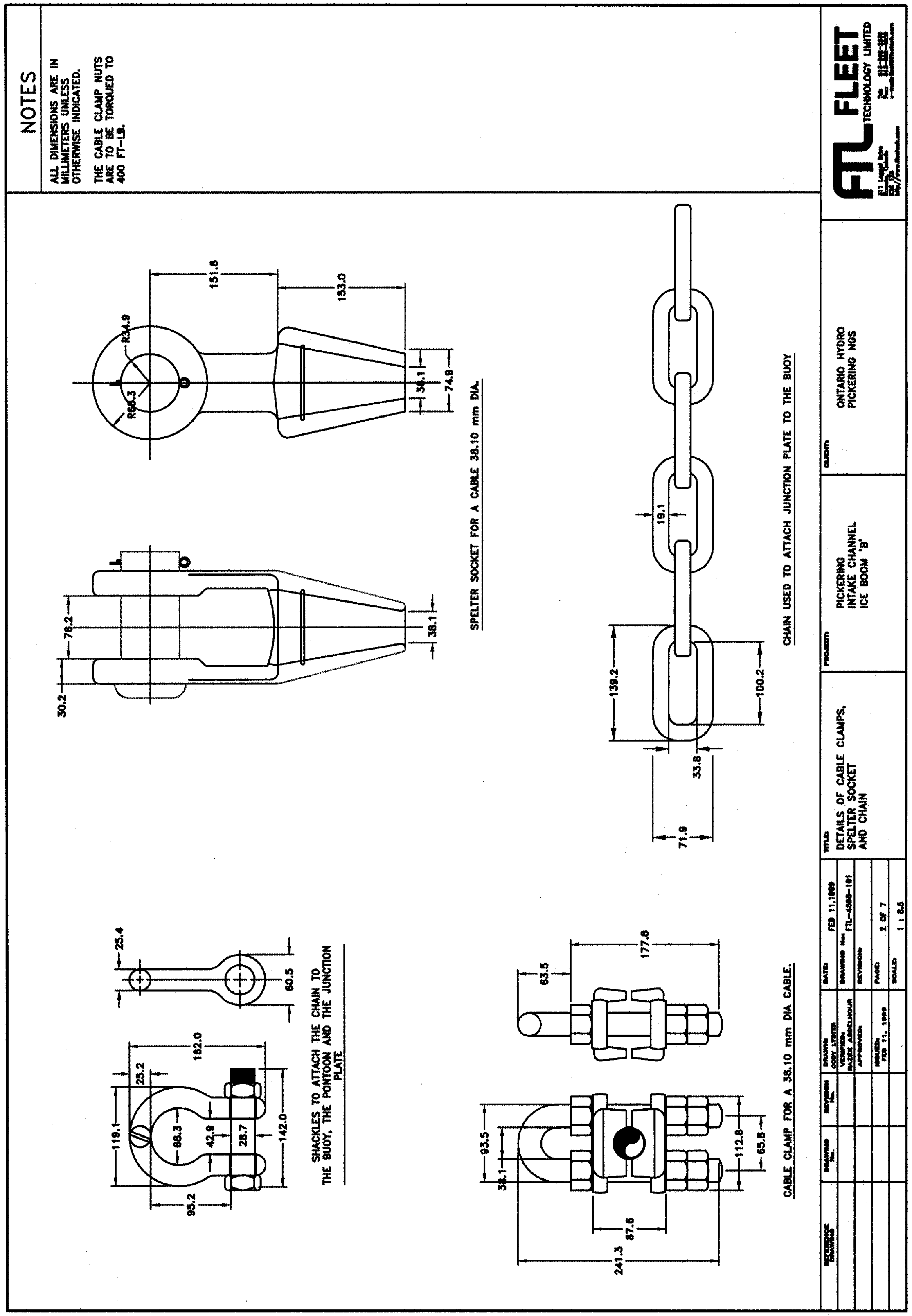
[14] S.L. Ross & Associates, D.F. Dickins & Associates, and Vaudrey & Associates, 1998, Evaluation of Cleanup Capabilities for Large Blowout Spills in the Alaskan Beaufort Sea During Large Periods of Broken Ice, contractor report submitted to the United States Department of the Interior.

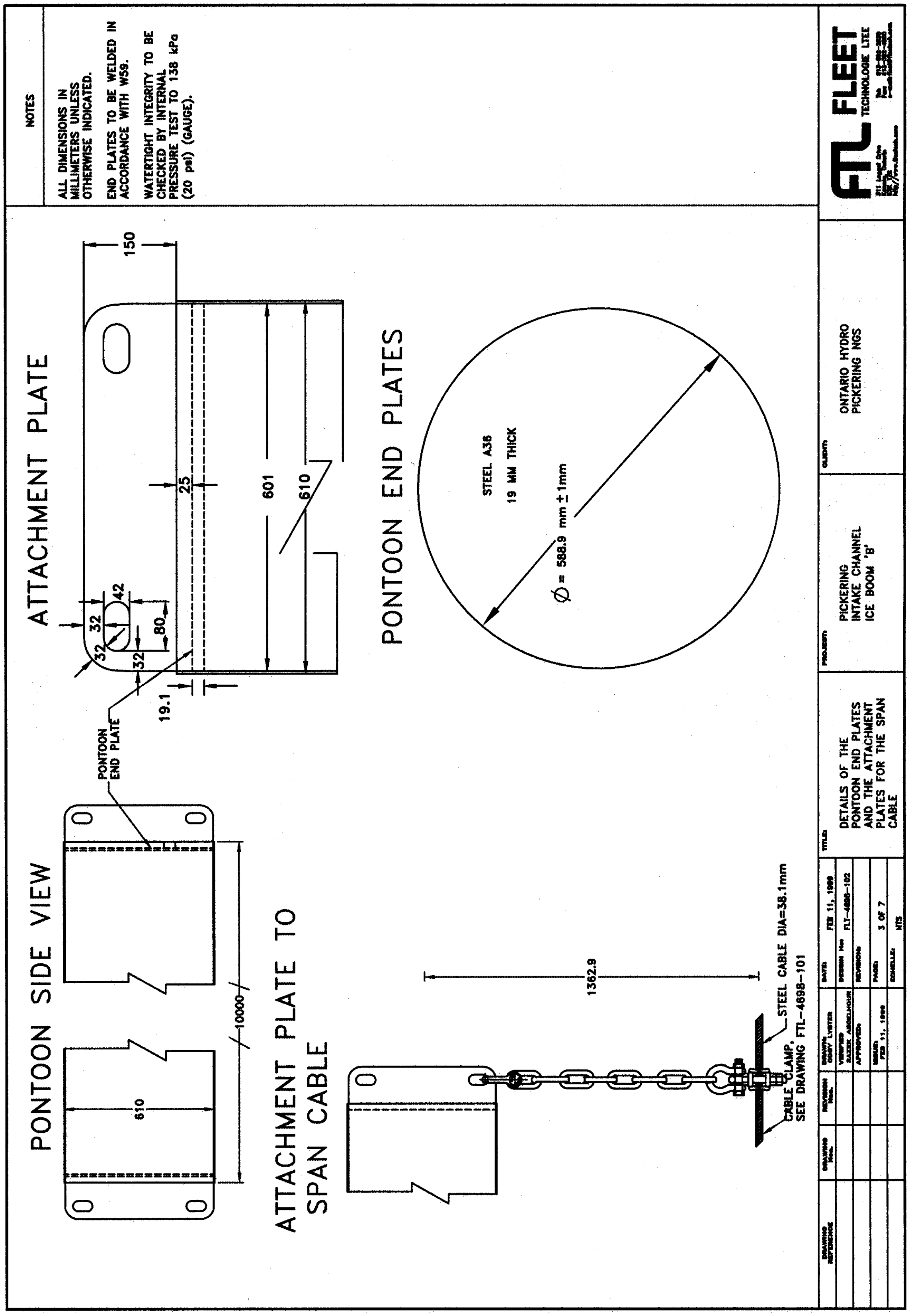
[15] Wright, B., 1999, Evaluation of Full Scale Data for Moored Vessel Station-Keeping in Pack Ice, PERD/CHC Report 26-200.

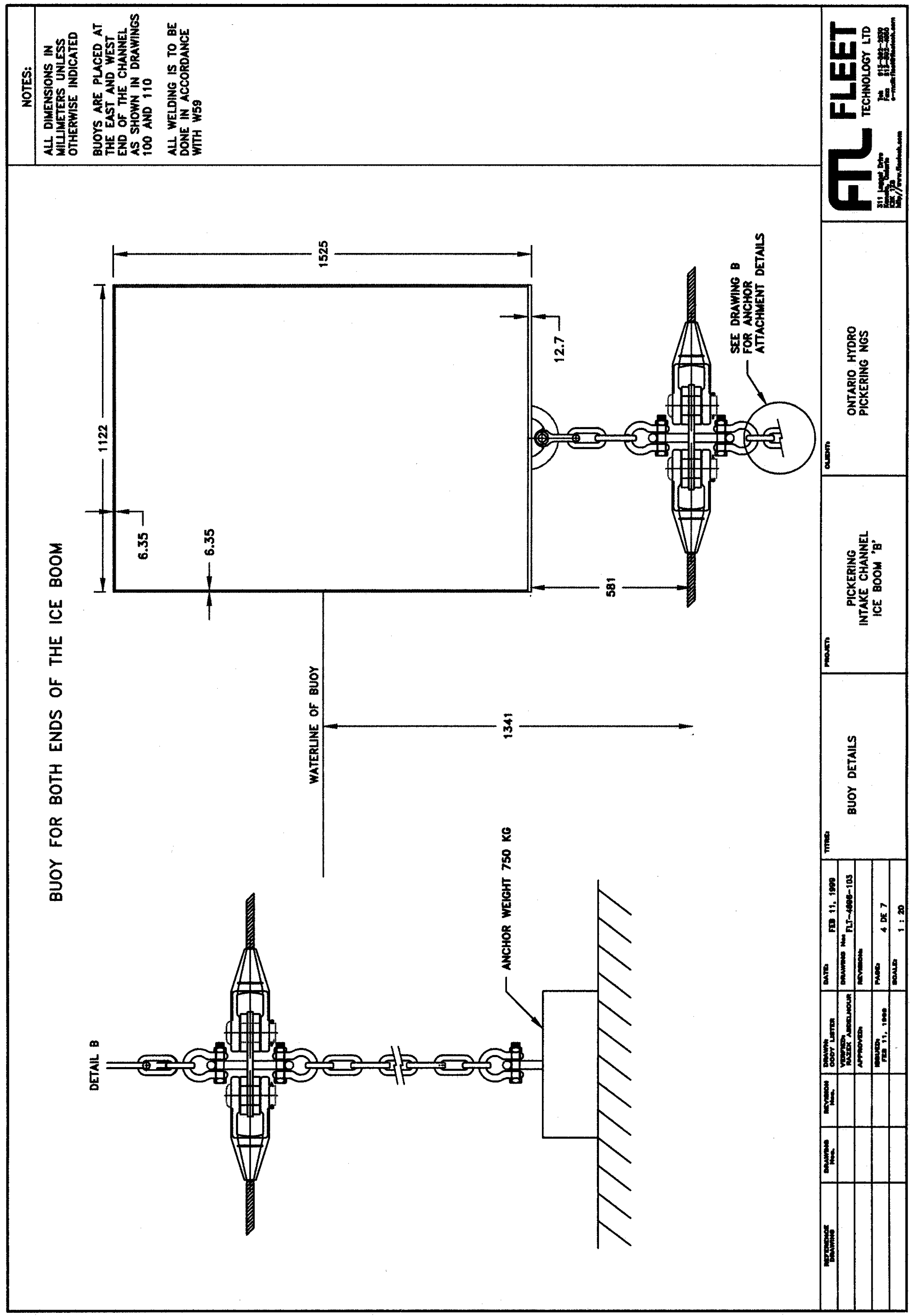
APPENDIX A

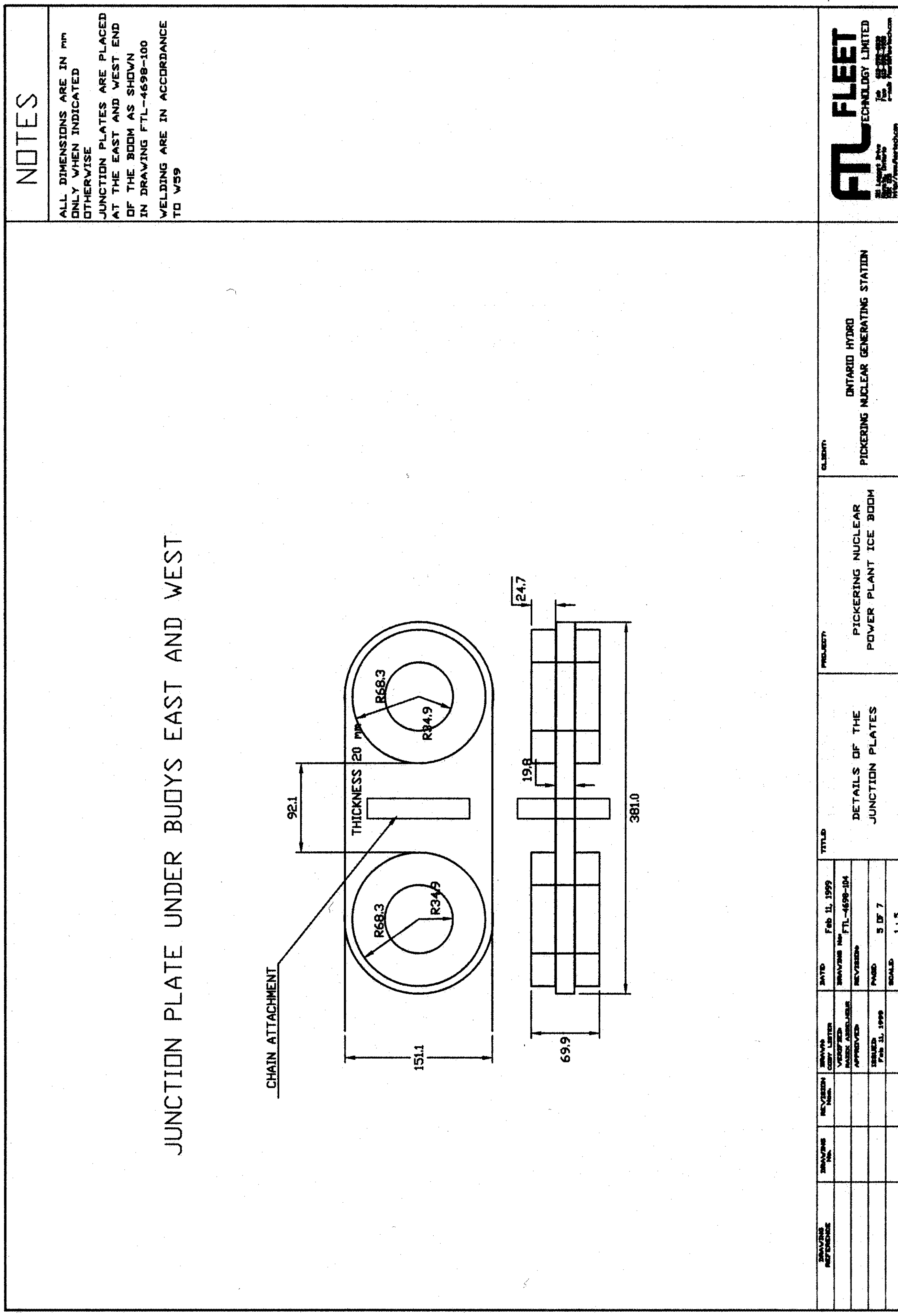
TYPICAL DESIGN DRAWINGS FOR AN ICE BOOM

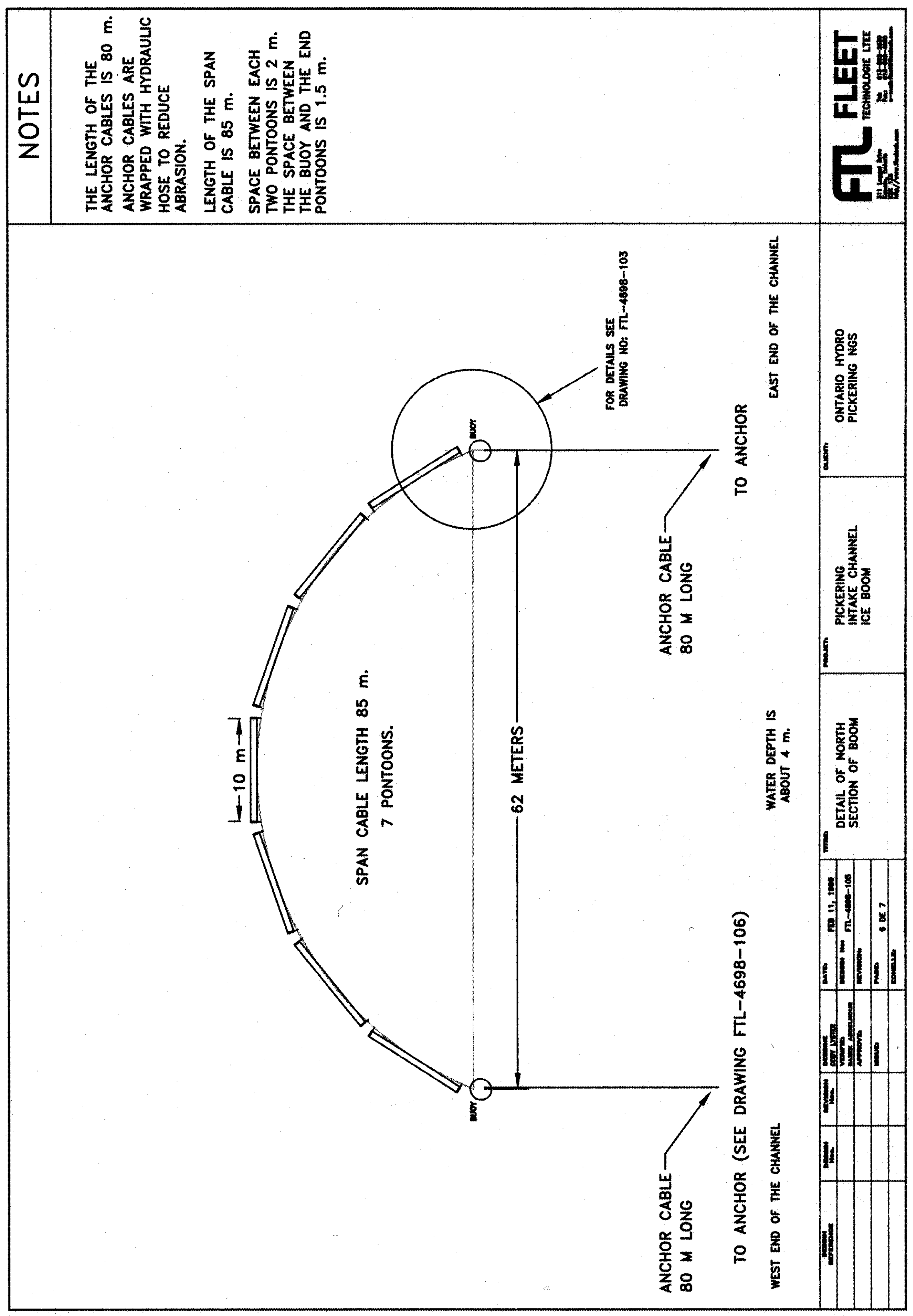

NOTES
ICE BOOM DETAILS IN DRAWING NO. FTL-4698-105
ALL DIMENSIONS IN m UNLESS INDICATED OTHERWISE
ASSUMED WATER LEVEL AT 74.7 M
DIKE TOP ELEVATION 78 M
COMMON INTAKE CHANNEL
STEEL PONTOONS
LENGTH = 10 M
DIAMETER = 61 CM
SPACING = 2 M
SPAN CABLE
GALVANIZED STEEL
80 TONS, 1.5" DIA.
LENGTH = 85 M
BUOY
BUOY
ICE BOOM 'B'
62
BOTTOM ELEVATION 70.1 M
ANCHOR CABLE
LENGTH = 80 M
68
ANCHOR (SEE DRAWING FTL-4698-106)
ONTARIO HYDRO
PICKERING NGS
PICKERING
INTAKE CHANNEL
ICE BOOM 'B'
ICE BOOM 'B'
LAYOUT IN
INTAKE CHANNEL
FEB 11, 1999
1 OF 7
FTL FLEET TECHNOLOGY LTD.

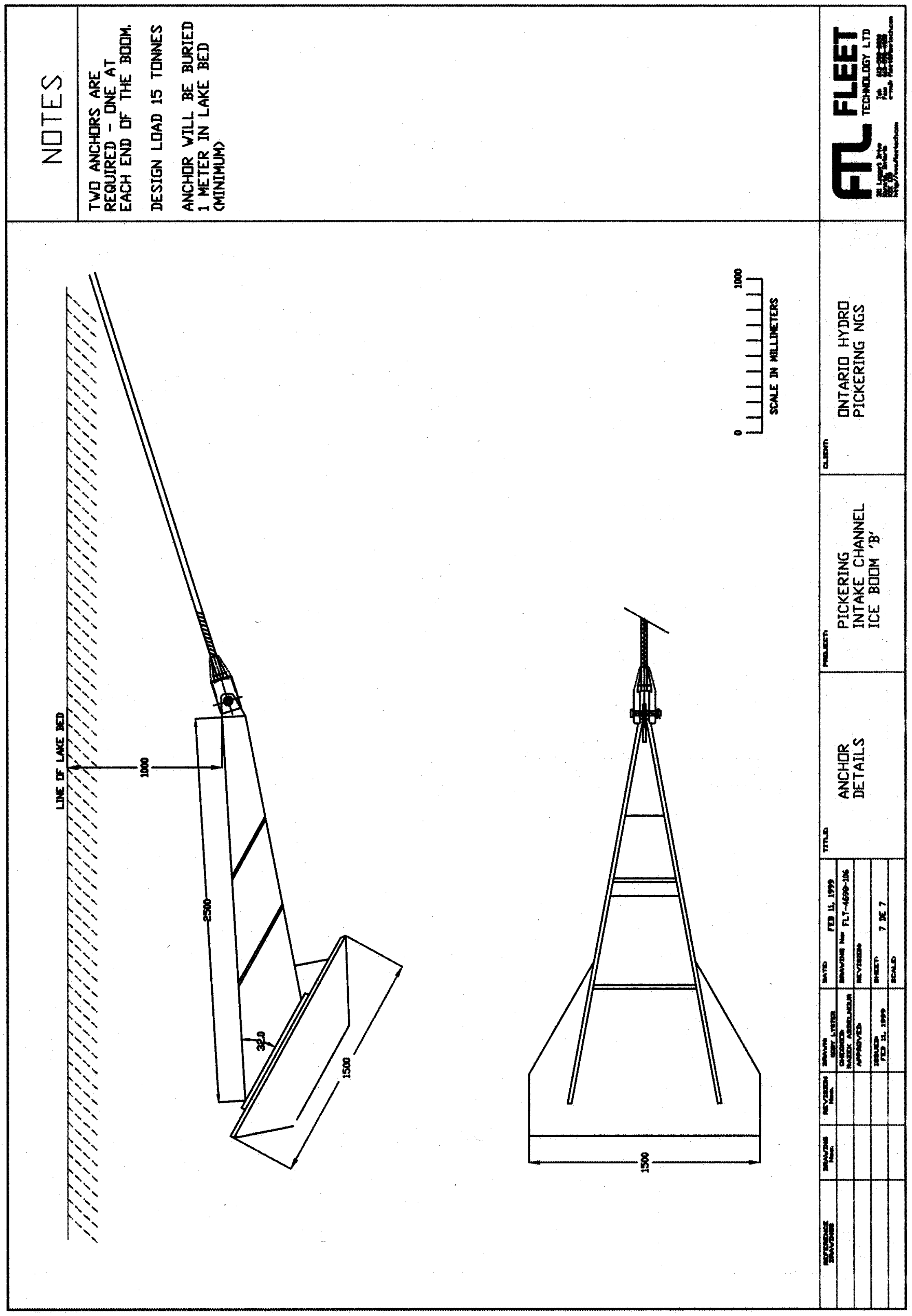

NOTES
ALL DIMENSIONS ARE IN MILLIMETERS UNLESS OTHERWISE INDICATED.
THE CABLE CLAMP NUTS ARE TO BE TORQUED TO 400 FT-LB.
SPELTER SOCKET FOR A CABLE 38.10 mm DIA.
CHAIN USED TO ATTACH JUNCTION PLATE TO THE BUOY
SHACKLES TO ATTACH THE CHAIN TO THE BUOY, THE PONTOON AND THE JUNCTION PLATE
CABLE CLAMP FOR A 38.10 mm DIA CABLE.
DETAILS OF CABLE CLAMPS, SPELTER SOCKET AND CHAIN
PICKERING INTAKE CHANNEL ICE BOOM 'B'
ONTARIO HYDRO PICKERING NGS
FLEET TECHNOLOGY LIMITED


NOTES
ALL DIMENSIONS IN MILLIMETERS UNLESS OTHERWISE INDICATED.
END PLATES TO BE WELDED IN ACCORDANCE WITH W59.
WATERTIGHT INTEGRITY TO BE CHECKED BY INTERNAL PRESSURE TEST TO 138 kPa (20 psi) (GAUGE).
ATTACHMENT PLATE
150
25
601
610
32
32
42
80
32
19.1
PONTOON END PLATE
PONTOON END PLATES
STEEL A36
19 MM THICK
Ø = 588.9 mm ± 1mm
PONTOON SIDE VIEW
610
10000
ATTACHMENT PLATE TO SPAN CABLE
1362.9
STEEL CABLE DIA=38.1mm
CABLE CLAMP, SEE DRAWING FTL-4698-101
DETAILS OF THE PONTOON END PLATES AND THE ATTACHMENT PLATES FOR THE SPAN CABLE
PICKERING INTAKE CHANNEL ICE BOOM 'B'
ONTARIO HYDRO PICKERING NGS
FEB 11, 1999
FLT-4698-102
3 OF 7
NTS
FLEET TECHNOLOGIE LTEE


NOTES:
ALL DIMENSIONS IN MILLIMETERS UNLESS OTHERWISE INDICATED
BUOYS ARE PLACED AT THE EAST AND WEST END OF THE CHANNEL AS SHOWN IN DRAWINGS 100 AND 110
ALL WELDING IS TO BE DONE IN ACCORDANCE WITH W59
BUOY FOR BOTH ENDS OF THE ICE BOOM
1525
1122
12.7
6.35
6.35
581
1341
WATERLINE OF BUOY
SEE DRAWING B FOR ANCHOR ATTACHMENT DETAILS
ANCHOR WEIGHT 750 KG
DETAIL B
FLEET TECHNOLOGY LTD
ONTARIO HYDRO PICKERING NGS
PICKERING INTAKE CHANNEL ICE BOOM 'B'
BUOY DETAILS
FEB 11, 1999
FLT-4898-103
4 DE 7
1 : 20


NOTES
ALL DIMENSIONS ARE IN mm ONLY WHEN INDICATED OTHERWISE
JUNCTION PLATES ARE PLACED AT THE EAST AND WEST END OF THE BOOM AS SHOWN IN DRAWING FTL-4698-100
WELDING ARE IN ACCORDANCE TO W59
JUNCTION PLATE UNDER BUOYS EAST AND WEST
CHAIN ATTACHMENT
THICKNESS 20 mm
92.1
151.1
R68.3
R34.9
69.9
381.0
19.8
24.7
DETAILS OF THE JUNCTION PLATES
PICKERING NUCLEAR POWER PLANT ICE BOOM
ONTARIO HYDRO
PICKERING NUCLEAR GENERATING STATION
Feb 11, 1999
FTL-4698-104
5 OF 7
1 : 5
FLEET TECHNOLOGY LIMITED


NOTES
THE LENGTH OF THE ANCHOR CABLES IS 80 m.
ANCHOR CABLES ARE WRAPPED WITH HYDRAULIC HOSE TO REDUCE ABRASION.
LENGTH OF THE SPAN CABLE IS 85 m.
SPACE BETWEEN EACH TWO PONTOONS IS 2 m. THE SPACE BETWEEN THE BUOY AND THE END PONTOONS IS 1.5 m.
FOR DETAILS SEE DRAWING NO: FTL-4698-103
EAST END OF THE CHANNEL
TO ANCHOR
ANCHOR CABLE 80 M LONG
SPAN CABLE LENGTH 85 m.
7 PONTOONS.
10 m
62 METERS
WATER DEPTH IS ABOUT 4 m.
BUOY
BUOY
ANCHOR CABLE 80 M LONG
TO ANCHOR (SEE DRAWING FTL-4698-106)
WEST END OF THE CHANNEL
FTL FLEET TECHNOLOGIE LTEE
ONTARIO HYDRO PICKERING NGS
PICKERING INTAKE CHANNEL ICE BOOM
DETAIL OF NORTH SECTION OF BOOM
FEB 11, 1999
FTL-4698-105
6 DE 7


NOTES
TWO ANCHORS ARE REQUIRED - ONE AT EACH END OF THE BOOM.
DESIGN LOAD 15 TONNES
ANCHOR WILL BE BURIED 1 METER IN LAKE BED (MINIMUM)
LINE OF LAKE BED
1000
2500
1500
SCALE IN MILLIMETERS
0
1000
ANCHOR DETAILS
PICKERING INTAKE CHANNEL ICE BOOM 'B'
ONTARIO HYDRO PICKERING NGS
FEB 11, 1999
7 OF 7
FLEET TECHNOLOGY LTD

APPENDIX B

DISCUSSION ON THE REPORT BY THE MMS, ALASKA OFFICE

February 13, 2001

Memorandum

To: Razek Abdelnour
From: Joseph Mullin

Subject: MMS Alaska review comments on the draft report entitled: Application of Ice Booms for Oil Spill Cleanup in Ice Infested Waters."

We did not concentrate our review on the engineering aspects. We concentrated on the application aspects as they might pertain to the Alaskan Beaufort Sea. We have addressed the proposed applications in respect to spring and fall conditions and rated each tactic on the basis of our understanding of these conditions and the effectiveness of skimming technology currently available on the North slope. A rating of 1 to 10 was assigned with 10 being the most effective. This is given in tabular form with comments following.

Understanding that in situ burning, while permissible by the On Scene Coordinator (OSC), cannot be used to satisfy the State of Alaska planning standard. We included in situ burning as an application strictly from an operations perspective.

We have included a brief anecdotal description of spring and fall ice conditions upon which our assumptions for relative effectiveness are based. Without going into specific ice terminology, they are generally as follows.

Fall Ice

This is newly forming, building ice at below freezing temperatures. It may be composed of various sized plate's of varying thickness' to several inches in depth, together with slush that is the product of grinding and wave action and newly forming ice crystals. This ice mixture has a tendency to coalesce should any ice force, natural or manmade be applied. None of the skimming systems presently on the North Slope are effective under these conditions.

Spring Ice

This is older ice in above freezing, melting conditions. It may consist of various sized plates of varying thickness' some of which may be several meters in depth. There will be little to no slush ice associated with spring ice so oil may be found between and as a coating rather than accumulated within and part of the ice matrix.

	SPRING ICE		FALL ICE
Prevention of Ice Ingress			
Fig. 3.1 - 1a - Deflection from Offshore Structure – Anchored	8		2
Fig. 3.2 - 1b - Deflection from Offshore Structure – Unanchored	0		2
Fig. 3.2 - 1b – In Situ Burning	5		1
Fig. 3.6 – Offshore Pipeline	8		5
Fig. 3.7 - Spill to Reservoir(Lake)	0		0
Oil/Ice Separation			
Figure 3.3 - 2a – In Situ Burning	6		1
Figure 3.3 - 2b - Batch Spill	4		0
Fig. 3.8 - Ice Drift in River	0		3
Containment of Spilled Oil			
5.2 - Fixed Installation	0		0

Fig. 3.1 - 1a - Deflection from Offshore Structure - Anchored

Spring: Assuming ice boom could be anchored, that the size of the flows would not overcome the boom, and wind direction is relatively constant, it may be possible to skim on the lee side of the island. It may also be possible to manage larger flows with the Bay boats before they encounter the boom. It is assumed that ice will reestablish itself at some distance behind the boom and island but likely at more manageable concentrations so as to allow some collection of oil in that area. The boom and means to deploy it would have to be placed at the island over winter to make this approach feasible. (Northstar is outside of the barrier Is. whereas areas inside are likely to still have shore and bottom fast ice when broken ice conditions might be expected to occur at Northstar).

Fall: The boom itself may be relatively effective in reducing the concentration and size of ice pieces down wind of it. However, with a gap between the boom sections of between 2 and 7 meters smaller flows and slush will infiltrate the protected area to some degree making skimming operations marginal at best.

Fig. 3.2 - 1b - Deflection from Offshore Structure - Unanchored.

Spring: Vessels of a horsepower necessary to deploy would be unable to deploy to Northstar because of the ice fast conditions at West dock.

Fall: The only benefit to boom management by utilizing vessels would be the ability to re-configure as an adaptation to wind change. Otherwise comments for Fig. 3.1 - 1a - Deflection from Offshore Structure - Anchored. **Fall** would apply.

Fig. 3.2 - 1b – In Situ Burning.

Spring: Several variables to considered here. If the spill were current (fresh enough to ignite) the problem would be to collect sufficient quantities of oil at a distance from the island where safe burning could be allowed. As spring ice is larger and heavier, and the ice boom is designed to depress under heavy loads, there may be ice in significant quantities or size to restrict collection in the fireboom that is not constructed for sufficient load strength to accommodate this. It remains a possibility on a case by case basis however depending on size and concentration of ice floes.

Fall: As in Fig. 3.1 - 1a - Deflection from Offshore Structure - Anchored. **Fall,** with a gap between the boom sections of between 2 and 7 meters smaller flows and slush will infiltrate the protected area and become mixed with the oil to form a more or less coalescent combination. S. L. Ross reports that oil mixed with this type of ice under freezing conditions is a poor candidate for burning.

Figure 3.3 - 2a – In Situ Burning.

Spring: Success with this tactic would depend on several factors as discussed in Fig. 3.2 - 1b – In Situ Burning. **Spring.** The one additional factor would be the ability to evacuate the oil from the ice in large enough quantities at a rapid enough rate to accumulate the necessary thickness for ignition. In addition, the fire boom would be best deployed with vessels in a dynamic configuration rather than anchored as shown. Under this scenario the oil would spread rapidly to equilibrium once it escaped the ice boom and the boom would be proceeding away from the catchment configuration at a rate of .3 knot in order to release the oil. Hence the distance would become continually greater allowing for maximum spread which is exactly what we're attempting to avoid. Since this evacuation effect cannot be tested with real oil in Alaska waters as would be necessary to gather the proper data; this test might better be done at the OMSETT or similar facility.

Fall: See Fig. 3.2 - 1b **–** In Situ Burning. **Fall**

Figure 3.3 - 2b - Batch Spill

Spring: This was rated at a 4 because we felt it would be limited to smaller sized spills. In a catenary configuration a limited finite amount of ice and therefore oil could be collected. In the deflection configuration it is assumed that as the ice progresses to the outer end of the boom while the oil would travel *through* the openings. The ice might also occur in somewhat lesser concentrations in the deflection configuration because it is in motion.

In this configuration, no matter what the starting concentration of ice it will accumulate to 100% relatively rapidly. Additional ice and oil would then shear off the ice wedge. This would not be efficient in a large spill. Also, if used the catchment boom would need to be in a dynamic configuration rather than anchored similar to the Fig. 3.2 - 1b – In Situ Burning. **Spring** discussion**.**

Fall: Given the preceding discussion of fall ice conditions we would be making a snow cone.

Fig. 3.6 - Offshore Pipeline.

Spring: This has some possibilities since the boom could be placed in closer proximity to the source therefore the skimming could also take place closer to the boom allowing for more of an open water type operation. This assumes that both the boom and the vessels to deploy it would be available. These would most likely be available only if they were stationed at Northstar through the winter and could physically be deployed from there. It's also the only practical tactic we've seen for this scenario that has a reasonable chance of success. The problem a success would pose however would be tankage and transportation of the collected oil.

Fall: As in the spring scenario it's the best option we've seen but there are always the same skimming limitations. One possible tactic might be to collect the oil -in-ice mixture, tear drop it to allow it to freeze in place and ice mine it when pack ice thickness allows. Even if the force in the ice pack squeezes the oil out as the pack forms it should stay in a relatively confined area.

Fig. 3.7 - Spill to Reservoir (Lake).

There are no lakes on the slope large enough that spill response can not be accomplished by existing conventional means.

Fig. 3.8 - Ice Drift in River

Spring: Water depths in North Slope rivers are likely to shallow for ice boom to be effective. In the spring ice is likely to deflect underneath the boom.

Fall: The only application we can envision would be an aid in building an ice dam which would seem to exacerbate the problem because there would still be a good rate of flow under or around the dam.

5.2 - Fixed Installation

We see no benefit to this tactic. It is impractical for offshore installations in the Beaufort.

RECOMMENDATIONS

We would agree that some deployment of ice boom in the Alaskan Beaufort Sea would be beneficial to determine it's best use.

It has possibilities when used in the deflection configuration and may have some applications. Rigorous testing is required, under the ice conditions encountered in the Beaufort Sea, to determine the extent and duration of open water this boom might produce.

It is recommended that additional testing in moving water (.3 knots) with oil and ice be performed to determine the rate at which oil is evacuated from the ice through the boom. This data would be useful in determining feasibility in any configuration where the intent is to capture oil when the boom is utilized in this tactical fashion.

This would best be done at OMSETT or a similar facility. If there is no means to refrigerate the test facility fall ice could not be approximated, only spring. This would be most appropriate in any case given the previous discussion.