Cook Inlet Mooring Study

Berth Design, Moorage Arrangements, and Port Management

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“Support for safe and secure ships, cleaner oceans, effective emergency response.”
Cover picture: LNG ship Polar Eagle moored at the ConocoPhillips dock, Nikiski, Alaska. This photo was provided courtesy of ConocoPhillips Alaska, Inc. and cannot be otherwise released or published without the express written consent of ConocoPhillips Alaska.

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Executive Summary

Conduct of the study

Cook Inlet Regional Citizens’ Advisory Council (CIRCAC) commissioned this study to identify additional changes in berth design, mooring arrangements, or port management that may reduce the risk of breakaways for vessels moored at Cook Inlet facilities. To meet this objective, this paper:

- Reviews general industry standards for berth design.
- Consolidates and summarizes the mooring line tending and maintenance practices from major reference sources with particular regard for factors that induce excessive mooring line strain.
- Reviews berth management practices at many of the international cold weather ports.
- Summarizes, and in some cases comments on, the conclusions of the various investigations into the February 2, 2006 M/V Seabulk Pride breakaway.
- Highlights recent changes to the Cook Inlet guidelines for operating in ice.
- Compares and contrasts two berths in Nikiski: ConocoPhillips gas terminal and the Kenai Pipeline (KPL) oil terminal.

Conclusions and recommendations

1. Berths in Cook Inlet are substantially designed and built to withstand the harsh wintertime environments. Many of the Cook Inlet offshore and shoreside structures are the pioneers of cold water design. The hundreds of platform and berth-years of experience without a major failure speak to the adequacy of Cook Inlet structures.

2. Of the many northern latitude international ports reviewed, Nikiski terminals were the only oil and gas terminals that address ice hazards at berth. Other ports address high winds and ice navigation.

3. Other northern latitude ports and berths have two or more tugs immediately available. Of all the northern ports surveyed, only Nikiski conducts operations without two or more tugs. A formal needs analysis for tugs at Nikiski should be conducted.

4. Sullom Voe Harbour, a major North Sea oil and gas terminal in the Shetland Islands, requires a formal mooring audit for each ship calling at the terminal. This practice should be considered for Cook Inlet oil and gas berths.
5. The Cook Inlet Special Operating Procedures for Ice Conditions in Cook Inlet are helpful and supportive of safe navigation in ice.

6. Mooring lines are always the weakest component of any mooring system. Spring lines are usually the most susceptible to failure. That was the case with the M/V Seabulk Pride breakaway and with many other incidents at other berths.

7. One of the root causes of the M/V Seabulk Pride breakaway of February 2006 was poor mooring line tending and maintenance. Strong tidal currents contributed to the mooring line failure and exacerbated its consequences. The role of ice forces in the breakaway, if any, was not determined.

8. If ice floes or ice floe ‘clusters’ of the size used in the London Offshore Consultants calculations (350 m or more in diameter) are common in Cook Inlet, then berthed vessels can be at risk during the ice months and at any time during the tide cycles. As of March 2007, there was no definitive data on ice floe size in Cook Inlet. The size, thickness, and frequency of large ice floes in Cook Inlet should be studied. The recent initiative by CIRCAC, where a network of marine operators and facilities are networked to track ice movement in upper Cook Inlet, should include observations on ice floe size.

9. As of February 2007, both ConocoPhillips gas berth and KPL oil berth are designed and operated in a manner that meets or exceeds common industry best practice for berthing tank ships. The absence of two or more tugs for berthing and standby, however, is noted.

10. There is no completely satisfactory explanation for why vessels moored at the KPL and Agrium occasionally have mooring line failure, while the ConocoPhillips dock does not. It may be that ConocoPhillips, because they employ only two identical ships whose crew have extensive experience in Cook Inlet and working with the facility dock force, have substantially reduced the risk from the ‘human element’.

11. Almost always, the root cause or contributing cause of mooring line failure is poor line tending, poor line maintenance, and/or poor mooring line arrangements. The responsibility for good line tending lies primarily with the ship’s crew and not the terminal’s dock force. Berth design and facility personnel training will not manage or eliminate this risk. Therefore, facilities should consider:

- Implementing a ‘Declaration of Mooring’ (DoM) as recommended by the Coast Guard Seabulk Pride accident investigation report. Similar to a Declaration of Security (DoS) or Declaration of Inspection (DoI), the DoM would include documentation that ship and dock personnel had discussed tide, potential for ice and ice monitoring, emergency alarms and communication, emergency underway procedures, line tending protocols, and safety.

- Conducting a formal ship-specific mooring audit for each ship on the occasion of its first call at the facility. This audit would consist of a checklist of good mooring management practices, many of which are addressed in Section 4 of this study.
1. Introduction

At 5:25 a.m. on February 2, 2006 the Seabulk Pride, a 601-foot double-hull oil cargo tanker, broke free of its moorings at the Cook Inlet port of Nikiski. It drifted north until grounding about a half mile away along the bluff at the East Forelands. Strong tidal currents and possibly ice were main factors in causing the breakaway. The vessel was re-floated without significant oil spillage. However, catastrophe was narrowly averted, given the numerous rocks and reefs in the vicinity. This is not the first instance of vessels being torn from their moorings in Cook Inlet by a combination of wind, tidal currents and ice. Cook Inlet Regional Citizen’s Advisory Council (CIRCAC) commissioned this study to better understand the risks to vessels operating in harsh winter conditions in Cook Inlet. In particular, CIRCAC is interested in whether improvements to mooring systems (structures, equipment and operating practices) can reduce the risk of another breakaway or quickly control the vessel in the event of a breakaway.

In completing this analysis this study moves from the general to the particular. First, I describe the various components of mooring systems and how they are built and managed according to marine industry best practice. The primary focus is on mooring lines, which by design and necessity are the weak links in a vessel mooring system. This general section concludes with an overview of the common causes of mooring line failure. The next component of the study provides an overview of northern latitude ports with environments similar to Cook Inlet. The purpose of this section is to identify common denominators in port operations to highlight practices that may be applicable to Cook Inlet. The remainder of the report focuses on Cook Inlet with a review of the various Seabulk pride breakaway investigations, examination of changes to the Cook Inlet special operating guidelines under ice conditions, and, finally, comparison of the main features of the two present winter moorings at Nikiski, the ConocoPhillips gas tanker berth and the Kenai Pipeline Oil Terminal.

2. Key Terms and Acronyms

**Auxiliary lines:** Here the term auxiliary refers to lines other than winch-mounted mooring lines which are deployed on bitts to provide additional mooring capacity.

**CINSC:** Cook Inlet Navigation Safety Committee. A group of pilots, vessel operators, and facility operators, all with extensive experience operating in extreme Cook Inlet conditions, who advise the Coast Guard Captain of the Port regarding safe shipping in Cook Inlet.

**COTP:** The US Coast Guard Captain of the Port. The Coast Guard official who has, among other responsibilities, the regulatory authority to control the movement of ships or close waterfront facilities when unsafe conditions or security threats exist.
**Displacement:** In essence, the amount of water a vessel displaces when submerged to the draft mark. Expressed in metric tons or cubic meters of water (~1000 kgs) this is an indication of the true weight of the vessel.

**Dolphins, Breasting:** The component of the mooring structure where the ship is fendered up to the dock or wharf. Spring lines and usually breast lines are attached to the breasting dolphins. See Figure 4, Diagram B.

**Dolphins, Mooring:** Typically refers to pile-driven structures for attachment of head, stern and, often, breast lines. Mooring dolphins are often connected to the wharf, dock or breasting dolphins by catwalks. See Figure 1 and Figure 4, Diagram B.

**DWT:** Dead weight tonnes (DWT). The deadweight of a ship is its carrying capacity at a particular draught expressed in tonnes weight. Summer deadweight is the normal reference when describing the ship's size.

**Fairlead:** A chock or other deck device that allows a line to be lead from the winch and over the side of a vessel without entanglement.

**HMPE Mooring Lines:** High-Modulus Polyethylene (HMPE) mooring lines. The fiber materials used in these ropes are much stronger and also stiffer than the conventional rope-making fibers of nylon, polyester, and polypropylene. Examples of such materials are aramid (duPont "Kevlar" and Akzo Nobel "Twaron") and high-modulus polyethylene (HMPE) (Allied "Spectra" and DSM "Dyneema"). Because they are much stiffer, the ropes made of this new class of fibers are called high-modulus fiber ropes.\(^1\) One additional advantage of some HMPE lines is their low density. The SPECTRA© lines used on certain Seabulk tankers calling at the Tesoro KPL moorage in Nikiski will float on the water surface, thus decreasing that possibility that a line will foul the prop of the ship.

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**Hooks, mooring:** When used here, a mooring hook refers to the dock appurtenance to which the ship’s mooring lines are placed. Mooring hooks are quick release thus reducing the number of line handlers needed. See Figure 2.

**Figure 2:** A hook with quick release handle at the ConocoPhillips dock in Nikiski.

Note the two tension monitoring sensors immediately below the forearm of the mooring master.

**Kip:** 1,000 pounds of force. The kip is mainly used by architects and structural engineers in the United States and will appear in design calculations for US berths and moorages. The name comes from combining the words "kilo" and "pound", thus 1,000 pounds. As a unit of force it is sometimes called the kip-force (symbol kipf or klbf) to distinguish it from the unit of mass. In the international maritime community, ‘tonnes’ is used as a shorthand unit of force in describing the strength of mooring lines. See definition of tonnes below.

1 Kip = 1000 foot-pounds = 0.454 tonnes of force  
1 Kip = 224.8 Newtons (N) = 0.22 kN (1000 Newtons)

**LOA:** Length overall of a vessel.

**Minimum Breaking Load (MBL):** The MBL is the rated break strength of a mooring line or wire. It is the smallest load at which a rope or wire will break under factory test conditions. For mooring lines, the MBL is expressed in tonnes, pounds or kilo-Newton (kN).
Newton: The amount of force required to accelerate a mass of one kilogram at a rate of one meter per second squared.

- $1 \text{ N} \approx 0.2248 \text{ pounds-force} \approx 0.10197 \text{ kilogram-force (kp)}$
- $1000 \text{ N} = \text{kN} \approx 224.8 \text{ pounds-force} \approx 1 \text{ tonne} \approx 0.2248 \text{ Kip}$
- $1 \text{ kg-force} \approx 10 \text{ N}$
- $1 \text{ tonne} = 1000 \text{ kg-force} \approx 10,000 \text{ N} \approx 10 \text{ kN} \approx 100 \text{ mN}$

OCIMF: Oil Companies International Marine Forum. A voluntary association of oil companies engaged in marine shipment of crude oil and oil products. OCIMF has over the years published a number of guidelines for ship handling including *Effective Mooring* and *Mooring Equipment Guidelines*. The guidelines within these publications have become industry best-practice and are thus frequently referred to in this paper.

Rope (synthetic) pendants (tails): Attached to the ends of wire rope with shackles, synthetic rope pendants allow line handlers to more easily move the mooring wire. In addition, pendants, because they are more elastic than wire, provide some shock protection from waves, swells, passing ships or other action. See Figure 12 for a picture of rope pendants or tails.

SPECTRA© lines: A brand name for a High-Modulus Polyethylene (HMPE) mooring line that have been used to replace some of the wire lines on ships calling at the Tesoro KPL moorage in Nikiski.

Safe Working Load (SWL): SWL is the maximum strain a mooring line should be subjected to under normal conditions. For mooring lines, the SWL is expressed in tonnes, pounds or kilo-Newtons (kN). OCIMF recommends that the forces on a ship at berth not exceed 55% of the MBL of the lines.2

Tonnes: In international shipping, tonnes may be used precisely as a unit of mass (1000 kilograms or metric ton) or, by convention, a shorthand unit of force. In most of the articles and reports cited in this paper, tonnes will be a unit of mass when referring to the deadweight or fuel/cargo capacity of a vessel or metric-tons of force when referring to the strength of mooring lines and the force exerted on a ship by wind, current, and ice.

- As unit of mass: $1 \text{ tonne} = 1000 \text{ kilograms} = 1 \text{ long ton} = 1 \text{ metric ton} = 2200 \text{ pounds} = 2.2 \text{ tons}$
- As unit of force: $1 \text{ tonne} = 1 \text{ metric-ton of force} = 2200 \text{ foot-pounds} = 2.2 \text{ Kips} \approx 10 \text{ kN}$

Winch: Here, an item of dock or vessel deck equipment used to haul in (heave) or pay out (render) mooring lines.

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**Winch brakes:** Brakes on the winch drum that secure the mooring lines. Winch brakes should have a holding power of at least 60% of the breaking load of the vessel’s mooring lines. Thus, the brake should slip before the mooring line breaks.

**Wire lines:** Steel mooring lines that are much stronger and less elastic than synthetic lines. Wires are the majority of the lines used in mooring tank ships. Wire lines are actually wire ropes that consist of a number of wires turned to form a strand, then several strands are turned to make the rope.

### 3. Sources

Exponent Failure Analysis Consultants, *Non-Destructive Examination of Seabulk Pride Mooring Wires*. Project No. SF36473.000. May 8, 2006


Lloyd’s Register Fairplay Port Guide. [www.portguide.com](http://www.portguide.com)


OCIMF *Mooring Equipment Guidelines*, Witherby & Co., London,

OCIMF, *SHIP MEASUREMENT DEADWEIGHT: OR DISPLACEMENT?* (undated)


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US Coast Guard Sector Anchorage, *Coast Guard Report of Investigation: Grounding of the Tank Vessel SEABULK PRIDE in Cook Inlet February 2nd, 2006*

US Department of Defense Unified Facilities Criteria, *Design: Piers and Wharves*,

US Department of Defense Unified Facilities Criteria, *Design: Moorings*
4. Overview of Industry Standards for Moorage Structures and Arrangements

Mooring structures (docks, piers and wharves), mooring tension members (chain, wire, line) and mooring compression members (fenders and camels) restrain a moored ship against the action of wind, wave, current, and, in the case of Cook Inlet, ice. Under harsh conditions such as those often encountered in Cook Inlet during the winter, environmental forces (wind/current speed and direction, ice) may exceed the holding capacity of the mooring tension members. In other words, mooring lines alone cannot hold a vessel to a berth under the most extreme conditions. Good standard operating practices must be employed. These may include quick release protocols, increased manning and monitoring, assist tugs, and, in some cases, prohibitions on mooring.

This section is not intended to be an exhaustive treatment of design standards for ship moorages or protocols for berth management. It is intended to provide a brief overview of general moorage structures and mooring line arrangements, particularly for tank ships, which will in turn support or augment the descriptions of the moorages for Nikiski as described in a later section. Hopefully, this section is presented in a manner understandable to the non-mariner. Readers who are interested in more technical detail may refer to several sources listed in this paper, including OCIMF Mooring Equipment Guidelines, US Department of Defense Unified Facilities Criteria, Design: Piers and Wharves, and Design: Moorings, and Transport Canada, TERMPOL Review Process (TRP) for Marine Terminals.4

In general:

- The mooring system (lines and line attachment points) is normally designed to withstand a wind of 60 knots plus a current on the beam of 0.75 knots or a current ahead or astern of 3 knots.5
- Berth structures (dolphins, jetties, piers, wharves) are designed to withstand the worst environmental conditions encountered and to handle the full range of vessels the facility is expected to accommodate.
- Berths should be fair or nearly fair (within 10°) of the currents.

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4 The TRP is not a regulatory instrument and its highly specific and technical provisions are not mandatory. The TRP’s criteria, however, are used by Transport Canada Marine Safety in determining the need for making or revising specific regulations, or for implementing special precautionary measures that may affect a ship’s operation within a particular marine terminal system or transshipment site.

4. A. Berth Design Guidelines

Different berths are commonly characterized by the maximum deadweight tonnage (DWT) of the vessel they can accommodate. In reality, whether a berth can accommodate a certain ship depends on several ship parameters, including:

1. Length overall (LOA)
2. Beam
3. Draft (Draught)
4. Air draught (free board)
5. Arrival displacement
6. Maximum/minimum height of manifold or hatch coaming above waterline
7. Maximum trim and minimum draft for berthing and unberthing
8. Maximum longitudinal distance between foremost and aftermost cargo matches (applicable to bulk solid trades)
9. Maximum/minimum distance bow/stern to centre of manifold and maximum/minimum distance ship side rail to manifold
10. Special mooring requirements such as size, number and breaking strength of wires/ropes
11. Parallel length of hull
12. Maximum broadside windage area
13. Minimum SWL of crane/derrick for hose connection

Transport Canada’s TRP recommends that load calculations for berth structural elements should include at a minimum:

- Dead loads of all piping, mechanical equipment, their liquid contents, superstructures and supporting structures.
- Berthing forces exerted by vessels arising from normal fender thrusts and horizontal and vertical frictional shear forces.
- Mooring forces arising from wind, current, ice and wave pressures on largest ships in ballast and full displacement conditions at the extreme operating conditions.
- Seismic forces from any horizontal direction computed for the dead loads and superimposed static loads, as well as seismic loads transmitted through pipeline anchors.
- Temperature loads due to thermal expansion and contraction of the structures including those transmitted through pipeline anchors.
- Wind loads on the structures, superstructures and equipment.
- Wind, wave and ice pressures on components of the structure. Wind and wave forces should be based on a storm loading having average expected recurrence interval of 50 years.
- Live loads of moving vehicles and cranes.

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6 OCIMF, *SHIP MEASUREMENT DEADWEIGHT: OR DISPLACEMENT?* (undated)
7 Section 3.13. Transport Canada, TERMPOL Review Process (TRP) for Marine Terminals. (TP 743 E)
• Earth fill and hydrostatic pressures.
• Each structural component should be proportioned to resist bending and shear in two directions, torsion and axial forces.
• Each structure should be analyzed for combination of permanent loads and transient peak loads.

With regard to docking, mooring arrangements and mooring protocols, Transport Canada recommends that berth designers and terminal managers:

• Determine the upper limits of wind velocity for design ship berthing operations - arrivals and departures.
• Determine the wind velocity which would require the design ship to vacate the berth.
• Determine any other limiting environmental / operational criteria.
• Provision of speed of approach measurement devices and a means of communicating this information to the berthing vessel.
• Ascertain maximum current measurements in the vicinity of the berth and its effect on berthing operations.
• Ascertain tidal range, velocities and directions and the maximum recorded spring tide measurements.
• Ascertain prevailing wind statistics in relation to the directional lie of the berth.
• Consider the effects, if any, of bathymetry in the vicinity of the berth and its approaches, on berthing strategy.
• Consider berth loading and dolphin fendering aspects.
• Consider the use of mooring points, mooring techniques, quick release hooks, and mooring line monitoring systems.
• Determine the method of docking and undocking the design ship and the number of tugs, if required.
• Consider that the safety of the ship and the terminal berth may be threatened by the simultaneous transfer of some bulk cargoes and ship’s stores.

**Summary:** Cook Inlet moorings are generally well designed and constructed to withstand the environment forces encountered. In fact, pioneering studies and designs for off-shore platforms and shore facilities were developed for Cook Inlet and later adopted by the American Petroleum Institute. The hundreds of platform and berth years of experience without a major failure speak to the adequacy of Cook Inlet structures.8

4. B. **Mooring Arrangements**

The elements of good mooring arrangement and management presented here are not comprehensive or complete. They are not intended to be used for moorage design. However, a consideration of these factors is helpful in describing or evaluating Cook Inlet moorage systems in subsequent sections of this paper.

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Transport Canada mooring guidelines and codes for oil terminals\(^9\) has set general berthing and moorage line arrangements for tank ships as seen in Figure 3.

![Diagram A: Breasting Arrangement](image)

**Diagram A: Breasting Arrangement**

\(L_1 = \text{largest design ship}\)

\(L_2 = \text{smallest design ship}\)

Figure 3: Minimum mooring structures and arrangements for tankships under Transport Canada TEMPOL Review Code

Note that the breasting pier or wharf (the portion of the ship that is fendered to the moorage) should not be less than thirty-five percent (35\%) of the overall length of the

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largest design ship and the distance between the inner corners of the breasting faces should not exceed fifty percent (50%) of the overall length of the smallest design ship which the berth is designed to accommodate. The moorage dolphins, where the headlines, stern lines and breast lines are attached should allow for the angles as shown in Diagram B of Figure 3.

Figure 4: Two-inch Teflon fender fitted to the outer face of a breasting dolphin at the Nikiski ConocoPhillips moorage

The primary purpose of fenders are to protect the ship and the moorage from damage while the ship is coming alongside and while the ship moves up and down in relation to the moorage structures due to cargo operations, ballasting, and tide action. Thus, fendering systems must have excellent energy absorbing and load distribution capacity. The Teflon affixed to the wharf faces at the ConocoPhillips and KPL docks are examples of modern fender systems. See Figure 4. I am not aware of any serious ship damage in Cook Inlet due to fender system failure or poor design. The interested reader is referred to an excellent monograph on fender system design available on the Transport Canada website.10

Mooring lines are the weakest component in the network of restraining forces for ships at berth. This is as it should be. Why?

- Because the ship must be able to depart the dock quickly in the event of a fire, explosion, threat of sabotage, severe weather, etc.

10 Transport Canada. www.tc.gc.ca/marinesafety/tp/tp743/Appendix3.htm
• Because the vessel floats – rising and falling with the tide – and the mooring facility does not. Lines allow for this movement.
• Ships vary in size. Berths do not. Lines allow for this flexibility in ship length, draft, and DWT.

Vessels moored at berth move not just horizontally and vertically but in six directions around the center of gravity of the ship. These ‘Six-degrees of freedom’ are shown the Figure 5. Fendering and mooring lines restrain, but should not completely arrest, the movement of the vessel in these six directions.

Design engineers can calculate static forces and moments for moored vessels along each direction. Of particular importance to this paper are the transverse (sway), and longitudinal (surge) forces of current, wind and ice. Figure 3, Diagram B shows that spring lines and breast lines are the primary restraint for surge and sway, respectively. Stern and bow lines do not contribute as much to the overall mooring strength as supposed, primarily because the forces of wind and current are nearly transverse or longitudinal, or in direction of the breast or spring lines. In fact, head and stern lines leading from large ships may have lines of restraint more like breast lines because they are more perpendicular than parallel to the wharf.

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In general:

- Mooring lines should be arranged as symmetrically as possible about the midships point of the ship.
- Breast lines should be orientated as perpendicular as possible to the longitudinal center line of the ship and as far aft and forward as possible.
- Spring lines should be orientated as parallel as possible to the longitudinal centre line of the ship.
- The vertical angle of the mooring lines should be kept to a minimum.
- Generally mooring lines of the same size and material should be used in all leads and if this is not possible all lines in the same service should be of the same size and material.\(^{13}\)

Figure 3 shows the ideal line arrangement under normal conditions.

### 4. C. Safety Factors in Effective Mooring Arrangements

- Ships bitts – Generally, a safety failure factor of 3 times the minimum break strength of the largest line. (US Department of Defense Unified Facilities Criteria (DOD UFC) *Design: Mooring*. Table 3-7)

- Ship Bollards - Generally, a safety failure factor of 3 times the minimum breaking load of the largest line. (DOD UFC *Design: Mooring*. Table 3-7)

- Wire rope – Forces on the line should not exceed 55% of the minimum breaking load.\(^{14}\) (OCIMF *Mooring Equipment Guidelines*)

- Synthetic line - Forces on the line should not exceed 55% of the minimum breaking load.\(^{13}\) (OCIMF *Mooring Equipment Guidelines*)

- Loading arms – Surge (longitudinal) and sway (transverse) should not exceed 3.0 meters for oil tankers or 2.0 meters for gas ships. (DOD UFC *Design: Mooring*. Table 3-8) or the design criteria ‘envelop of movement’ for the specific moorage.

### 4. D. Factors Contributing to Excessive Strain or Slippage on Mooring Lines

- Short lines, which take the greater proportion of the load when vessel movement occurs. (OCIMF *Effective Mooring*. P. 6)

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\(^{13}\) United Kingdom Marine Accident Investigation Board, Havkong

\(^{14}\) DOD UFC *Design: Mooring*. Table 3-7 that forces should be only 1/3 of the MBL.
• Short lines affixed to a wharf hook or bollard substantially below the vessel fairlead (vertical ‘dip’), which will have greatly reduced holding strength. (OCIMF *Effective Mooring*. P. 8) Vertical ‘dip’ is of particular concern for breast and spring lines.

• Mixed wire and synthetic lines leading in the same direction, which may place excessive strain on the least elastic line. Because of the elasticity of the synthetic line (HMPE lines are an exception) the wire may take up to 95% of the extra load, thus effectively reducing the holding strength of the arrangement to one line. (OCIMF *Effective Mooring*. P. 7) This is not to say that elastic pendants should be not be used. See next bullet item.

• Use of wire or HMPE line without tails. Low elasticity lines (wire and HMPE) are subject to shock loads from waves, swells, passing ships or other action. Short synthetic fiber tails, not exceeding 11 meters, provide shock load protection. The synthetic tails should be rated at 125% of the minimum breaking load of the wire or HMPE line. When joining shackles are used, the eyes of the lines should be inspected frequently for wear. (OCIMF *Effective Mooring*. P. 10) See Figure 12.

• Winch brake holding capacity set too high. The brake should be set at about 60% of the MBL of the line, allowing the line to slip before it breaks. (OCIMF *Effective Mooring*. P. 19) Note: Coast Guard investigators have reported the possibility of brake calibration being effected by low ambient temperatures. They suggested that winch brakes be re-calibrated when the ship sails to cold weather, and vice versa.

• Layering and line pile-up in one area of a non-split drum winch, which reduces the brake holding capacity. Brake holding capacity can be reduced by up to a third or more due to layering. (OCIMF *Effective Mooring*. P. 16) This problem can be addressed by using split drum winches (Figure 6) where the tension drum always carries only a single layer of line.

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15 Informal conversation with Lieutenants Ken Phillips and Court Smith, US Coast Guard Sector Anchorage. (28 March 2007) In evaluating a recent incident involving a moored tank ship at the Nikiski, Alaska, KPL dock where a spring line wire began to separate, but not break, before the brake slipped. They speculated that the brake winch might have been out of recalibration due to the sub-zero ambient temperatures at that time in Cook Inlet.
• Self-tensioning winches designed to allow tension loads to be pre-set. Self-tensioning winches at opposite ends of a vessel can actually work against each other, allowing the vessel to ‘walk’ along the dock. This occurs when forces at the bow and stern of the ship are unequal. If the line tension is exceeded at, for example, the bow, the line will pay-out (render). Since the heaving power of the winch is always less than the render, the line may slack, allowing the vessel to surge (walk-back) astern. (OCIMF Effective Mooring. P. 13)

• Leading a wire through an excessive angle, which may cause the wire to break before the brake slips. (OCIMF Effective Mooring. P.31) An acute angle between the brake and the mooring point, such as a bend through a fairlead, increases the holding power of the brake winch. This is the same as a mountain climber bending a rope around a rock or tree to increase the holding strength (brake) of the person holding rope.

• Leaving a winch in gear with power on, which may cause the line to break before the brake slips. The reason is that with the winch gear on the render or ‘pay-out’ load is added to the brake holding capacity. Thus the total holding capacity of the winch may exceed the MBL of the line. The combined render value and brake holding capacity of the winch should be 80% of the MBL of the attached line. (OCIMF Effective Mooring. P. 21)
• Incorrect slacking of lines. This is likely the cause of most line parts. Incorrect slacking can cause the entire mooring load to be transferred suddenly to one line, which may then part. Releasing the brake, rather than powering the winch, to slack the line is one incorrect method.

• Low under keel clearance. A ship’s draft will block water flow, which causes a build up of force with either the increase of current or a reduction in the clearance between keel and the sea bottom. At the Nikiski docks which require 5-foot minimum under keel clearance, a 1 knot current may generate up to 4 times the force of a dock where the under keel clearance is much greater. (OCIMF Effective Mooring. P. 2, Fig 1)

• Pre-tensioned breast lines that are not nearly perpendicular, stern lines that are lead forward, and head lines that are lead aft can transfer force to the spring lines. This was the case in the LPG tanker Havkong break away\textsuperscript{16} in 1993 where subtle changes in mooring line geometry placed excessive loads on the two forward spring lines, causing them to break during a wind squall.

5. International Oil Terminals and Ports of Interest

A major component of this study was to identify international ports with environmental challenges similar to Cook Inlet and to examine safe berth management at these ports.

This survey was an internet search which used two data bases – the World Port Index\textsuperscript{17} and Lloyd’s Register Fairplay Port Guide\textsuperscript{18} – to identify ports and terminals of interest for further investigation. What follows is a brief review of these identified terminals and ports. Items of interest and relevance to Cook Inlet moorage management are noted in each summary.

\textsuperscript{16} United Kingdom Health and Safety Executive, Marine Accident Investigation Board, A joint report of the ‘Havkong’ incident at Braefoot Bay Terminal by Aberdour, Fife on 23 January 1993.

\textsuperscript{17} National Geospatial-Intelligence Agency, World Port Index, Publication 150 (2005) Eighteen Edition. Bethesda, Maryland. The world Port Index contains the location, characteristics, known facilities, and available services of major ports, shipping facilities and oil terminals throughout the world (approximately 64,000 entries). The data in this publication is mostly tabular and new editions are published bi-annually. This publication is available in its entirety on the website and there are also database queries available for all of the port information contained within.

\textsuperscript{18} Lloyd’s Register Fairplay Port Guide, which is on-line at www.portguide.com, provides comprehensive details of over 9,400 ports and terminals worldwide, including port plans, port maps, mooring diagrams, port distance tables, vessel index, tanker berth information, shipping atlas, port news, as well as details of port service providers.
5.A. Sullom Voe Harbour

Shetland Islands, United Kingdom  
60°27.5'N, 001°17'W

Sullom Voe is a major deep water harbor, owned and operated by the Shetland Islands Council as Harbour Authority. The Sullom Voe Oil and Gas complex is operated by BP Exploration.

The harbor accepts tankers up to around LOA 365 m with a draft of up to 24 m and LPG carriers up to about 286 m LOA with a draft up to 16.8m. Tankers exceeding 350,000 DWT have moored at the terminal. Four tankships can be accommodated at a time.

The Sullom Voe harbour complex has the most comprehensive and prescriptive mooring requirements of any port surveyed for this study. Crude oil and gas tankers must have a mooring audit on the occasion of their first visit and moor according their mooring plan on all subsequent port visits. Moorage requirements follow OCIMF guidelines. Line arrangement guidelines for all four jetties are provided for various vessel sizes. See Figure 7.

Although the harbor is not subject to ice, it is subject to high winds year round. Ships with large windage areas are wind restricted for berthing. Tugs must be called alongside for certain forecasted winds, depending on the size of the tank vessel and its berth. See Table 1. A tug must be called out when the tank ship’s mean freeboard height exceeds the mean draft. For comparison purposes, see Figure 8 for a picture of a Cook Inlet tankship.

<table>
<thead>
<tr>
<th>Wind restrictions on berthing at Sullom Voe Harbour, Shetland Island</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vessel windage (square metres)</td>
</tr>
<tr>
<td>--------------------------------</td>
</tr>
<tr>
<td>Up to 6,000</td>
</tr>
<tr>
<td>6,001 - 6,700</td>
</tr>
<tr>
<td>More than 6,700</td>
</tr>
</tbody>
</table>

Windage is calculated as LOA times mean freeboard.

19 See Sullom Voe moorage requirements at: http://www.shetland.gov.uk/ports/sullomvoe/mooring/
Figure 7: Mooring arrangements for tankships at Sullom Voe Harbour
Figure 8: The tank ship Overseas Hercules (51,000 DWT, 183 meter LOA), seen here on approach to the KPL dock in Nikiski, has a windage surface area of about 1200 square meters. Under Sullom Voe restrictions, this ship could not dock when winds are in excess of 30 knots. (Picture courtesy of KPL Terminal.)

Of particular concern to the harbour authorities is main propulsion failure for ships entering and leaving the port. Independent surveys are required when a vessel reports main propulsion problems and up to four tugs will be required for the vessel to leave its berth.

5.B. New Russian Oil Terminals in the Baltic

Within the past five years two new marine oil terminals have been opened in western Russia at the eastern Baltic, Gulf of Finland. These terminals, Primorsk and Vysotsk which are only 18 miles apart, form the terminus of the Baltic Pipeline System (BPS). Together they are capable of exporting 150 million tonnes of crude oil and refined products annually and significant increases in export capacity is planned for the near future.

The eastern part of the Gulf of Finland is an area which is difficult for navigation due to its shallow depths, numerous banks, high beds and islands, and which is distinguished by its storms and frequent periods of reduced visibility. Thus, new fairways and traffic separation schemes have been developed for these ports.

Both Primorsk and Vysotsk have been subject to scrutiny by authorities and citizen’s groups in neighboring Finland.
Primorsk

A Russia oil terminal on the north coast of the Gulf of Finland/Baltic Sea
Lat 60°01'9"N, Long 28°042' E

Primorsk is an oil terminal open for navigation year round. Ice has to be navigated in winter, usually from the end of November up to the end of April. Average ice coverage is 140 days per year with an average ice thickness of 50 cm and maximum of 90 cm. The harbor has ‘good’ sheltering.

A Russian-to-English translation of the complete port guide and regulations are on the web. The Port requires double hull tankers for loading with double bottom tankers under certain conditions. During the ice season the tank ships must have a hull class (ice strengthened) of 1A or above or receive an ice certificate from the Russian Federation.

Five tugs are available (5000 – 2500 hp) and tug attendance during docking and undocking is compulsory. Tugs are on immediate recall while the ships are at berth.

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According to Lloyd’s Port Guide, typical mooring arrangements include 4 head lines, 4 breast lines, 4 spring lines, and 4 stern lines. Lines must be supplied by the vessel. However, the port regulations state that 9 lines at a minimum be used in the manner shown in Figure 9. Note that, interestingly, no spring lines are required under this arrangement.

The regulations also state requirements for ships navigating in ice in the Gulf of Finland. They are:

- Steel plates of the main deck and freeboard must be made of steel graded not less than D(AH).
- Mooring equipment, deck cranes and other gear must be adjusted for use at minus 30 deg. C.
- Living spaces shall have the heating which meets low temperature requirements.
- Tankers shall have 2 sea openings on the opposite side of the hull to pump water for cooling main and auxiliary engines, at least one of them shall be in the bottom or almost in the bottom to minimize the possibility of water-cooling system being clogged with ice.
- Propellers shall be made of steel or high quality bronze for vessels sailing in ice.

**Of interest:** The Baltic Pipeline System has estimated the risk of an oil spill during loading from parting of mooring lines and shift of the vessel due to the unexpected, momentary gusts of wind (particularly at the beginning of loading when a tanker has the maximum free-board) is estimated as $1 \times 10^{-4}$ per year.\(^{23}\)

Figure 10: Primorsk Oil Terminal, Gulf of Finland. Note tugs and icebreakers at the wharf.
Vysotsk Lukoil Terminal
North coast of the Gulf of Finland/Baltic Sea
Lat 60°35‘N, Long 28°32‘E

Completed in September 2006, this terminal is reported to be a state of the art moorage with an annual export capacity of 11,600,000 tonnes of refined product. The fairways are being deepened to allow for the export of crude oil.

The port operates throughout the year with the assistance of two icebreakers during the winter period.

There are three moorings at the terminal. Two of them receive tankers with of 100k DWT. One mooring is designed to receive river-sea class tankers, which deliver fuel to the port for export, although most of the oil for export is delivered to the port by rail. See Figure 11.

The terminal is equipped with laser mooring guidance, vessel traffic system, and several tugs in constant attendance.

Figure 11: The Vysotsk Lukoil Terminal. The tankers in this photograph are approximately 165 meters LOA. The moorage is 375 meters long.

Riga, Latvia

Baltic seaport at the mouth of the Daugava River
Lat 56° 58’ N, Long 24° 06’ E

The port is open year round with icebreaker assistance required in the winter. Only vessels with appropriate ice classification hulls may use the port in the winter.

When the NW winds exceed 14 knots, at least two tugs are required for mooring and unmooring at the gas berth and oil terminal.

For tanker berths eight mooring lines both forward and aft are required. Tug assistance is compulsory. The Harbourmaster will resolve any dispute between the master and pilot as to how many tugs are needed.

Vladivostok

Far east Russia on the southern extremity of Muravyov-Amurski peninsula
Lat 43° 07’ N, Long 131° 52’ E

Berths 13-16 are susceptible to high winds and swells. When southeast winds reach force 7 (28-33 knots), and/or sea swell from SE reaches force 4 (whitecaps), all vessels at these berths must keep their main engines on stand by and be ready to leave depart. Captain and crew must stay on board.

Four tugs are normally available.

Anadyr

Siberian port in the northern part of the Bering Sea
Lat 64° 44’ N, Long 177° 32’ E

Ice-bound most of the year. Ice-breaker assistance is required at the beginning and end of the ice season.

Low tide currents can be as high as eight knots.

During mooring a tug and pilot are required. Mooring is prohibited at wind speeds greater than 27 knots.

At the beginning of the ice season, vessels must secure themselves with steel wires, which are provided by the port, of not less than 40mm diameter, three from the bow and one from the stern. Ships must also maintain a continuous watch on the Bridge and Engine Room, with the main engines on Stand-by. Engines should be worked ahead,
starting with Slow Ahead and increasing to Full Ahead if necessary, with the rudder put half over towards the berth, to ease the tension of the moorings due to drifting ice pressure.

At certain times of the year and under certain conditions, this harbor may have the most precarious berths in the world. Apparently, tank vessel operations are not conducted at Anadyr.

**Korsakov**

Island of Sakhalin in far eastern Russia. 
Lat 46°37’N, Long 142°46’E

There is poor protection of the inner harbor from westerly winds and rough seas when mooring. The mooring of vessels with petroleum cargoes is prohibited at wave heights by the jetty of more than 1.0 m and a westerly wind of more than 19 knots and an easterly wind speed of more than 29 knots. Use of wire rope is prohibited for reasons that are not specified.

**5.C. Summary of the International Ports Survey**

1. Many ports and terminals warn of the hazards of ice along the approaches of the berths. Of all the information available about international ports on the web, only at Anadyr and the Nikiski terminals are the hazards of ice while at berth mentioned, with the Nikiski hazards described in the most detail.  

2. Where there is ice, icebreakers escort the vessels to the berth. At least two tugs are in attendance or immediately available. Of all the northern ports surveyed, only Nikiski conducts operations without tugs.

3. Sullom Voe harbor required a mooring audit for each ship. This practice should be considered for Cook Inlet.

4. The Nikiski terminal mooring line requirements are equal to or exceed the requirements at the international ports. This will be reviewed in detail in the Nikiski specific section of this study.

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25 Lloyd’s Fairplay Port Guide has the following entry regarding Nikiski terminals: Mooring information: Berthing alongside: During winter months, ice floes can be a problem at the wharves and are more prevalent during the ingoing tidal stream. They can be a severe problem during the months of Jan-Feb. Vessels accordingly berth port side alongside, stemming the ingoing tide, and are required to maintain their engines on instant readiness at all times whilst alongside. During occasions when the ice is heavy it has proved convenient to maintain the engine turning over at slow speed to resist the pressure from ice and tide. The range of tide can be as much as 8.5m, and vessels are required to have onboard from 20 to 24 mooring lines, each a minimum length of 122m, of which from 16 to 22 may be used to moor the vessel. Vessels are required to advise the number of mooring lines onboard prior to arrival at the pilot embarkation point off Homer Spit and, if necessary, additional mooring lines will be delivered onboard while off Homer, on a hire basis.
6. Items of Interest from Seabulk Pride Breakaway Reports

During the months following the breakaway of the Seabulk Pride on February 2, 2006, several investigations were conducted and reports produced. Each have a different emphasis and reach different conclusions as to the root cause of the accident. Each makes important points that contribute to this mooring analysis.

In reviewing these reports it is helpful to summarize the relevant events leading up to the breakaway. The following sequence of events is taken from the Coast Guard investigation report.

- At 0500, February 2, 2006, the tankship Seabulk Pride was moored portside to the KPL dock. The vessel was loading refined oil products from the Tesoro Refinery. According to the pilot on watch, there was no ice in the vicinity of the vessel.

- At 0515, according to the pilot, ice began flowing near the vessel again, and quickly rose to approx. 50-60% coverage. Video footage from the facility shows a significant but ‘not alarming’ amount of ice moving past the dock following the break away. Medium sized pans of ice were distinguishable.

- In the minutes before the breakaway, the able-bodied seaman (A/B) on watch was tending lines. He had begun at the bow of the ship and worked his way aft releasing tension on the lines via the hydraulic winch controls. The tension diagrams for the mooring lines provided correspond with this account of events and it is possible to identify each instant when the lines were slacked.

- At 0523 the after-spring wire (BP2B) parted between the winch and chock (fairlead). After-spring wire BP2A had just been slacked. Springs wires BP2A and BP2B were arranged in parallel and affixed to two, side-by-side, mooring hooks. See Figure 12.

- Mooring lines continued to part or spool off their winch reels over the next three minutes. At one point the ship was being held by the loading arms for approximately 30 seconds before they parted according to one eyewitness account. The ship was then adrift in the flood tide drifting towards the East Forelands.

- At the time of the breakaway, the flood tide current was in excess of 5 knots.

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26 In analyzing an accident, the root cause should always be clearly distinguished from the events leading up to an accident. For example, in the case of an engine room fire on a hypothetical ship, the apparent cause of the fire may be excessive soot build up in the boiler flue. However, the root cause would actually be the failure to follow the boiler manufacturer’s guideline for cleaning the fire tubes within the boiler.
6.A. US Coast Guard Investigation Report

US Coast Guard Sector Anchorage conducted an informal investigation\(^{27}\) into the T/V Seabulk Pride casualty of February 2, 2006. They examined and analyzed the circumstances leading to the breakaway and the grounding. For the purpose of this study, I note only the facts and conclusions related to the breakaway and not those related to the grounding.

The Coast Guard investigators concluded that the *initiating event* was a massive force directed on the bow of the ship pushing it parallel to the dock. They assumed that this force was caused by an unseen large flow of ice and the max flood current. “This is not the generally expected risk from ice at this location. Ice will normally wedge between the vessel and the shoreline generating a force perpendicular to the dock.”

They identified one root cause of the breakaway as improper slacking of the mooring lines during the tending process. “At several points during the line tending process strains were noted by tension gauges above the SWL of the mooring lines. The failure of the first mooring line was exacerbated by the failure of other lines to arrest the aft motion of the ship or to carry any substantial load. In essence, one line was carrying the bulk of the fore-aft loading. Most of the other lines intended to stop the aft motion of the ship were not carrying a load as intended in the mooring arrangement. It is possible that if the lines which were not carrying load had been loaded prior to slacking lines (*pre-tensioning*) that were exceeding the SWL, the mooring system may not have failed.”

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\(^{27}\) A Coast Guard informal investigation means the Coast Guard did not convene a hearing and take recorded testimony.
The Coast Guard concluded that the involved parties failed to conduct an adequate risk assessment of the ice conditions and invoke additional operational conditions. The Coast Guard noted that the facility’s operations manual was not strictly followed. The manual called for mooring lines to be doubled or tripled in extreme ice conditions, and that transfer operations should be suspended within two hours of max flood and max ebb currents during ice conditions.

Finally, they suggest that mooring lines with a higher breaking strength may have prevented the breakaway. At least one line was observed to have been hand spliced and should have been replaced or de-rated due to the decreased strength resulting from the hand splice.

6. B. Hayes Report

Webb Hayes, a senior consulting engineer, examined the line tending on the Seabulk Pride at the time of the breakaway.28 This study was commissioned by Tesoro Refining and Marketing Company, the owner/operator of the KPL facility.

Immediately prior to the Seabulk Pride breakaway, ship’s crew were adjusting the mooring lines. Mr. Hayes analyzed the mooring line loads recorded on the tension monitoring system in the minutes leading up to the breakaway. He then attempted to recreate mooring line adjustments using a computer model (OPTIMOOR).29

In Mr. Hayes opinion:

- Ice did not appear to cause rapid or significant increases in mooring line loads. He notes that the ice observed at the time of the incident was broken and moving around obstructions. He states that Cook Inlet offshore platforms break up ice as it moves up and down Cook Inlet with the tide, thus preventing large pans of ice from forming.30


29 OPTIMOOR, available through Tension Technology International, is a mooring analysis computer program designed for vessel and terminal operators, and port designers and naval architects. It is based on the OCIMF recommendations and procedures and includes OCIMF wind and current coefficients for tanker moorings. See:  [http://www.tensiontech.com/software/optimoor.html](http://www.tensiontech.com/software/optimoor.html)

30 The Hayes report presented no support for this statement. Both the Coast Guard and the authors of the LOC study which is reviewed in the next section believe that ice forces were at least a contributing factor in the breakaway. Ice forces were a factor in the breakaway of the Ocean Laurel at the Agrium dock in 1999, and damage to other vessels by ice has been documented by the Coast Guard. However, though there have been anecdotal reports, there is no data on ice floe size in Cook Inlet. See US Army Corp of Engineers, Marine Ice Atlas for Cook Inlet Alaska (2005), page 11. Mr. Hayes’ opinions should be carefully
• Based on OPTIMOOR analysis, the mooring arrangement was satisfactory and, if properly tended, would have held the ship in place without excessive line loads.

• When after spring line BP-2A was improperly slacked all the load forces were transferred to after spring line BP-2B, causing it to fail. At that point, there “were an insufficient number of lines with enough tension to keep the ship from accelerating to the point where the lines could not absorb the energy and stop the ship. The “zipper like” failure of the entire mooring was the result.”

6.C. Post-Incident Mooring Line Examinations

Two consultants were retained by Tesoro Refining and Marketing Company to examine the mooring lines in use on the M/V Seabulk Pride at the time of the February 2, 2006 breakaway.

Exponent conducted a detailed visual examination of the 12 wire ropes in use including the five that parted during the breakaway. They determined that these wires exhibited metal loss due to wear. The spring line that failed first, BP2-B, may have had a weak splice near the eye that was made up for the pendant attachment. See Figure 17. In addition, Exponent noted that spring line BP2-A, adjacent to BP2-B and which was reported to have parted immediately after BP2-B, exhibited extensive wear and damage.

Tension Technology International (TTI) also visually examined the mooring lines in question, reviewed the mooring loads recorded by the computerized mooring load monitoring system (MLMS) immediately before and at the time of the incident, and developed a sequence of mooring line failures. TTI concluded that improper release of tension on one after spring line transferred excessive load to the other initiated the line failure. Both after spring lines (BP2-A and BP2-B) failed at about 70% of their rated strength (MBL) due to a poorly applied hand-made splice on BP2-B and broken wires and external abrasion on BP2-A. The damage and wear on BP2-A should have been detected and removed from service before the breakaway.


London Offshore Consultants Ltd. (LOC) was retained by Seabulk Tankers, Inc to determine whether the Cook Inlet ice guidelines and the current mooring arrangements at the KPL facility provide an adequate margin of safety for Seabulk tankers berthed at the facility. As in the Hayes study, LOC employed an OPTIMOOR computer model to evaluate the load line tensions on the Seabulk Pride for the February 2006 casualty. They also researched and developed an estimation of ice load for the Seabulk Pride based on thickness of ice floes.

considered. Additional support for Mr. Hayes’ claim is the fact that ships moored at the ConocoPhillips dock have ever had a mooring line failure.

31 Exponent Failure Analysis Consultants, Non-Destructive Examination of Seabulk Pride Mooring Wires. Project No. SF36473.000. May 8, 2006
32 Tension Technology International, Seabulk Pride at Nikiski Terminal Incident. September 29, 2006
LOC concluded:

- That “with a 5 knot head current, and a 30 knot headwind the mooring arrangement used by the SEABULK PRIDE on February 2, 2006 an ice floe about 12 cm (4.7 in) thick would exceed the SWL of the mooring lines. An ice floe 17 cm (6.7 in) thick would exceed the MBL of the lines. Doubling the wire lines would allow the ice to increase in thickness to 15 cm (5.7 in) and 22 cm (8.7 in) before the SWL and MBL are exceeded, respectively. LOC notes that the size of the ice floe33 used in the calculations are between 350 and 1000 meters in diameter.”

- The forces exerted by ice floes are only marginally affected by the ice floe velocity.

- Using the ship’s engine to relieve strain on the mooring lines will be of little benefit.

- Whenever young or first year ice is present the safety of the berth is compromised and that ships using the berth have an unacceptably high risk of breakaway.

**Comment Regarding the LOC Report**

This report is not a strict casualty analysis in the manner of the Coast Guard and Hayes reports. Their objective was to determine whether the ‘post-breakaway’ USCG ice guidelines and mooring enhancements at the KPL dock provided an adequate margin of safety for Seabulk tank ships calling at Nikiski.

LOC notes that no medium or big ice floes were actually observed in the vicinity of the Seabulk Pride at the time of the breakaway. Furthermore, LOC did not address the contribution of mooring line management to the mooring line loads. Their objective was to develop an estimation of ice loading on mooring lines. LOC used ice load measurements from one study34 of Cook Inlet offshore platform loading conducted in 1965-1966 to interpolate loads for ice in the vicinity of Nikiski. This interpolation is presented in Figure A of the LOC report and reproduced here as Figure 13.

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33 According to the World Meteorological Organization system of sea ice classification the size of the ice floes mentioned here would be medium to big ice floes.
Figure 13: Shown as Figure A in the LOC report. It should only be used for a like-sized vessel.

This graph is an interpolation of data taken from one 40-year old study and as noted earlier, there is no definitive data on the size of ice floes in Cook Inlet. However, this graph is an important contribution to understanding ice forces in ship handling. This type of research should be continued.

Regarding ice floe velocity, at first it would seem counter-intuitive that the ice force is only marginally affected by the speed of the current moving an ice floe. After all:

\[
\text{Force} = \text{(mass)(acceleration)} = \text{(mass)(change in velocity)/(time)} = \text{(mass)(distance/time)/(time)}
\]
According to papers cited in the LOC report\textsuperscript{35} as ice is compressed (as in pressing against a ship hull) it fails in a creep-like fashion and later, with increasing compression, by crushing. This seems to be similar to throwing a fully extended, but stiff, accordion against a wall. Initially there is force exerted but much of the acceleration force component is used to compress the accordion bellows. Thus the force against the wall comes largely from the size (mass) of the accordion rather than its velocity. So apparently, as long as an ice floe of sufficient mass (350-1000 meters in diameter, 10 or more centimeters thick) is moving towards the ship, its speed of movement is of little consequence. If the LOC conclusion is correct, it has two important implications:

- Excessive ice force can occur at any time during a tide cycle.
- Ice bound ports need not have the high tidal currents common at Cook Inlet to be subject to excessive ice forces.

This is not to say that current velocities are not important. In water bodies that are not already completely ice covered, high currents can increase the probability that ice floes are carried to a moored vessel. Thus, the peak flood tides at Nikiski are the periods when ice floe impingement is most likely. In addition, if a ship’s mooring lines fail due to ice forces, the high currents are more likely to exacerbate consequences by helping sweep the vessel off the berth. Thus, the Coast Guard ice guidelines\textsuperscript{36}, which require suspending operations at certain facilities when the tide current is above 4 knots and leaving the berth when the tide current exceeds 5 knots, are reasonable and prudent.

6.E. Conclusions from the Investigation Reports

1. If ice floes or ice floe ‘clusters’ of the size used in the LOC calculations (500 m in diameter) are common in Cook Inlet then berthed vessels can be at risk during the ice months and at any time during the tide cycles. The size and frequency of ice floes in Cook Inlet should be studied. The recent initiative by CIRCAC\textsuperscript{37}, where a network of marine operators and facilities are networked to track ice movement in upper Cook Inlet, should include observations on ice floe size.

2. Poor mooring line tending and maintenance are still root causes or contributing causes in mooring line failure.

\textsuperscript{35} (a) Recommended Practice for Planning, Designing and Constructing Structures and Pipelines for Arctic Conditions, American Petroleum Institute, 2\textsuperscript{nd} ed. (1995) and (b) Blenkarn, K.A. Measurement and Analysis of Ice Forces on Cook Inlet Structures. Pan American Petroleum Group. (1970)

\textsuperscript{36} US Coast Guard Captain of the Port, Western Alaska, Navigation Advisory: Special Operating Procedures for Ice Conditions in Cook Inlet. Letter of January 12, 2007 (ser no. 16710)

\textsuperscript{37} CIRCAC newsletter, Council Briefs, 1\textsuperscript{st} quarter 2007.
7. Overview of the Cook Inlet Ice Guidelines

For several years, the US Coast Guard Captain of the Port (COTP) for Western Alaska has imposed special guidelines for vessels operating in Cook Inlet during icing conditions. Although published as guidelines these procedures are essentially mandatory since failure to follow the guidelines may result in a COTP order against the vessel not following them.

The ice guidelines were first developed during severe icing conditions in 1999 when the M/V Ocean Laurel parted numerous mooring lines due to ice forcing while moored at the Agruim dock in Nikiski. They were revised substantially immediately following the M/V Seabulk Pride breakaway in February 2006, and again in January 2007. The COTP has developed these guidelines in consultation with the Cook Inlet Navigation Safety Committee (CINSC) which includes pilots, vessel operators, and facility operators; all with extensive experience operating in extreme Cook Inlet conditions.

Table 2: Summary of changes in the guidelines over the years
This table is not a complete summary of the Cook Inlet ice guidelines. It is intended only to show the development of the guidelines over time.

<table>
<thead>
<tr>
<th>Guidelines issued on 28 November 2005(^{38})</th>
<th>Guidelines issued on 12 Jan 2007(^{39})</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>When shall they be used?</strong></td>
<td>Conditions for implementation of guidelines were removed. Now, implementation is apparently up to the discretion of the COTP in consultation with the CINSC.</td>
</tr>
<tr>
<td>Guidelines implemented during sustained low ambient temperatures, strong tidal currents, winds from the west and during presence of large pans of thick, hard ice.</td>
<td></td>
</tr>
<tr>
<td><strong>Specific conditions for transit:</strong></td>
<td>No ice forcing while underway. Ice forcing is understood to be a condition where the vessel slows to 50% or less of the speed made before entering the ice. Under these conditions the transit must be aborted.</td>
</tr>
<tr>
<td>None, but special ‘ice forcing’ prohibitions issued on 30 Jan 2006.</td>
<td>Tank barges must have a transit plan and an escort tug in addition to the towing tug.</td>
</tr>
<tr>
<td>Tank barges and vessels greater than 1600 GT must have an inspection in Homer on the occasion of the first visit to Cook Inlet.</td>
<td></td>
</tr>
<tr>
<td><strong>Required draft while underway:</strong></td>
<td>More general: Sea suction and propeller should be well below the ice. The bulbous bow should be submerged.</td>
</tr>
<tr>
<td>Prescriptive: Self-propelled vessels should have at least 10 feet forward with bulbous bow submerged, 6 feet below the propeller.</td>
<td></td>
</tr>
</tbody>
</table>

\(^{38}\) Issued with COTP Western Alaska letter (16710) of 30 Jan 2006
\(^{39}\) Issued with COTP Western Alaska letter (16710) of 12 Jan 2007
Table 2: Continued

While moored:

**Guidelines issued on 28 Nov 2005**

- Moor to mitigate worst case conditions. Tugs and tank barges moored at Anchorage should be facing the flood tide or portside to.
- Additional mooring lines should be available.

**Guidelines issued on 12 Jan 2007**

- Moor facing the flood tide.
- Additional mooring lines should be available.

**Readiness to depart berth**

- Engines on immediate standby to relieve strain on the mooring lines or to leave the moorage.
- Given that there were different interpretations as to what 'immediate standby' meant, the term was dropped. Engines should be in a status that allows the most expeditious means of mitigating mooring line strain or for getting the vessel underway.

**Manning while moored:**

- Underway watches in the engineering spaces and on the bridge.
- Slight changes in emphasis. Vessels are to be continuously manned to allow the most expeditious means of mitigating mooring line strain or for getting the vessel underway.

**Requirements specific to Nikiski terminals:**

- None
- At KPL and Agruim docks for ships: At tidal currents in excess of 4 knots – cease transfer and disconnect transfer hoses and loading arms. An ice scout vessel should be positioned up current of the moorage. (See Figure 12) At tidal currents in excess of 5 knots – Leave the moorage, berthing prohibited.
  - For barges: When current is in excess of 2.0 knots an assist tug is assigned in addition to the towing tug.
  - At ConocoPhillips dock for ships: At tidal currents in excess of 5 knots - cease transfer and disconnect transfer hoses and loading arms. An ice scout vessel should be positioned up current of the moorage.

None
8. Evaluation of Nikiski Mooring Structures

Having surveyed common practices at international ports, summarized the moorage design criteria and factors that contribute to excessive strain on mooring lines, reviewed conclusions from several investigations into the Seabulk Pride breakaway, and changes in ice navigation procedures as a result of that breakaway, the two tank vessel terminals at Nikiski, the KPL oil terminal and the ConocoPhillips gas ship berth, can be evaluated against industry standards.

This study does not evaluate the Agrium terminal in Nikiski. This moorage did not receive vessels during the winter of 2006-2007. The Drift River terminal and the Port of Anchorage were also not evaluated. However, the evaluation criteria developed here can be easily applied to those facilities.

Table 3: Review of industry standards and practices as applied to Nikiski moorages

<table>
<thead>
<tr>
<th></th>
<th>Kenai Pipeline Berth</th>
<th>ConocoPhillips Berth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of Moorage (alignment with currents)</td>
<td>T-configuration piers (fair with current)</td>
<td>T-configuration piers (fair with current)</td>
</tr>
<tr>
<td>Largest ship accommodated</td>
<td>125K DWT 261.5 m (850 Ft) LOA 43 m (144 Feet) beam</td>
<td>66K DWT LOA 240 m (780 ft) LOA 40 m (130 ft) beam</td>
</tr>
<tr>
<td>Maximum draft</td>
<td>11.4 m (37 ft) for ships over 50,000 DWT</td>
<td>11.0 m (35.7 ft)</td>
</tr>
<tr>
<td>Depth alongside mooring</td>
<td>12.8 m (42 ft) MLLW</td>
<td>12.1 m (39 ft) MLLW</td>
</tr>
<tr>
<td>Minimum keel clearance</td>
<td>1.4 m (5.0 ft) under all conditions</td>
<td>1.4 m (5.0 ft) under all conditions</td>
</tr>
<tr>
<td>Typical length of time ship is moored</td>
<td>36 hours</td>
<td>24 hours</td>
</tr>
<tr>
<td>Are tugs used?</td>
<td>In February 2006, one 5000 hp tug was assigned as an assist and berth standby for tankships using the facility.</td>
<td>No</td>
</tr>
<tr>
<td>Are icebreakers assigned for escort?</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Number of mooring dolphins</td>
<td>6 steel pile plus 108 m of breasting pier (dock)</td>
<td>6 steel pile plus 127 m of breasting pier (dock)</td>
</tr>
<tr>
<td>Distance between breasting dolphins (dock)</td>
<td>108 m (350 ft)</td>
<td>127 m (412 ft)</td>
</tr>
<tr>
<td></td>
<td>Kenai Pipeline Berth</td>
<td>ConocoPhillips Berth</td>
</tr>
<tr>
<td>----------------------------------</td>
<td>----------------------------------------------------------</td>
<td>----------------------------------------------------------</td>
</tr>
<tr>
<td>Breasting dolphin length to ship length ratio</td>
<td>108/261.5 = 0.41</td>
<td>127/240 = 0.53</td>
</tr>
<tr>
<td>Length of moorage (outermost dolphins)</td>
<td>395 m (1285 ft)</td>
<td>320m (1042 ft)</td>
</tr>
<tr>
<td>Number of mooring points</td>
<td>8 double hooks plus several auxiliary bitts</td>
<td>4 triple hooks (head, stern, 2 breast dolphins), double hooks for springs plus two spare hooks for severe weather</td>
</tr>
<tr>
<td>Number of mooring hooks</td>
<td>16 (two at each mooring point) 100 tonne</td>
<td>16 60M tonne, test loaded @90 M Tonnes</td>
</tr>
<tr>
<td>Do mooring hooks have keep closures?</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Total number of mooring lines used in the winter</td>
<td>16 - 19</td>
<td>16</td>
</tr>
<tr>
<td>Minimum winter line configuration</td>
<td>2 bow, 2 stern, 4 forward breast lines, 4 aft breast lines, 2 spring lines aft, 2 spring lines forward, 2 aux lines to bitts</td>
<td>3 head, 3 stern, 3 forward breast lines, 3 aft breast lines, 2 spring lines aft, 2 spring lines forward</td>
</tr>
<tr>
<td>Description of typical mooring lines used by ships</td>
<td>SEABULK arrangement: HMPE (Spectra©) for bow, stern and breasting; wire cable for spring lines. Other vessels may use a combination of wire rope and synthetic line, but not mixed to the same mooring point. See Figure 6.</td>
<td>All lines are steel wire rope with nylon tails.</td>
</tr>
<tr>
<td>Angle of head and stern lines for largest ship moored.</td>
<td>45° or less</td>
<td>45° or less</td>
</tr>
<tr>
<td>Safe Work Load (SWL) / Minimum Breaking Load (MBL) of Lines</td>
<td>98K/178K pounds (44/81 tonnes) for &gt;80K DWT ship. Wires must have rope pendants (tails), of polyester or other synthetic fiber construction with similar stretching properties (&lt;10%), 11 meters long, with a minimal breaking strength 125% of the attached wire.</td>
<td>538 kN (≈ 54 tonnes)/978 kN (spec) 1015 kN (actual) (≈ 101.5 tonnes) Regularly maintained with greasing machine. Nylon tail rope –1170 kN (spec) 1410 kN(actual) breaking load. Replaced annually.</td>
</tr>
<tr>
<td>Type of compression members</td>
<td>Large flexible Teflon 2-inch fenders are affixed to the outer faces of each breasting dolphin.</td>
<td>Large flexible Teflon 2-inch fenders are affixed to the outer faces of each breasting dolphin.</td>
</tr>
<tr>
<td><strong>Kenai Pipeline Berth</strong></td>
<td><strong>ConocoPhillips Berth</strong></td>
<td></td>
</tr>
<tr>
<td>-------------------------</td>
<td>-------------------------</td>
<td></td>
</tr>
<tr>
<td>MLMS Calibration</td>
<td>Annually or as needed.</td>
<td>Annually, to exceed manufacturer’s specifications.</td>
</tr>
<tr>
<td>Standard Operating Procedures and Prohibitions</td>
<td>No tension winches, wires on hydraulic capstans or warping drums. All winches to be filled with wire. Polypropylene and nylon lines are not permitted. HMPE lines such as Spectra® or Kevlar may be substituted for mooring wires but need approval from the KPL Terminal Manager on a case by case basis.</td>
<td>Only two ships (Gas carriers Polar Eagle and Arctic Sun) use the berth. The berth was designed specifically for these ships. These vessels employ identical mooring plans (See Figure 7). No other arrangements are permitted.</td>
</tr>
<tr>
<td>Pre-mooring meeting held? Attended by:</td>
<td>Yes. Terminal Person-in-Charge (PIC) and the 6-8 person mooring crew. Every ship gets a mooring diagram via e-mail from the marine superintendent 3-5 days prior to arrival. See Figure 6. The marine superintendent and master e-mail or talk by satellite phone to resolve any issues or address questions.</td>
<td>Yes. Plant manager or maintenance superintendent, mooring master, port engineer, and mooring crew. Mooring conditions, weather and only pertinent factors are discussed.</td>
</tr>
<tr>
<td>Training/Qualification of Shoreside Mooring Team</td>
<td>KPL line handlers fill various positions at the marine terminal. New employees assigned to the dock receive training in Health, Safety, and Environmental issues including 40-Hour HAZWOPER Course. New linehandlers are supervised at all dockings and undockings until such time as they are deemed qualified. This is usually 4-6 weeks of on-the-job training.</td>
<td>Employees have safety training in addition to supervised on-the-job training before being assigned as a qualified member of the mooring team. A professionally produced safe mooring training DVD has been developed specifically for the Nikiski ConocoPhillips moorage.</td>
</tr>
<tr>
<td></td>
<td>Kenai Pipeline Berth</td>
<td>ConocoPhillips Berth</td>
</tr>
<tr>
<td>-----------------------------------------------------------------</td>
<td>----------------------</td>
<td>----------------------</td>
</tr>
<tr>
<td>Does the facility use formal checklists documenting discussions and agreements between the vessel and terminal regarding ice conditions and mooring arrangements?</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Does the facility require a mooring audit for each vessel on the vessel’s first call at the facility?</td>
<td>No, although the marine superintendent does send the ship a mooring diagram in advance of the ship’s arrival.</td>
<td>Not applicable. Only two ships use the berth. They always moor in the same manner everytime.</td>
</tr>
<tr>
<td>Emergency Procedures Written?</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Emergency release crew assigned?</td>
<td>One person is on the dock at all times. During conditions of ice and strong flood tide two extra personnel are kept on the dock. Five persons can be called to the dock within 5 minutes.</td>
<td>5-8 persons are assigned. During marginal conditions two persons are on the dock at all times and the complete team is on immediate recall.</td>
</tr>
<tr>
<td>Incident Management Team</td>
<td>Trained in-house team with support and back-up from the local oil spill cooperative (CISPRI), and the Nikiski Fire Department.</td>
<td>In-house team with back-up from the local oil spill cooperative (CISPRI), Nikiski Fire Department, and Anchorage Corporate Office</td>
</tr>
</tbody>
</table>

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40 Recommended by the USCG Seabulk Pride accident investigation report.
Figure 14: Copy of mooring diagram sent to the tankship Baltic Front by the KPL marine superintendent 5 days to the ship's arrival in Nikiski.

MOORING ARRANGEMENT
KENAI PIPE LINE COMPANY
NIKISKI TERMINAL

LEGEND
D - 2- QUICK RELEASE MOORING HOOKS
(100 TON CAP.)
MD - MOORING DOLPHINS
Figure 15: Mooring Arrangements for Gas Carriers Polar Eagle and Arctic Sun at ConocoPhillips berth at Nikiski, Alaska.
8.A. Mooring Load Monitoring System (MLMS)

Both the ConocoPhillips and KPL docks are equipped with a mooring load monitoring system (MLMS). These systems are capable of measuring, displaying and recording the load tension on each mooring line deployed to one of the dock mooring hooks that are part of the system. (See Figure 2 for a picture of the mooring sensor.) The sensors convert the tension forces on the mooring lines into electrical signals which are passed to a computer in the dock office where the loads are displayed in tonnes on a computer video monitor. The display shows the dock layout, the position of the moored vessel, the actual mooring lines in use, and the tension load on each line. The load is displayed digitally and in histograms (bar chart). The computer can be pre-set to warn of an over-load or under-load (slack line), with the appropriate histogram changing color and flashing to attract attention as well as an audible alarm sounding. The MLMS display is provided to the berthed vessel bridge by Wi-Fi.

Figure 16: ConocoPhillips Load Monitoring Display (ship not moored in this picture)

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41 This narrative description was taken, in part, from the KPL Port Information Guide. (January 2007)
Figure 17: KPL MLMS computer terminal display.

Figure 18: Mooring line tension monitoring from the KPL dock house. This display is provided to the moored ship by Wi-Fi.

Photographs for Figures 17 & 18 courtesy of KPL Terminal.
8.B. Changes in Berthing Protocols Since the M/V Seabulk Pride Breakaway in February 2006

Immediately after the Seabulk Pride breakaway in February 2006 the Cook Inlet guidelines for operating in ice were substantially rewritten. These revisions are described in the Section 7. In addition, the KPL terminal changed its mooring line arrangements somewhat (Figure 19) and brought in a standby assist tractor tug (Figure 20) for winter operations.

Figure 19: One of two auxiliary lines added to the mooring arrangements for tank ships berthed at the KPL dock. This line was added to support the aft spring lines and to provide some transverse (off-dock) restraint. Photo courtesy of KPL Terminal.
Figure 20: The 5000 hp Crowley tractor tug Protector alongside the Seabulk Arctic at the KPL terminal in Nikiski during a flood tide in February 2007. Note that at this point ice forces are longitudinal (bow on) due to the flood tide, but also transverse (portside) due to the restriction of ice movement by the breasting dolphins.
Cook Inlet Mooring Study: Berth Design, Mooring Arrangements, and Port Management

Figure 21: An ‘Ice Scout’ monitoring Cook Inlet ice conditions off of Nikiski. This vessel provides advance notice of ice approaching to the terminal and moored vessel by marine radio. It transmits a general e-mail message of observed ice conditions about twice per day. The ice scout works under the direction of the navigational watch of the moored vessels at Nikiski. It travels in a quadrant pattern in ahead/astern of the vessel.

8.C. Comparing the ConocoPhillips Berth with the KPL and Agrium Berths

Over the past several years vessels moored at the Agrium and KPL berths have, on occasion, had mooring line failure. Interviews with the Nikiski ConocoPhillips terminal manager and mooring master reveal that ships using that facility have never had a mooring line failure. On only a few occasions has the mooring load monitoring system recorded a tension alarm, where the strain on a line has exceeded the SWL. Why is this so? Three reasons have been commonly offered.

1. The berth at ConocoPhillips was built specifically for the two ships that use it. In other words, the dolphins or mooring points were designed and placed to maximize the holding strength of the ship’s mooring arrangement. However, although the strength of berth structures requires careful design calculation, I am not aware that the relationship of the ship’s fairleads to facility mooring points must be precise. Head and stern lines should be at an angle of 45° or less, breast lines should be nearly perpendicular to the ship, spring lines should extend fore and aft nearly parallel to the ship, and short mooring lines must be avoided. See

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42 Interview with ConocoPhillips terminal manager and mooring master on 23 Feb 2007.
43 Safe Work Load (SWL) which is set at 55% of the minimum breaking load of the line.
Figure 3. Both KPL and ConocoPhillips meet these design standards for mooring line arrangements. Perhaps lessons could be learned by applying reverse-engineering to the KPL and Agrium docks, taking the specifications of the dock and designing the ideal ship and mooring arrangement.

2. *ConocoPhillips dock, being in the middle of the three docks, enjoys the benefit of the “ice-breaking or ice-disruption” effect of the south pier (Agrium) and the north pier (KPL).* If that is the case then the KPL dock has the benefit of two ice-disrupting piers during flood tides. In addition, the ConocoPhillips dock extends further out into Cook Inlet than the other berths. See Figure 22.

![Figure 22: Nikiski Docks (Courtesy of Lt. Ken Phillips, USCG)](image)

3. *The masters of the Artic Sun and Polar Eagle only sail between the ConocoPhillips dock in Nikiski and Tokyo. They and the senior members of their crew have extensive experience in ice conditions and severe weather in Cook Inlet. Their mooring protocols are set, refined, and consistent.* Certainly this is an advantage that few terminals have. It may well be that these two ships have perfected the art of mooring and line tending in Cook Inlet. KPL berths a variety of ships – three to four US flag tanks ships on regular service runs and about 20 foreign flag tank ships on spot charter.\(^{44}\) Human error accounts for 90% of

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marine casualties\textsuperscript{45} and the variety of ships and crews calling at both KPL and Agrium on spot charter may introduce more opportunity for human error. However, Seabulk Tanker ship captains also have extensive experience working in the extreme weather conditions of Cook Inlet; likely on a level equal to that of the ship captains calling at ConocoPhillips. Perhaps off-setting this is the conclusion of the Coast Guard that inexperience of the able-bodied seaman tending the lines on the morning of the Seabulk Pride breakaway may have been a contributing factor in the casualty.\textsuperscript{46}

8.D. Summary of ConocoPhillips and KPL facility evaluation

1. As of February 2007, both terminals are designed and operated in a manner that meets or exceeds common industry best practice for berthing tank ships.

2. The Cook Inlet Special Operating Procedures for Ice Conditions in Cook Inlet are helpful and supportive of safe navigation in ice. They are mature guidelines, given that they have been refined through lessons learned and receive input from a variety of experienced mariners and facility operators.

3. There is no completely satisfactory explanation for why the KPL and Agrium occasionally have mooring line failure, while the ConocoPhillips dock does not.

4. Almost always, the root cause or contributing cause of mooring line failure is poor line tending or poor mooring line arrangements. The responsibility for good line tending lies primarily with the ship’s crew and not the terminal’s dock force. Berth design and facility personnel training will not manage or eliminate this risk. Therefore, facilities should consider:
   - Implementing a ‘Declaration of Mooring’ (DoM) between a ship’s master or chief mate and the facility dock master each time a ship moors.\textsuperscript{47} Similar to a Declaration of Security (DoS) or Declaration of Inspection (DoI), the DoM would include documentation that ship and dock personnel had discussed tide, potential for ice and ice monitoring, emergency alarms and communication, emergency underway procedures, line tending protocols, and safety.
   - Conducting a formal ship-specific mooring audit for each ship on the occasion of its first call at the facility. This audit would consist of a checklist of good mooring management practices, many of which are addressed in Section 4 of this study.

\textsuperscript{45} A statistic commonly quoted by the International Maritime Organization.
\textsuperscript{46} Coast Guard Report of Investigation: Grounding of the Tank Vessel SEABULK PRIDE in Cook Inlet, February 2\textsuperscript{nd}, 2006, Section 2.0
\textsuperscript{47} A recommendation in the Coast Guard Report of Investigation: Grounding of the Tank Vessel SEABULK PRIDE in Cook Inlet, February 2\textsuperscript{nd}, 2006.