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Ice Guideline for Docks in Lower Thames River - Report v2

October 5, 2021
Project No. 173

Attn.: Mark Peacock, P. Eng.
CAO/Secretary-Treasurer
Lower Thames Valley Conservation Authority
100 Thames Street
Chatham, ON N7L 2Y8

Sent by email to: mark.peacock@ltvca.ca

Dear Mr. Peacock:

To follow up our telephone meeting last week, I have changed the recommendation regarding the maximum offshore dock length that is permissible. This version of the report is being submitted in advance to expedite the production of the final report. I understand that editorial comments will be coming later; and these will be addressed when they have been received.

Please do not hesitate to contact me with any further inputs or comments. Thank you.

Yours truly,

George Comfort, P. Eng.,
Ice Engineering Technical Specialist
G. Comfort Ice Engineering Ltd.

cc:
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Ice Guideline for Docks in Lower Thames River: Report v2

Summary Table of Contents

1.0 Introduction and Objectives

1.1 Background and Objectives

This Ice Guideline is intended assist the Lower Thames Valley Conservation Authority (LTVCA) in decision-making regarding ice issues with respect to permitting for docks. A detailed technical background to this Ice Guideline is provided in Comfort, 2021.

1.2 Applicable Return Period for the Ice Guideline

Of course, ice actions vary from year-to-year. The LTVCA provided the guidance that the Ice Guideline should generally err conservatively with respect to ice actions and issues.

The following recommendations are made for docks in the Lower Thames River:

(a) Applicable return period for ice actions – this should be taken as 100 years.
(b) The safety factors that must be applied – this is a related issue of course. Recognizing that LRFD Load and Resistance Factor Design) is typically used at present, it is recommended that factors should be applied to both the loads, and the foundation or structural resistance, in accordance with the Canadian National Building Code.

2.0 Range of Applicability

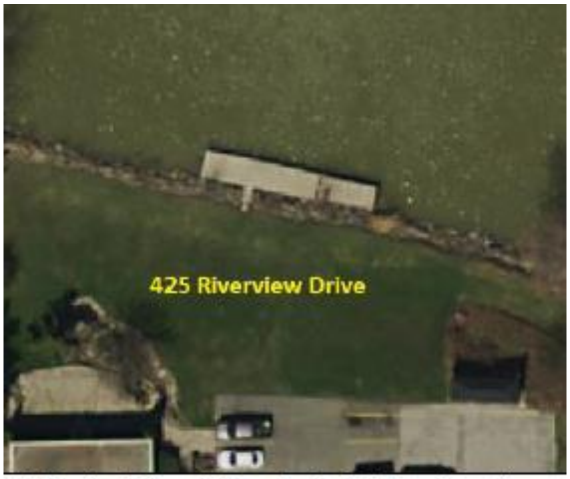
2.1 Docks

This Ice Guideline is intended to be applicable to "recreational" docks, and not "industrial" ones. This removes sheet pile/retaining walls from consideration for the Ice Guideline. Based on aerial photos for 82 recreational docks in the Lower Thames River, recreational dock configurations can be broadly divided into the following general categories:

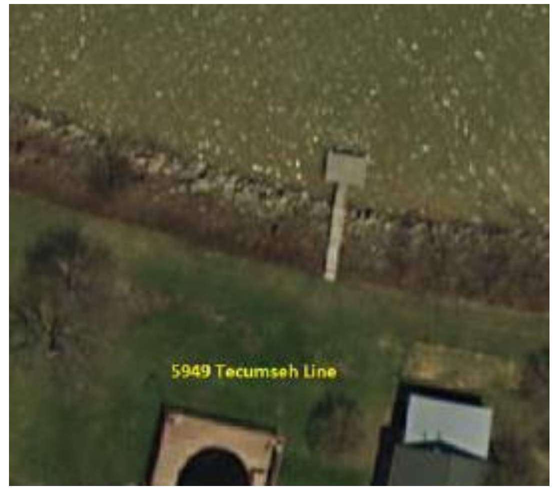
(a) A single-piece dock that is placed along the shore – these docks tend to be generally rectangular. See Figure 2.1 for an example.
(b) A two-piece dock that consists of a walkway extending out from shore to a deck offshore, at the end of the walkway. See Figure 2.1 for an example.

With respect to ice actions, it is of interest to define the following overall dock dimensions:

(a) The length that the dock extends out into the River (termed the "offshore" length) – the offshore length averaged about 5.5m, with a range from about 1 to 12.5m. Figure 2.2 shows the dock with the largest offshore length.
(b) The length that the dock extends along the shore of the River (termed the "alongshore" length) – this averaged about 10.9m, with a range from about 1 to 124m. Figure 2.2 shows the dock with the largest alongshore length.

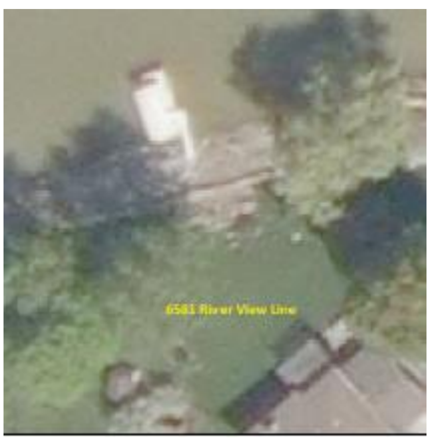


Single-piece dock alongshore

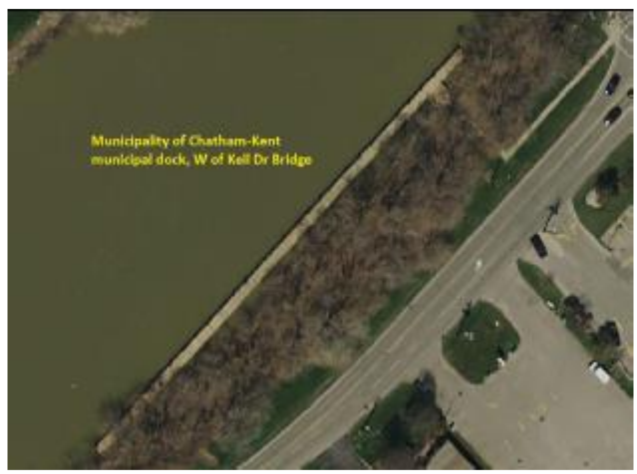


Two-piece dock with walkway

Figure 2.1: Sample Docks in the Lower Thames River (photos courtesy of V. Towsley, LTVCA)



Dock with max. offshore length (i.e., 12.5m)



Dock with max. alongshore length (i.e., 124m)

Figure 2.2: Selected Docks in the Lower Thames River (photos courtesy of V. Towsley, LTVCA)

2.1.2 The Components of a Dock

Recreational docks can be considered to have the following components:

(a) The abutment – which connects the dock to shore. This might be concrete for example.
(b) The support for the dock – for example, this might be piles or cribs.
(c) The superstructure – this Ice Guideline is limited to open decks. Other potential additions such as a canopy or a deckhouse are beyond the scope of this Ice Guideline, as they would be governed by policy (M. Peacock, LTVCA, personal communication).

Because all of the existing docks are vertical, this Guideline is limited to vertical structures.

This Ice Guideline provides separate guidance for each of the dock components as a given case may not involve all of them. For example, some docks might get taken out in winter, leaving only the piles exposed to ice. Furthermore, the Ice Guideline considers the effects of dock layout, for docks that are either: (a) perpendicular to the shoreline; or (b) parallel to it.

Anchored docks are a complex case as many scenarios are possible. To avoid undue complexity, anchored docks were not covered explicitly in the Ice Guideline except to state that the anchors and mooring system must be adequate to withstand the horizontal and vertical ice loads on the deck or walkway, as given in subsequent sections.

2.2 Geographic Region

The Ice Guideline's area of jurisdiction extends from the mouth of the Thames River up to Communication Road, which is near the western city boundary for Chatham. Furthermore, the Ice Guideline's area of jurisdiction is limited to the Lower Thames River itself, and it excludes the tributaries (i.e., various creeks and canals) that feed into the River.

2.3 Dykes

Dykes are a very important consideration as about half of the river shoreline in the area of jurisdiction for the Ice Guideline is dyked. Most of the dykes are along the shore although some are up to about 100 m back. The LTVCA does not want to have any construction on dykes (M. Peacock, LTVCA, personal communication). Dykes are out-of-scope for the Ice Guideline as they will be covered by policy (M. Peacock, LTVCA, personal communication).

3.0 Ice Design Criteria and Ice Loading Scenarios

3.1 Ice Design Criteria

The following ice design criteria were established:

(a) Ice thickness: 0.6m
(b) Ice effective strength, for calculation of ice impact loads from level ice sheets, within the context of the Canadian Highway Bridge Design Code (CSA S6-19; CSA, 2019): 1100 kPa

3.2 Ice Loading Scenarios

The dock components in contact with the ice may vary as usually, the water level is elevated at the time of an ice run. Three cases are possible as follows:

(a) The water level is low enough that the ice only contacts the piles beneath the deck.
(b) The water level is high enough that the ice only contacts the deck.

(c) The water level is in an intermediate range where the ice contacts both the deck and piles.

Ice loads must be considered for all three cases. Horizontal and vertical ice forces will be exerted on the components of the dock in contact with the ice, by various loading scenarios as summarized in Table 3.1.

Table 3.1: Ice Loading Scenarios

Dock Component	Loading Type	Ice Loading Scenario		
		Impact by Large Sheet Ice Pan	Water Level Change	Ice Jamming
Pile	Horizontal	Potential load case	Not relevant	Potential load case
	Vertical	Not relevant	Potential load case	Not relevant
Deck	Horizontal	Potential load case	Not relevant	Potential load case
	Vertical	Not relevant	Potential load case	Potential load case

4.0 Horizontal Ice Loads

4.1 Calculating Unfactored Horizontal Ice Loads

4.1.1 Overview of the Calculation Process

The analyses must start by assessing the elevation of the dock with respect to water level, as this affects which dock components will be exposed to ice. This will vary as the water level is typically elevated at the time of an ice run. Ice loads must be considered for all possible cases.

First, the horizontal loads acting on the various individual dock components in contact with the ice must be calculated using the recommended approaches (Table 4.1). For some cases (e.g., horizontal ice loads on a pile or crib – Table 3.1), ice loads may get generated by more than one scenario. Ice loads must be calculated for all relevant ice loading scenarios; and the governing one must be taken as the one that produces the highest ice loads. Note that, for all the cases listed in Table 3.1 for horizontal loadings, the different scenarios would not occur at the same time; so a loading case combining the ice loads from different scenarios need not be included in the ice design criteria.

The individual horizontal ice loads should then be summed as appropriate taking into account the specific dock geometry and the water surface elevation.

Table 4.1: Recommended Approach for Horizontal Ice Loads on Individual Dock Components

Dock Component	Loading Type	Ice Loading Scenario and Recommended Calculation Approach		
		Impact by Sheet Ice	Water Level Change	Ice Jamming
Pile or Crib	Horizontal	As per Section 4.3 and 4.4	Not relevant	As per Section 4.2
Deck or Walkway	Horizontal	As per Section 4.3 and 4.4	Not relevant	As per Section 4.2
Abutment	Horizontal	As per Section 4.3 and 4.4	Not relevant	As per Section 4.2

Then, horizontal ice forces should be evaluated for the range of loading directions that is physically possible, as governed by the geometry of the river and the dock. The structure's structural integrity must be checked for all possible loading directions.

Finally, stress concentrations should be evaluated for corners and sharp changes in dock layout, such as at the joint between the walkway and deck of a dock. The dock must have adequate structural integrity to resist all possible stress concentrations.

4.1.2 Application Notes

The following notes are applicable to all cases related to horizontal ice loads.

(a) As will be discussed in the next section, vertical ice loads may also get exerted on the dock. The vertical and horizontal loads will not act at the same time. Hence, a combined case with both vertical and horizontal ice loads does not need to be included in the ice design criteria.

(b) The horizontal loads defined for all cases are <u>unfactored</u>. Load factors or safety factors must be applied to them within the context of the design basis being used.

(c) The dock's design should be in conformance with the National Building Code of Canada.

(d) Various components of the dock may be contacted by the ice (e.g., only the deck and a walkway if present; only the supports to the deck such as piles or cribs, and; a combination of the two). The dock must provide adequate structural integrity against horizontal ice loads for all possible cases. For the case where both the deck and the piles are contacted by the ice, the dock's structural integrity for horizontal ice loads must be checked for the case where the respective horizontal ice loads are exerted on each of the individual dock components (i.e., piles only and deck only).

(e) Horizontal ice forces shall be applied as a line load acting uniformly over the full width of contact between the ice and the pile or deck, or both, depending on the case being considered. Note that the ice load for the deck or walkway reduces with the loaded width (Section 4.3). Ice loads must be considered as follows:

   a. Deck or walkway – The deck's structural integrity must be checked for all possible loading widths. Furthermore, the location of the most severe ice load (corresponding to a low loaded width) may occur at any point along the length of the dock face or the walkway if present. The dock's structural integrity must be checked for all possible cases.

b. Pile or cribs – The number of piles loaded during an ice impact may vary from only one, to all of those potentially in contact with the ice. The dock's structural integrity must be checked for all possible cases.
c. Abutment - The abutment's structural integrity must be checked for all possible loading widths. Furthermore, the location of the most severe ice load (corresponding to a low loaded width) may occur at any point along the length of the abutment. Its structural integrity must be checked for all possible cases.

(f) For a dock with multiple components (e.g., a deck and a walkway), horizontal loads may act on either structure at the same time. The possible cases range from only one of the structures being loaded to all structures being loaded at the same time. The dock's structural integrity must be checked for all possible cases.

(g) Horizontal ice forces may be exerted from any direction that is physically possible, as governed by the geometry of the river and the dock. The structure's structural integrity must be checked for all possible loading directions. For an ice-dock contact oriented at an angle to the dock's longitudinal axis, horizontal ice loads should be resolved into components acting simultaneously that are normal to, and parallel to, the dock face. The deck's structural integrity must be checked for all possible loading directions.

(h) The ice line load should be presumed to act one third of the ice thickness below the water level. Because the water surface elevation can vary, all possible cases must be checked.

(i) Stress concentrations will occur at offshore corners of the dock, as well as at sharp changes in geometry such as at the joint between a deck and the walkway. The dock must have adequate structural integrity to resist all possible stress concentrations.

4.2 Horizontal Ice Loads Produced by Ice Jamming

It is recommended that ice jamming forces be calculated based on the Canadian Highway Bridge Design Code (CSA S6-19; CSA, 2019). Horizontal ice jamming forces on docks in the Lower Thames River should be calculated by presuming that an ice pressure of 10 kPa acts on all structure surfaces exposed to the ice jam.

4.3 Horizontal Ice Loads Produced from Impacts by Sheet Ice

4.3.1 The Calculation Approach in the Canadian Highway Bridge Design Code (CSA S6)

It is recommended that ice impact forces be calculated based on the Canadian Highway Bridge Design Code (CSA S6-19; CSA, 2019). Key aspects of the calculation process in CSA S6-19 are summarized in Table 4.2. The reader should refer to the Code for detailed evaluations.

Firstly, the engineer is required to calculate the ice force resulting from: (a) ice bending failure, F_b; (b) ice crushing failure, F_c, and; (c) the transition between the bending and crushing force, F_{bc}. The ice force, F, is determined based on the fact that ice loads will be governed by the failure process leading to the lowest loads. The logic for determining the governing ice load case is also shown in Table 4.2.

Table 4.2: Summary of the Key Components in CSA S6 for Calculating Ice Impact Loads

Item	Approach
Ice load due to bending failure, F_b	$F_b = C_n \sigma t^2$ [4.1] where: $C_n = 0.5 \tan(\alpha + 15°)$ α = the angle between the pier face and the horizontal σ = the ice strength, which is to be selected from the values below
Ice load due to crushing failure, F_c	$F_c = C_a \sigma t w$ [4.2] where: C_a = aspect ratio coefficient = $[(5t/w) + 1]^{0.5}$ w = the pier width t = ice thickness
Ice bending to crushing transition, F_{bc}	$F_{bc} = [(C_n + \sqrt{6}6)/72] \sigma w^2$ [4.3]
Ice strength, σ	**3.12.2.1 Effective ice strength** Unless more precise data is available, the following values for the effective crushing strength of ice, *p*, shall be used: (a) the ice breaks up at melting temperature and is substantially disintegrated: 400 kPa; (b) the ice breaks up at melting temperature and is somewhat disintegrated: 700 kPa; (c) the ice breaks up or ice movement occurs at melting temperature and is internally sound and moving in large pieces: 1100 kPa; and (d) the ice breaks up or ice movement occurs at temperatures considerably below the melting point or the ice: 1500 kPa.
Governing ice load, F	• Ice crushing load <= ice bending force: $F = F_c$ • Ice crushing load > ice bending force: ○ if $F_{bc} >= F_c$, $F = F_c$ ○ if $F_{bc} <= F_b$, $F = F_b$ ○ if $F_c > F_{bc} > F_b$, $F = F_{bc}$

Because CSA S6 was developed for application to highway bridges, not all of it is considered to be applicable to docks in the Lower Thames River. The ice-related procedures in CSA S6 related to Design Cases 1 and 2, non-aligned piers, and small streams are considered to be inapplicable.

4.3.2 Recommended Ice Design Criteria for Calculating Sheet Ice Impact Loads

The following values are recommended for the ice properties, for calculating ice impact loads on docks in the Lower Thames River using the algorithms in CSA S6:

(a) Ice thickness, t: 0.6m
(b) Effective ice crushing strength, σ: 1100 kPa

4.4 Corners

More severe ice actions will occur if the deck has abrupt changes in geometry, such as offshore “corners” protruding from the river shoreline; or at the joint between a walkway and deck. More severe ice action will occur in these locations over distances that are 0.6m or less away from the corner points for any exposed corners, or from abrupt changes in geometry. The line load for the corner sections affected by stress concentrations should be taken as 3 times the line load calculated using equations 4.1 to 4.3.

5.0 Vertical Ice Loads

5.1 The Process for Calculating Unfactored Vertical Ice Loads

5.1.1 Overview of the Calculation Process

The analyses must start by assessing the elevation of the dock above water level, as this affects which dock components will be in contact with the ice. This will vary as the water level is typically elevated at the time of an ice run. Ice loads must be considered for all possible cases.

Vertical ice forces will be exerted on the components of the dock in contact with the ice, by various loading scenarios. For some cases, vertical ice loads may get produced by more than one scenario (e.g., vertical loads on the deck or walkway, or an abutment – Table 3.1). For these cases, the vertical loads produced by each ice loading scenario must be determined using the approaches in Table 5.1; and the governing load must be selected as follows.

Table 5.1: Recommended Approaches for Vertical Ice Loads on Individual Dock Components

Dock	Loading	Ice Loading Scenario and Recommended Calculation Approach		
Component	Type	Impact by Sheet Ice	Water Level Change	Ice Jamming
Pile or Crib	Vertical	Not relevant	As per Section 5.3	Not relevant
Deck or Walkway	Vertical	Not relevant	As per Section 5.4	As per Section 5.5
Abutment	Vertical	Not relevant	As per Section 5.4	As per Section 5.5

The structural integrity of either a deck and walkway, or an abutment, must be checked for both ice loading scenarios as they apply different loadings. Vertical loads from water level changes are distributed uniformly around the perimeter of the structure that is in contact with the ice. However, the loads due to ice jamming are only exerted on the faces that are in contact with the moving ice in the River (e.g., the faces upstream or along the length of the River), which has the potential to cause the deck or walkway, or the abutment, to be rotated or lifted off its supports. As a result, the vertical loads due to ice jamming must only be applied to the faces that are upstream or along the length of the structure in contact with the ice.

Note that, for all the cases listed in Table 3.1, the different ice loading scenarios would not occur at the same time; so a loading case combining the ice loads from different scenarios need not be included in the ice design criteria.

The individual vertical ice loads should then be summed as appropriate taking into account the specific dock geometry and the water surface elevation.

Then, vertical ice forces should be evaluated for the range of loading directions that is physically possible, as governed by the geometry of the river and the dock. The structure's structural integrity must be checked for all possible loading directions.

5.1.2 Application Notes

The following notes are applicable to all cases related to vertical ice loads.

(a) As discussed in section 4, horizontal ice loads will also get exerted on the dock. The vertical and horizontal loads will not act at the same time. Hence, a combined case with both vertical and horizontal ice loads does not need to be included in the ice design criteria.

(b) The vertical loads defined for all cases are unfactored. Load factors or safety factors must be applied to them within the context of the design basis being used.

(c) The dock's design should be in conformance with the National Building Code of Canada.

(d) Vertical loads may act either downwards or upwards. The deck's structural integrity must be checked for both loading directions.

(e) Various components of the dock may be contacted by the ice (e.g., the deck or walkway only; the piles or cribs only; or a combination of the two). The dock must provide adequate structural integrity against vertical ice loads for all possible cases. For the case where both the deck and the piles are contacted by the ice, the dock's structural integrity for vertical ice loads must be checked for the case where the respective vertical loads are exerted on each of the individual dock components (i.e., piles only and deck only).

(f) Vertical ice forces for a pile or crib – these shall be applied as follows:

    a. Pile or crib – Vertical ice forces shall be applied as a line load acting uniformly over the full circumference of the pile. The number of piles loaded may vary from only one, to all of those potentially in contact with the ice. The dock's structural integrity must be checked for all possible cases.

(g) Vertical ice forces for a deck or walkway; or an abutment – the load application shall vary depending on the scenario producing vertical loads, as follows:

    a. Vertical loads produced by water level changes – Vertical ice forces shall be applied as a line load acting uniformly over the perimeter of contact between the ice and the deck or walkway. The deck's structural integrity must be checked for all possible loading widths, ranging from as low as 3m to the full length of the dock face. Furthermore, the location for a low loaded width (such as 3m) may occur at any point along the length of the dock face. The dock's structural integrity must be checked for all possible cases.

    b. Vertical loads produced by ice jamming – Vertical ice forces shall only be applied on the faces of the structure the faces that are in contact with the moving ice in the River (i.e., facing upstream or along the length of the River). Thus they have the potential to cause lifting or rotation of the deck or walkway; or abutment. The following shall be done:

i. Vertical loads shall be applied as a line load acting uniformly over various lengths up to the full length or width of the structure that is in contact with the moving ice in the River (e.g., the faces upstream or along the length of the River). The abutment's structural integrity must be checked for all possible loading widths, ranging from as low as 3m to the full length of the abutment face. Furthermore, the location for a low loaded width (such as 3m) may occur at any point along the length of the abutment. The abutment's structural integrity must be checked for all possible cases.
ii. For a dock with multiple components (e.g., a deck and a walkway), the number of structures loaded may vary from only one, to all of those potentially in contact with the ice. The dock's structural integrity must be checked for all possible cases.

(h) Vertical ice forces for a pile or crib – Vertical ice forces shall be applied as a line load acting uniformly over the full circumference of the pile. The number of piles loaded may vary from only one, to all of those potentially in contact with the ice. The dock's structural integrity must be checked for all possible cases.

(i) For a dock with a deck and a walkway, vertical loads may act on the face of either structure at the same time. The possible cases range from only one of the structures being loaded to all structures being loaded at the same time. The dock's structural integrity must be checked for all possible cases.

5.2 Unfactored Uplift Forces on a Single Pile or Structure

5.2.1 Single Vertical Cylindrical Pile

For a vertical cylindrical pile, the unfactored uplift force on a single pile, P_{uplift}, shall be calculated as follows:

$$P_{uplift} = \tau * A_c \quad [5.1]$$

where:

A_c = the area of the ice in contact with the pile, defined as: $K_{bustle} \pi dh$ [5.2]

τ = the ice failure stress, as defined in equation [5.3]

K_{bustle} = an empirical factor to account for the effect of an ice bustle at the pile (Table 5.2)

d = the pile diameter

h = the ice thickness. For docks in the Lower Thames River, "h" shall be taken as 0.6m.

π = a numerical constant, to be taken as 3.1416

The ice failure stress, τ, shall be calculated as follows:

$$\tau, \text{kPa} = K_{surface} * 300/(d/h)^{0.6} \quad [5.3]$$

where:

τ = the ice failure stress, in kPa

$K_{surface}$ = an empirical factor to account for a surface coating on the pile, as defined in Table 5.2

Table 5.2: Recommended Ice Bustle and Surface Factors

Pile Material	K_{bustle}	$K_{surface}$
Bare Solid Wood	1.0	1.0
Solid Wood with a low-friction surface coating (notes 2 and 3)	1.0	0.5
Bare Solid Concrete	1.0	1.0
Solid Concrete with a low-friction surface coating (notes 2 and 3)	1.0	0.5
Bare Steel Cylinder filled with air inside it	2.0	1.0
Bare Steel Cylinder filled with insulation inside it (note 1)	1.4	1.0
Bare Steel Cylinder filled with concrete	1.7	1.0
Hollow Steel Cylinder filled with air, and with a low-friction surface coating (notes 2 and 3)	1.0	0.5
PVC Cylinder filled with air inside it	2.0	0.2
Polyethylene Cylinder filled with air inside it	2.0	0.2

Notes:

1. The insulation inside the steel cylinder must have a thermal conductivity equal to or less than that for vermiculite.
2. The adhesion strength between the coating and the ice must be equivalent to or less than that for Inerta 160.
3. The low-friction coating must remain on the pile over the design life of the pile.

5.2.2 Single Non-Cylindrical Pile

For a non-cylindrical vertical pile, the unfactored uplift force on a single pile, P_{uplift}, shall be calculated using equations [5.1] to [5.3] with the following changes:

"d" "d" shall be determined as $(xy)^{0.5}$ where x and y are the length and width of the pile's cross-section at the waterline respectively.

"A_c" "A_c" shall be determined as: $2*(x+y) * K_{bustle} * h$

5.2.3 Single Rectangular Crib

The unfactored uplift force on a single vertical rectangular crib, P_{uplift}, shall be calculated using equations [5.1] to [5.3] with the following changes:

"d" "d" shall be determined as $(xy)^{0.5}$ where x and y are the length and width of the crib's cross-section at the waterline respectively.

"A_c" "A_c" shall be determined as: $2*(x+y) * K_{bustle} * h$

5.2.4 Group of Vertical Piles or Cribs

The unfactored uplift force on individual piles or cribs within a group shall be taken to be equal to the uplift force determined using equations [5.1] to [5.3] for single isolated piles or cribs.

The maximum total uplift force, $Uplift_{total}$, shall be determined as follows.

$Uplift_{total}$ = # of piles or cribs * P_{uplift} [5.4]

where:

# of piles or cribs = the number of individual piles or cribs in the group

P_{uplift} = the uplift force for a single pile or crib determined using equations [5.1] to [5.3]

For groups of piles, vertical loads may act on a number of the piles at the same time. The possible cases range from only one of the piles being loaded to all piles being loaded at the same time. The dock's structural integrity must be checked for all possible cases.

5.2.5 Application Notes

The following notes are applicable to all cases in section 5.2.

(a) The loads and stresses defined for all cases above are unfactored. Load factors or safety factors must be applied to them within the context of the design basis being used.
(b) Uplift forces shall be applied as a line load, defined as the total uplift force divided by the circumference or perimeter of the pile or crib respectively.
(c) Uplift forces act vertically in a direction that is either upwards or downwards. The pile's structural integrity must be checked for both loading directions.
(d) For groups of piles or cribs, vertical loads may act on a number of the piles or cribs at the same time. The possible cases range from only one of the structures being loaded to all of them being loaded at the same time. The dock's structural integrity must be checked for all possible cases.
(e) For cases in which treatments are done to the pile or crib to lower the ice uplift forces, as illustrated by the examples below, the dock proponent must demonstrate that the treatment will be effective over the design life of the pile or crib.
    a. Filling the pile's interior with insulation.
    b. Applying a low-friction coating to the surface of the pile or crib.

5.3 Uplift Forces Exerted by Water Level Changes on a Deck or an Abutment

5.3.1 Ice Uplift Forces on a Deck, Walkway or Abutment due to a Rise in Water Level

Similar to the uplift forces on a pile or crib, this loading originates from water level changes, with the structure being solidly frozen into the ice. However, because a deck or abutment is a much larger structure compared to a pile, the ice loading process is different in that radial and circumferential cracking are the dominant mechanisms.

This case is analogous to the vertical loads exerted on a bridge pier due to ice adhesion (as the size of a bridge pier is in the same range as that for a dock's deck). This is covered in CSA S6-19 which states that the vertical force due to water level fluctuations, F_v, on a pier frozen to an ice formation shall be calculated as follows:

(a) For circular piers:

$$F_v \text{ (in kN)} = 1250t^2 * (1.05 + 0.13R/t^{0.75}) \quad [5.5]$$

(b) For oblong piers:

$$F_v \text{ (in kN)} = 15L_p\, t^{1.25} + 1250t^2 * (1.05 + 0.13R/t^{0.75}) \quad [5.6]$$

where:

t = the ice thickness

R = radius of a circular pier, m; radius of half-circles at the ends of an oblong pier, m; radius of a circle that circumscribes each end of an oblong pier whose ends are not circular in plan at water level, m.

L_p = perimeter of an oblong pier, excluding half-circles at the ends, m

5.3.2 Application Notes

The following notes are applicable to all cases in section 5.3.

(a) The loads and stresses defined for all cases above are unfactored. Load factors or safety factors must be applied to them within the context of the design basis being used.
(b) Uplift forces shall be applied as a line load acting uniformly over the full length of contact between the ice and the abutment or deck. The uplift line load shall be calculated as the total uplift force (i.e., Fv) divided by the total dock perimeter that is in contact with the ice.
(c) Uplift forces may act vertically in a direction that is either upwards or downwards. The structure's structural integrity must be checked for both loading directions.
(d) For a dock with a deck and a walkway, vertical loads may act on either structure at the same time. The possible cases range from only one of the structures being loaded to all structures being loaded at the same time. The dock's structural integrity must be checked for all possible cases.

5.4 Uplift Forces Produced by Ice Packing in Under the Deck

5.4.1 Process Description and Recommended Calculation Approach

During an ice run, ice may "pack in" under the deck of a dock, thereby creating uplift forces. The vertical force will most likely be controlled by the strength of the rubble and the loading mechanism. Two force components must be defined to calculate the vertical ice loads for this case:

(a) The horizontal force exerted by the pack ice, and then;

(b) The component of the horizontal force that is exerted vertically.

It is recommended that the load to fail the rubble be determined using recommendations in the Canadian Highway Bridge Design code (i.e., CSA S6 – 19), which specifies a pressure due to ice jams of 10 kPa for openings of 30m or less. The horizontal line load is calculated as follows:

$$H_{Rubble\ Line\ Load} = q * d \quad [5.7]$$

where:

$H_{Rubble\ Line\ Load}$ = the rubble line load, in kN/m
q = the rubble ice pressure, to be taken as 10 kPa
d = the water depth, in m

The vertical load exerted on a deck may be determined presuming that a planar failure plane is produced in the rubble. Algorithms in ISO 19906 (ISO, 2010; 2018) are available to resolve the vertical line load, $V_{Rubble\ Line\ Load}$, for this case as follows:

$$V_{Rubble\ Line\ Load} = H_{Rubble\ Line\ Load} / \xi \quad [5.8]$$

$$\xi = (\sin\alpha + \mu\cos\alpha)/(\cos\alpha - \mu\sin\alpha) \quad [5.9]$$

where:

α = the angle of the failure plane, recommended as 45° here
μ = the friction factor along the failure plane, recommended as 0.2 here

5.4.2 Recommended Inputs: The Strength of the Rubble and Other Key Ice Properties

The following recommendations are made:

(a) Failure of the ice rubble through the creation a slip plane: the rubble load should be calculated using a horizontal pressure of 10 kPa as given in CSA S6-19.
(b) Shape of the failure plane: it should be considered to be planar with an angle of 45°
(c) Friction along the failure plane, for resolving vertical and horizontal forces: this should be taken as 0.2.

6.0 Criteria Related to Ice Jamming

6.1 Introduction

The recommendations here provide qualitative assessments of a dock's potential to exacerbate ice jamming. They are based primarily on the LTVCA's practical experience in this area.

6.2 Preliminary Recommendations

The LTVCA's experience to date must be interpreted with care. Nevertheless, it does provide useful insights regarding the likely effect of a dock on ice jamming.

The following preliminary recommendations are made:

(a) Docks on an outside bend versus at any location downstream of Chatham – it is not necessary to have different criteria depending on the dock's location along the River.
(b) Offshore length – the offshore length of a dock should not exceed 3m.
(c) Continued monitoring – the LTVCA should continue to monitor docks in the River and update these recommendations as appropriate.

7.0 Recommendations Regarding Ice Monitoring

The recommendations fall into two general categories:

(a) Observations and monitoring that would lead to an improvement in this Ice Guideline.
(b) The type of analyses that are required to ensure that a proposed dock meets the ice load criteria set out in this Guideline.

7.1 Field Monitoring to Optimize this Ice Guideline

The following field observations would help to improve this Guideline.

(a) Dock damage record – a record should be kept of all damages suffered by docks, especially ones that are ice-related. The record should include: (i) the location and type of dock damage that occurred, and; (ii) the type of dock that was damaged. Recognizing that it may be difficult to obtain a dock damage record in practice, it is suggested, that drone surveys be done each year after the ice season as an alternative.
(b) Impact of docks on ice jamming – records and notes should be kept regarding any impact that docks may have had on ice jams that occurred.
(c) Ice interaction with docks – it is suggested that photos be taken during the normal course of monitoring operations (of which there is an extensive record of photos and videos so far), that are aimed at showing the fate and behaviour of docks during ice runs.

7.2 Structural Analyses for Docks

Ice loads are specified in this Guideline. To be effective, dock proponents must be required to demonstrate that their proposed dock is safe for the prescribed ice loadings. Of course, this can be evaluated using various methods that vary in complexity.

For maximum flexibility, it is believed that the LTVCA should not specify the type of analysis that must be done, other than to require the following:

(a) The analyses must be in conformance with the Canadian National Building Code.
(b) The analyses must be stamped by a professional engineer licensed to practice in Ontario.

8.0 References

[1] Comfort, G., 2021, Ice Guideline for Docks in the Lower Thames River – Technical Background, report 173-1 submitted by G Comfort Ice Engineering Ltd. to the Lower Thames River Conservation Authority.

[2] CSA, 2019, Canadian Highway Bridge Design Code S6-19, Canadian Standards Association, Rexdale, ON.

[3] ISO, 2010, Petroleum and Natural Gas Industries – Arctic Offshore Structures, International Standards Organization ISO/DIS 19906.

[4] ISO, 2018, Petroleum and Natural Gas Industries – Arctic Offshore Structures, International Standards Organization ISO/DIS 19906, update at FDIS stage.