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COURSE

Coastal and Ocean Engineering - 8751

INSTRUCTOR

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TOPIC

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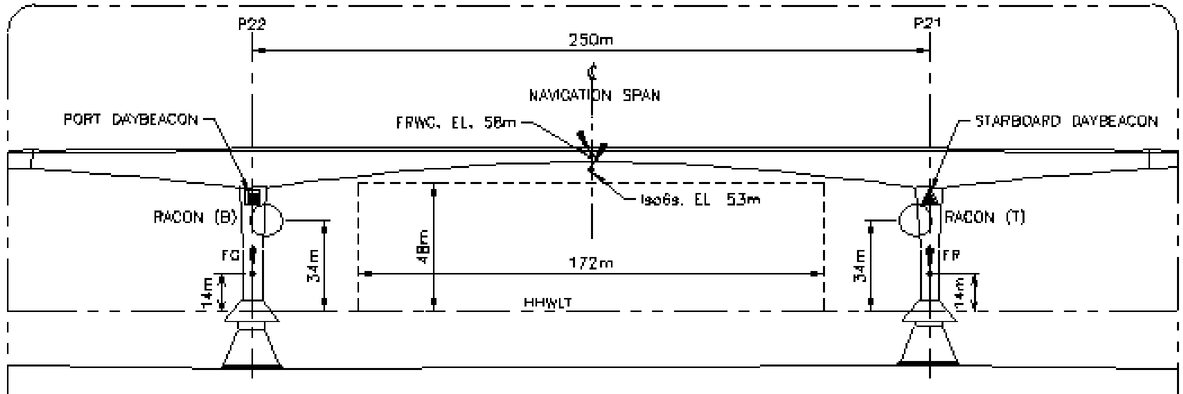
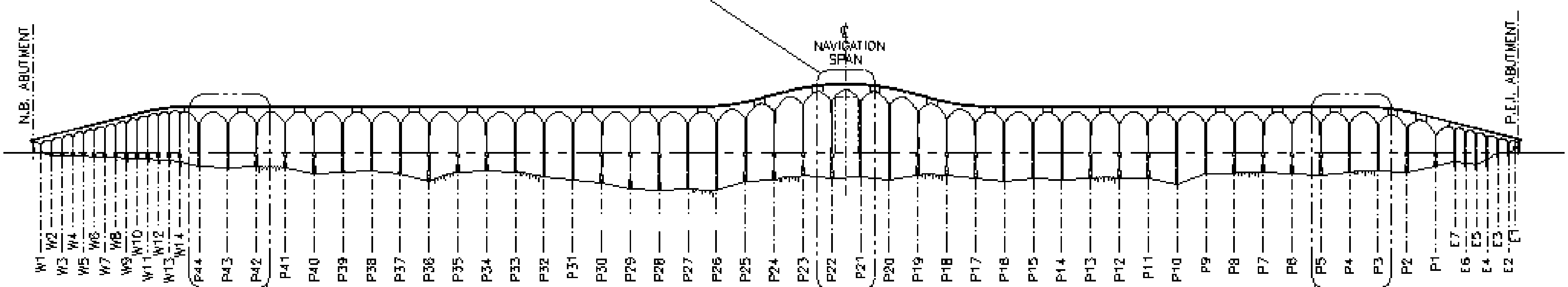
Confederation Bridge

http://www.confederationbridge.com/en/about_the_bridge/bridge_faqs.php



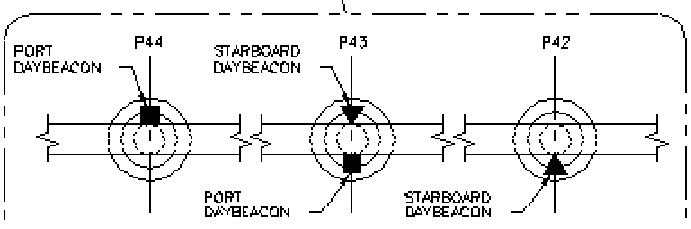
NAVIGATION SPAN ELEVATION

SCALE N.T.S.



ELEVATION OF THE CONFEDERATION BRIDGE

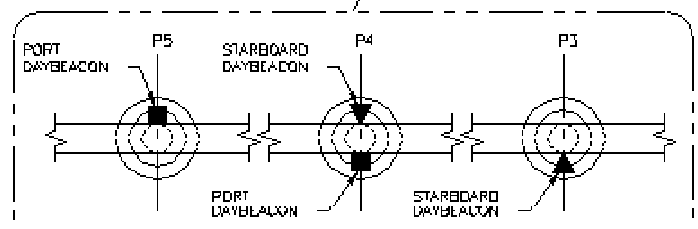
SCALE: N.T.S.



N.B. NEAR SHORE NAVIGATION CHANNELS
PLAN VIEW

SCALE: N.T.S.

PIER COORDINATES		
PIER NO.	LATITUDE	LONGITUDE
P3	46° 14' 33.29" N	63° 42' 53.76" W
P4	46° 14' 26.92" N	63° 43' 00.96" W
P5	46° 14' 20.54" N	63° 43' 08.16" W
P21	46° 12' 38.99" N	63° 45' 04.02" W
P22	46° 12' 32.85" N	63° 45' 11.62" W
P42	46° 10' 36.07" N	63° 47' 53.11" W
P43	46° 10' 30.16" N	63° 48' 01.09" W
P44	46° 10' 24.23" N	63° 48' 09.02" W



P.E.I. NEAR SHORE NAVIGATION CHANNELS
PLAN VIEW

SCALE: N.T.S.

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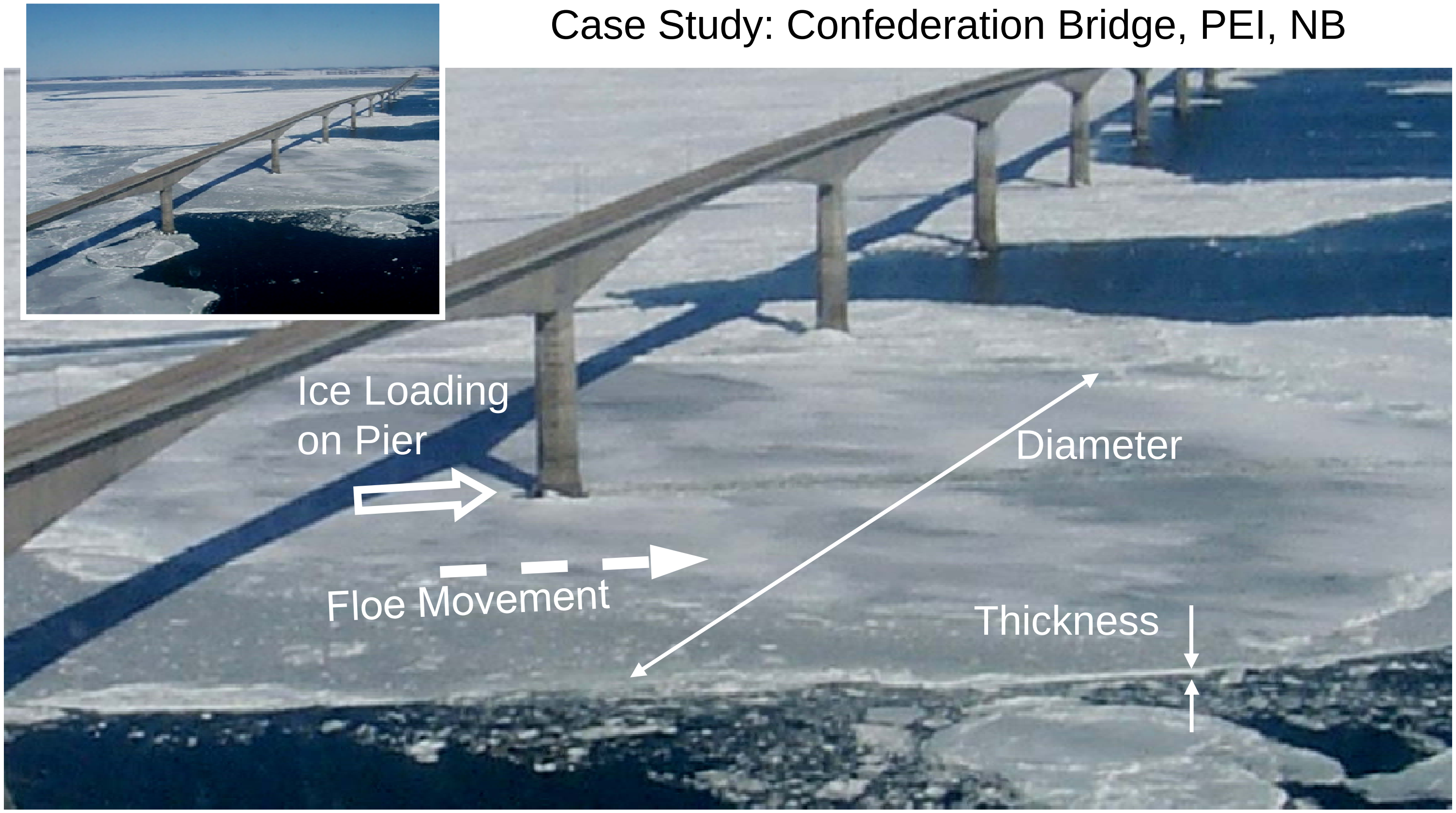
NOTES

Class Study in Monte Carlo Simulation for Probabilistic Load Estimating . . .

Case Study: Confederation Bridge, PEI, NB



Simplified Assumptions for Illustrative Purposes

A 100 year design load for pier stability required by developer. Models suggest:

1) Pier Force = Lesser of **Ice Crushing** or **Driving Force**
2) Ice Crush Resist = Ice Thickness * constants
3) Driving Force = Floe Diameter * Wind * constants
4) Ice thickness is independent of floe size is independent of wind

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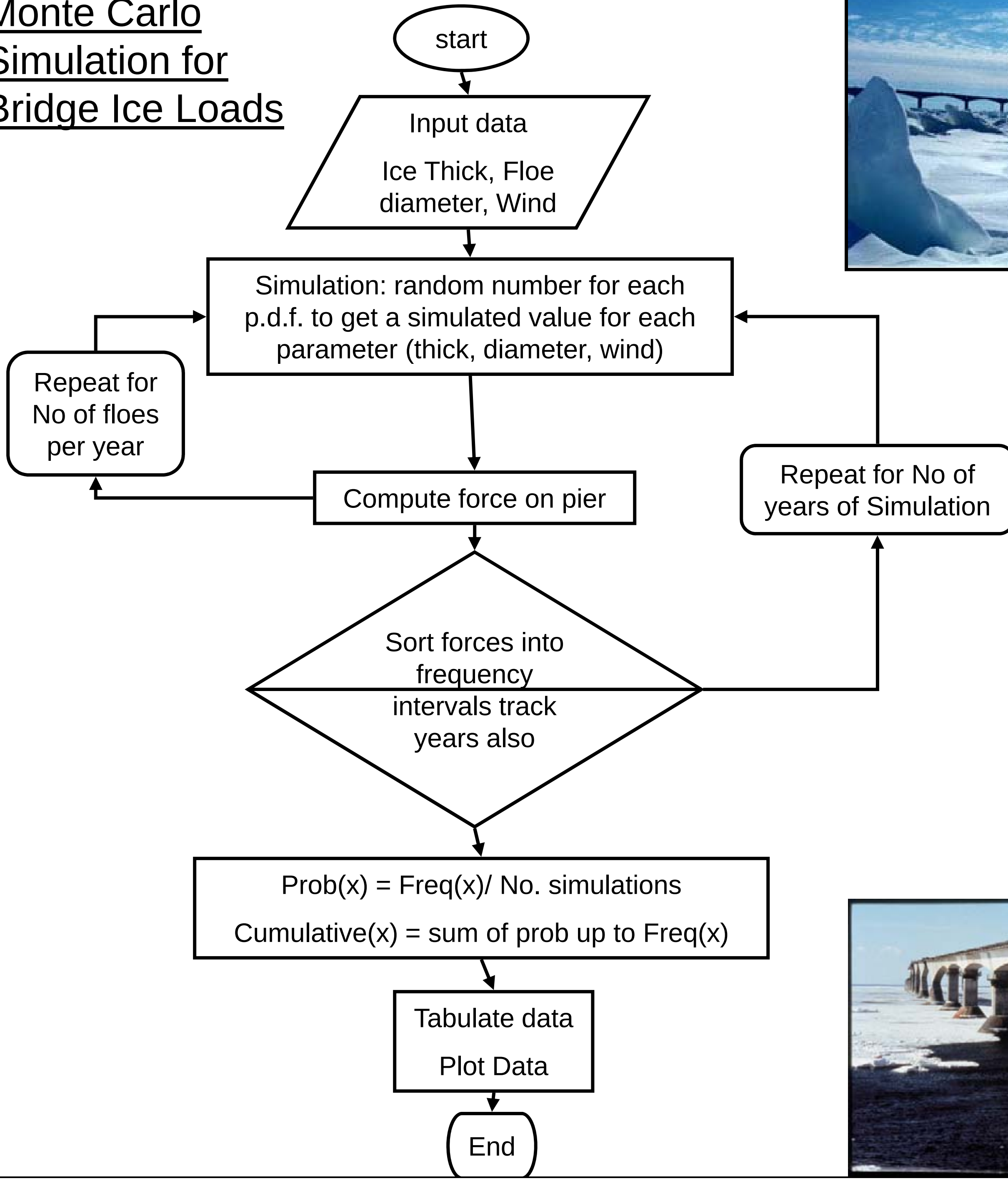
Monte Carlo Simulation for Bridge Ice Loads



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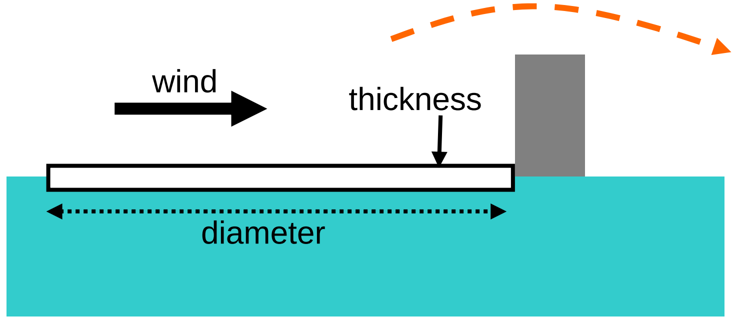
F(pier) = *lesser of* F(thick), F(diameter, wind)



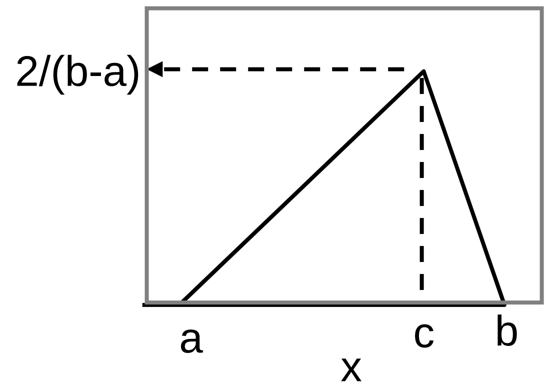
These three factors are naturally random independent variables that affect loading every time a collision occurs – perhaps millions of times over the life of the structure, therefore. . .

We must research and judge what the best representative probability distributions are that will provide the best long term estimates for each. In this case study lets assume that a ***triangular probability*** distribution is sufficient.

The Triangular Distribution is typically used in cases where the relationship between variables is known but data is scarce (possibly because of the high cost of collection). It is based on a knowledge of the minimum and maximum and an "inspired guess" as to the modal value. the **triangular distribution** is a continuous probability distribution with lower limit *a*, mode *c* and upper limit *b*

$$f(x|a,b,c) = \begin{cases} \frac{2(x-a)}{(b-a)(c-a)} & \text{for } a \le x \le c \\ \frac{2(b-x)}{(b-a)(b-c)} & \text{for } c \le x \le b \end{cases}$$

(height of triangle)



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Therefore, we define the triangular probability density functions for our random variables with estimates for a, b and c. For example:

For period of 100 years

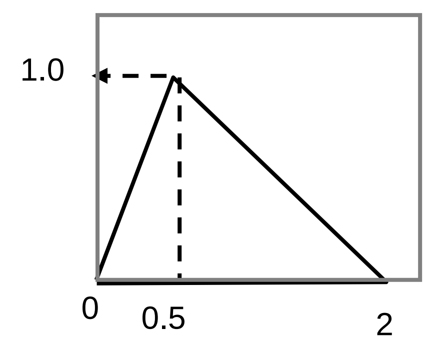
	Minimum a	***Mode*** c	***Maximum*** b
Ice Thickness	0	0.5	2
Floe Diameter	0	200	7000
Wind	0	20	140

Lets just say that this is what you guessed

Now, what do we know:

1. The area under a probability density function is equal to 1.0 (triangular included)
2. The random variable (thickness etc) always has a value somewhere between a and b
3. For each collision in a monte carlo simulation we need a value for the random variable that is between a and b and weighted towards c in accordance with the probability function.

For ice Thickness



We get this random value each time using the following …

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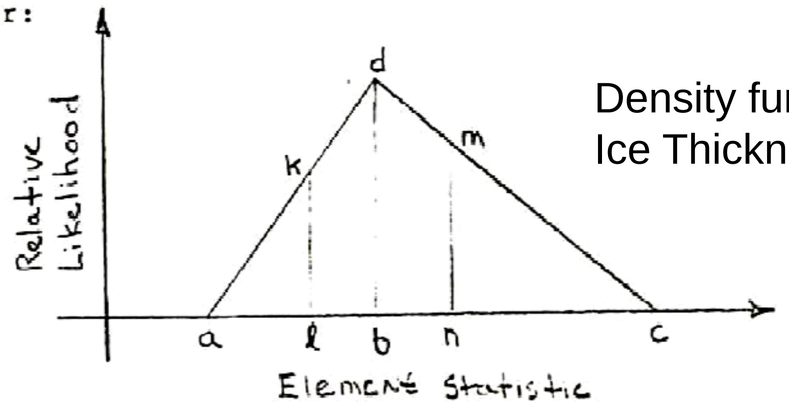
Select Triangular:



Density function for Ice Thickness

Area of Triangle:

$$\text{Area} = \frac{d}{2}\left[(b-a)+(c-b)\right] = 1.0 = \frac{d(c-a)}{2}$$

(A) Prob. from a-b:

$$k = \frac{d(l-a)}{(b-a)} = \frac{2(l-a)}{(c-a)(b-a)}$$

Probability of Thickness (l) = P

$$P = \frac{1}{2}(l-a)k = \frac{1}{2}(l-a)\frac{2(l-a)}{(c-a)(b-a)} = \frac{(l-a)^2}{(c-a)(b-a)}$$

Thickness at Probability P = (l)

$$l = \sqrt{P(c-a)(b-a)} + a$$

Similarly,

(B) Prob. from b-c:

$$M = \frac{d(c-n)}{(c-b)} = \frac{2(c-n)}{(c-a)(c-b)}$$

Probability of Thickness (n) = P

$$P = 1 - \frac{M}{2}(c-n) = 1 - \frac{(c-n)(c-n)}{(c-b)(c-a)} = 1 - \frac{(c-n)^2}{(c-a)(c-b)}$$

Thickness at Probability P = (n)

$$n = c - \sqrt{(1-P)(c-a)(c-b)}$$

So, a random number generator is used to give a value for P between 0 and 1, thus a value of l or n is computed with the formulas above, giving. . .

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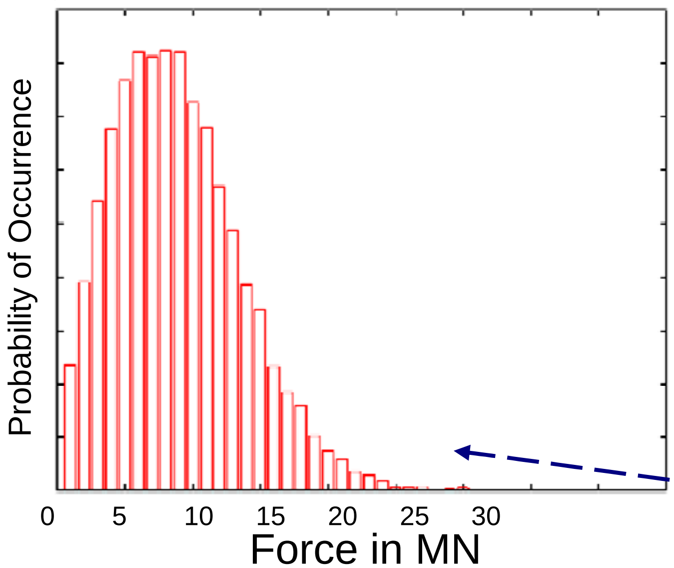
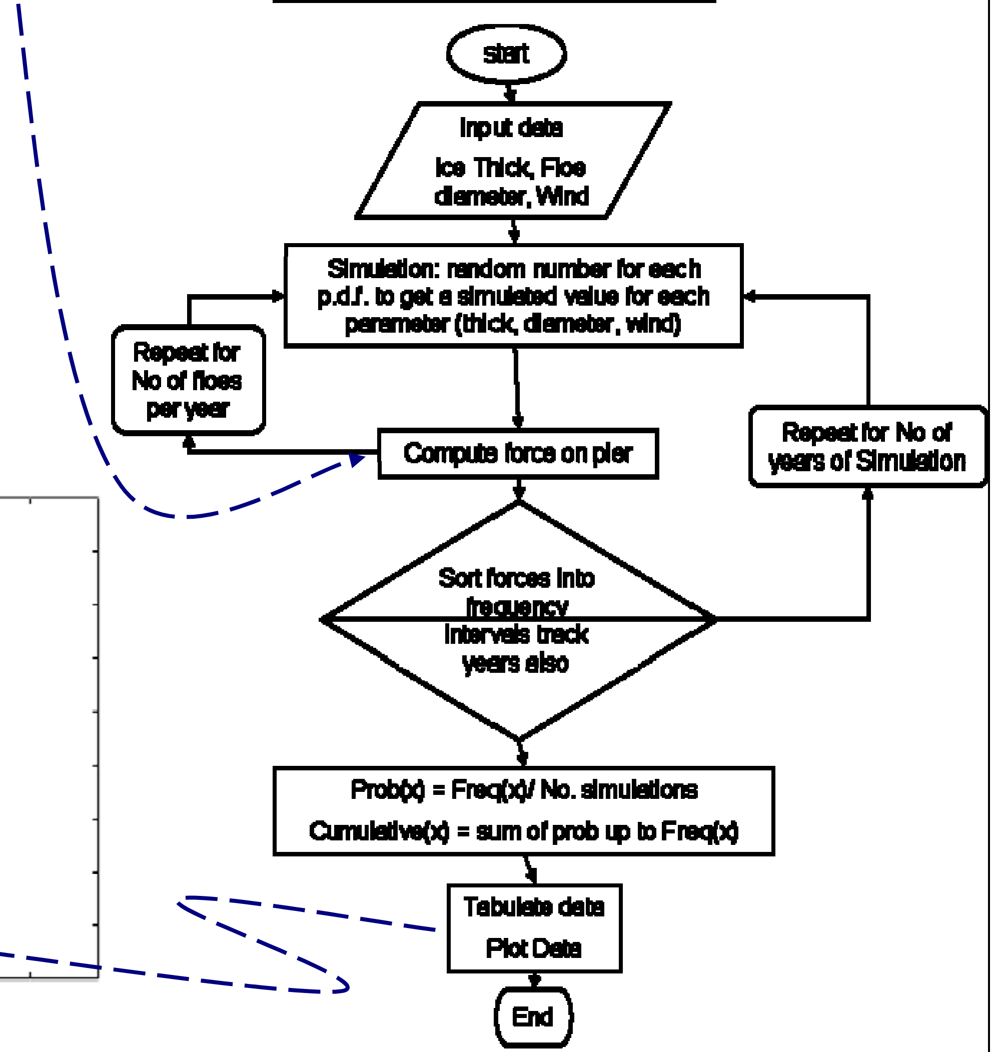
A value for thickness, diameter and wind. We then use the deterministic formulas that we know about for Ice Cruching Force and Driving forces to get a force on the pier , ie. . .

F(pier) = *lesser of* F(thick), F(diameter, wind)

So we end up with this after many, many collisions are modeled in the simulation



Monte Carlo Simulation



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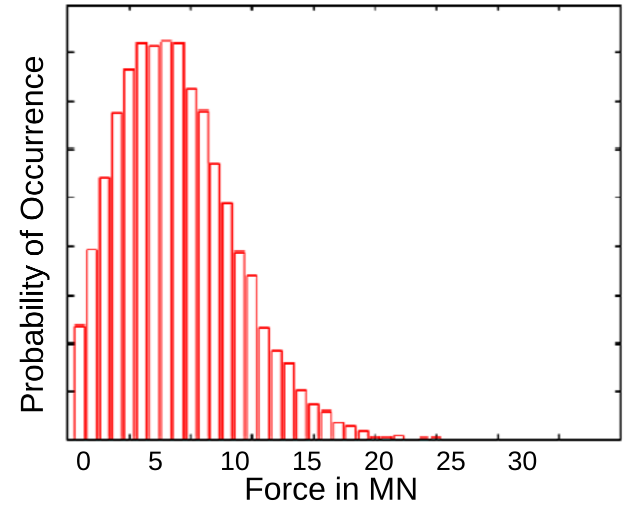
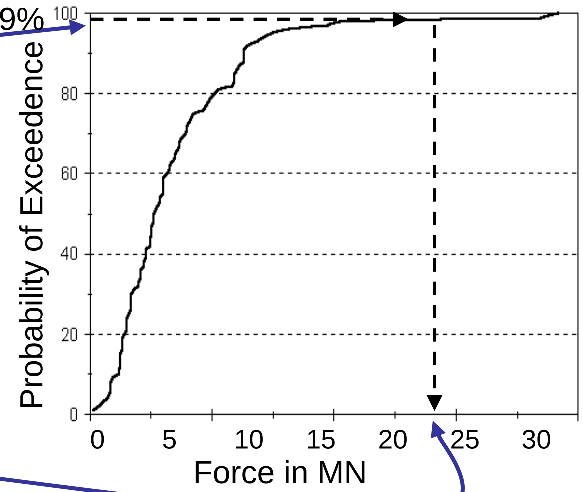
So from this figure we can get the probability of exceedance for any risk level over the period of the simulation.



So, if you want a design load value that will not be exceeded more than once in a 10,000 years

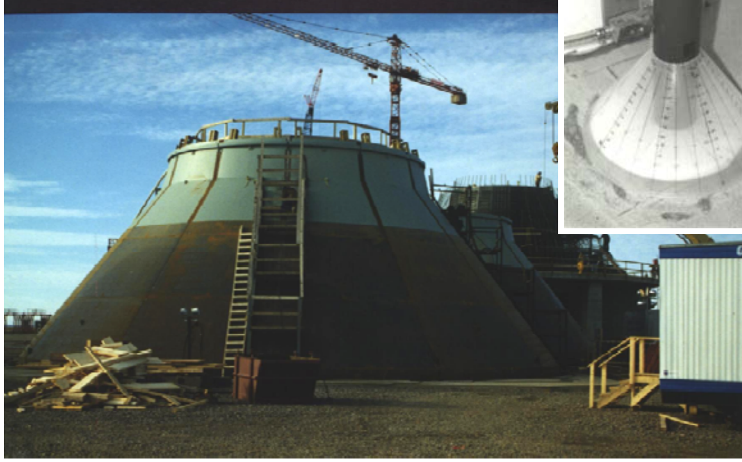
99.99%



Here's your number!

24 MN

Fixed Link and the Confederation Bridge



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Getting Ice Floe Thicknesses

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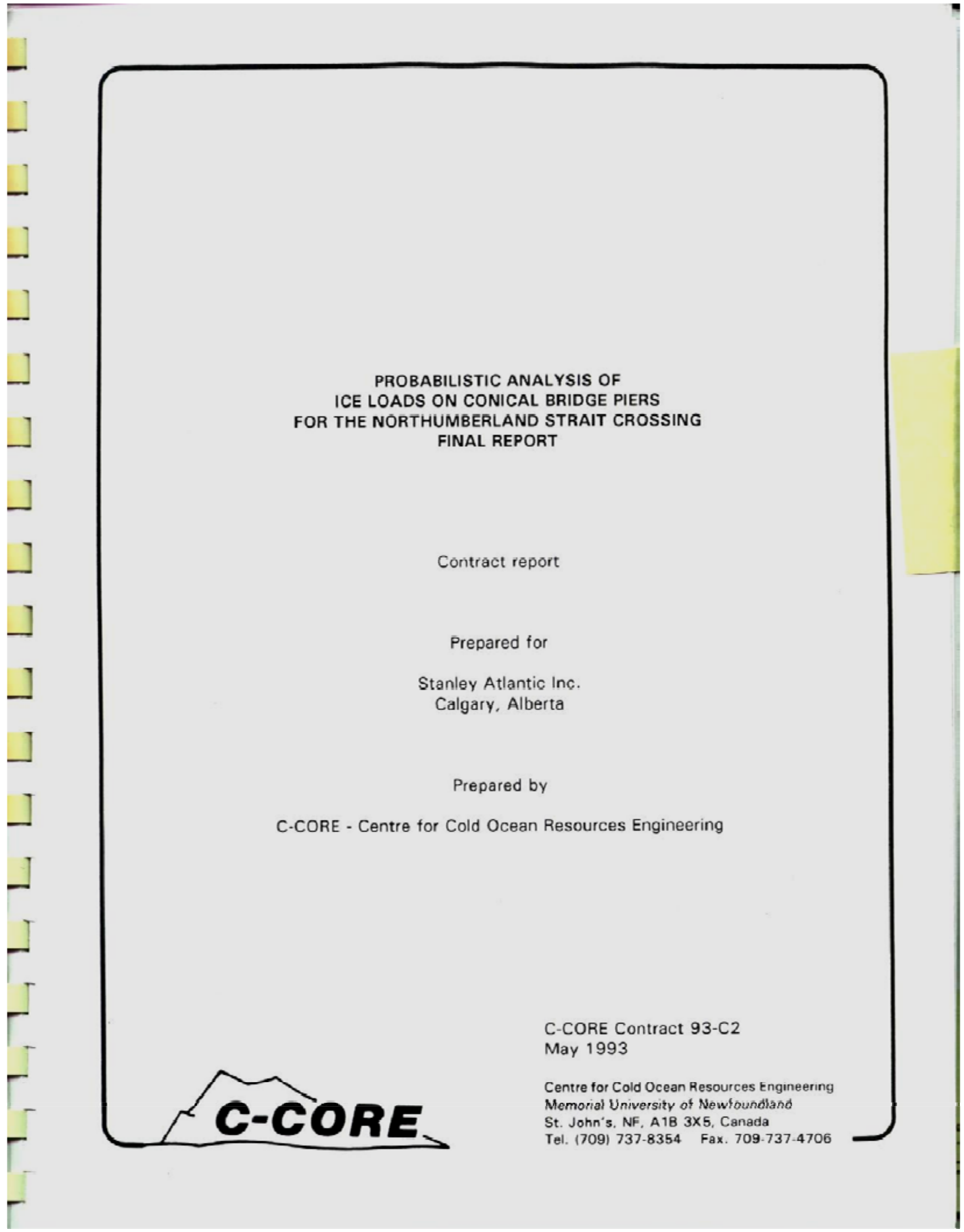

PROBABILISTIC ANALYSIS OF
ICE LOADS ON CONICAL BRIDGE PIERS
FOR THE NORTHUMBERLAND STRAIT CROSSING
FINAL REPORT

Contract report

Prepared for

Stanley Atlantic Inc.
Calgary, Alberta

Prepared by

C-CORE - Centre for Cold Ocean Resources Engineering

C-CORE Contract 93-C2
May 1993

C-CORE

Centre for Cold Ocean Resources Engineering
Memorial University of Newfoundland
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The correct citation for this report is:

Cammaert, A.B., Jordaan, I.J., Bruneau, S.E., Crocker, G.B., McKenna, R.F., and Williams, S.A. "Probabilistic Analysis of Ice Loads on Conical Bridge Piers for the Northumberland Strait Crossing Project". Contract report for Stanley Atlantic Inc., C-CORE Contract Number 93-C2.

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Probabilistic Estimating: Cost exampl

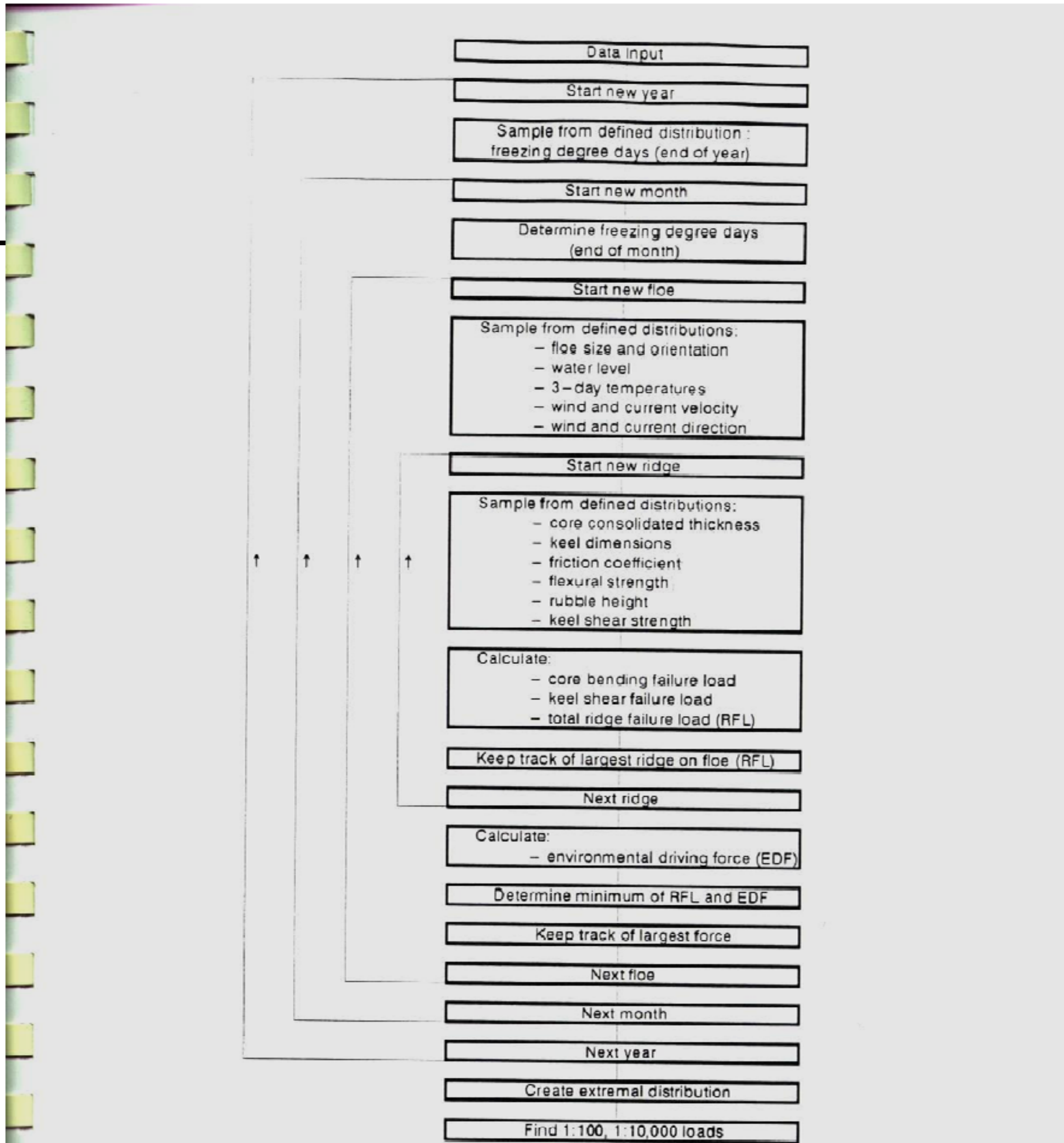

Figure 1.3 Overall Probabilistic Model Framework.

May 14, 1993

1.5

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NOTES

Probabilistic Estimating: Cost example

```
'
'***********************************************
'              C-CORE PROGRAM
'
'   PROGRAM TO ASSESS LOADING ON BRIDGE PIERS IN
'   NORTHUMBERLAND STRAIT
'
'   FORCE OF CRUSHING AND SHEARING CONSOLIDATED ICE RIDGE
'   (MONTHLY STATS TO BE INCORPORATED)
'
'   THIS FILENAME: kingcone2.BAS
'
'   REVISED: FROM PIERCOL2 ON SEPT14
'            FOR INCLUSION OF DRIVING FORCES
'            AND STATISTICAL WEATHER DATA
'
'            REVISED TO ACCOMMODATE WIND DIRECTION COSINE
'            CURRENT DIRECTION RELATIONSHIPS
'
'            REVISED ON JAN28/93 FOR FINAL SIMULATION
'            OF RIDGE LOADS ON PIERS
'
'            NEWCONE EVOLVED FROM CONEPIER ON MARCH 2/93
'            FOR FINAL RUN INCLUDING CHANGES FROM LATE
'            FEBRUARY TRIP TO CALGARY (CAMM)
'
'
'            SEB REVISED ON mARCH 31/93 FOR NEW RAN NUMBER GENERATOR
'            AND ALSO CHECK RIDGE KEEL STRENGTH CALC FOR PARALLEL CONTACT
'
'
'            EVOLVED FROM NCONE.BAS FOR LOOKING AT UPPER TAIL
'
'
'            REVISION AFTER mAY 12 MEETING FROM LONGCONE TO SCICONE.BAS
'
'         SEB92 -AUG25 - FEB93 - MAR93
'***********************************************

DECLARE SUB NORMAL (VAR#, MEAN#, STD#, IDUM&, IFF&)
DECLARE SUB LOGNORM (LVAR#, MEAN#, STD#, IDUM&, IFF&)
DECLARE SUB UNIFORM (THICKFAC#, THICKMIN#, THICKMAX#, IDUM&, IFF&)
DECLARE SUB GAMA (GAM#, MEAN#, STD#, IDUM&, IFF&)
DECLARE SUB RAN1 (IDUM&, IFF&, RANN#)
DECLARE SUB WDIRMAR (FETCH#, ALFA#, SPEED#, IDUM&, IFF&)
DECLARE SUB WDIRAPR (FETCH#, ALFA#, SPEED#, IDUM&, IFF&)
DECLARE SUB DAY3MAR (TEMP3#, IDUM&, IFF&)
DECLARE SUB DAY3APR (TEMP3#, IDUM&, IFF&)
DECLARE FUNCTION MODULUS! (B&, C&)

DIM NUMDAY(2)
DIM THICBIN(1000), TBIN(1000), SIGFBIN(1000)
DIM PIERBIN(1000), RIGBIN(1000)', DRIVBIN(10000)
DIM YCOREBIN(1000), YTHICBIN(1000)

COMMON SHARED IX1&, IX2&, IX3&
DIM SHARED R(100)
```

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EXECUTIVE SUMMARY

This report has been prepared in response to a request from Stanley Atlantic Inc. It deals with ice loading calculations for the main spans of the proposed Northumberland Strait Crossing Project. The current bridge pier design consists of an upward-breaking cone at the waterline, with a cone angle of 60°. The waterline diameter of the bridge pier at mean sea level is 12.9m.

Generally, the ice season in Northumberland Strait begins in late December or early January, with ice conditions worsening until late March. The average thickness of ice floes increases from about 0.10m in early January to about 0.30m in early March. The dynamic nature of ice movement in the Strait result in rafting and ridging of ice floes. Ice ridges usually consist of a consolidated core of refrozen ice at the waterline, with loosely bonded blocks of ice forming a small "sail" on top of the ridge core, and a much larger "keel" below water.

The most serious hazard to the bridge pier structure, which must be analyzed in terms of ice loads, is the consolidated ice in the ridge core. The ridge sail and keel will also contribute to the total loading on the structure, as will the broken ice pieces moving around the structure. As the on-coming ridge core makes contact with the edge of the cone, radial cracks will form within the ice sheet. The cracks divide the ice sheet into wedge-shaped beams that are subject to an upward force at the pier contact surface. The maximum ice loads occur just before several wedge shaped beams fail in bending. Subsequent circumferential cracks result in broken ice pieces and thereafter, with continuing ice movement, the broken ice blocks are pushed up and around the surface of the cone. An accumulation of ice blocks (i.e. "rubble") can form around the bridge pier; the weight of the ice rubble is supported partly by the cone and partly by the ice sheet. As the ice blocks move up the cone additional friction forces develop and the horizontal force on the structure is increased.

Many numerical models have been proposed for the calculation of ice loads on conical structures. The individual formulations have been reviewed and the basic approach and limitations of the theories are discussed in the report. The general conclusion of the report is that Croasdale's model, for bending failure of the ridge core, gives good, yet conservative estimates.

The actual load estimate for a given ridge pier interaction is chosen as the lesser value of two load estimates - the environmental driving force which is governed by pack ice pressures acting on the floe, and the ridge failure load which consists of bending, rideup, and clearing forces to fail the ridge core and shearing forces to fail the ridge keel.

It is important to evaluate the uncertainties associated with the load estimates. Maximum ridge loadings are calculated from a simulation of the ice and environmental data for a given year using statistical distributions as input data, and a specific structural configuration. The process is repeated for a number of years, and a distribution of annual extreme loads is derived. The design load is then given as a function of the expected occurrence of the load (as in once in 100 years, or once in 10,000 years).

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The design loads determined by the project team for the 60° conical pier are 18.5 MN for a 100 year period, and 24.3 MN for a 10,000 year period. A 55° cone has also been analyzed; this configuration results in design loads of 13.5 MN and 18.0 MN for the same return periods. These loads are based on a carefully researched set of environmental and ice parameters which are judged to be on the conservative side in many instances. The methods of predicting ice failure loads and environmental driving forces have been evaluated against the best analytical models available, and the results from field and laboratory measurement programs. The probabilistic model framework simulates at least 1000 years of ice events; this has been checked against measured ice forces on a Baltic lighthouse which is very similar to the proposed bridge piers. The project team therefore expresses a very high level of confidence in the results of this assessment of ice loadings.

We were right!