The Story of Offshore Arctic Engineering – Theory and Practice

Dan Masterson

$\sigma_{max} = 0.275(1+\mu)\frac{P}{h^2}$

$\log[\frac{Eh^3}{kb^4}]$

Maximum Stress Under the Main Load

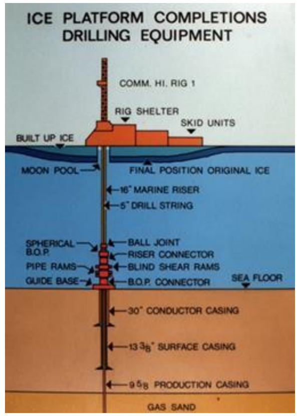
$\sigma_x = \sigma_{max} exp\frac{-x}{0.691\,l}$

Stress at distance x from the load

$$l = \left[\frac{Eh^3}{12(1-\mu^2)k}\right]^{\frac{1}{4}}$$

Characteristic length of the ice

$$\sigma_{total} = \sigma_o + \sum_{n=1}^{i} \sigma_n exp\left(-\frac{x_n}{0.691\,l}\right)$$



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A summary of The Story of Arctic Engineering

1. **Introduction**
2. **Ice strength Tests**
3. **Building Ice Structures**
4. **Conclusion – “To be or not to be” - Hamlet by Shakespeare**

Introduction

- **I begin my book saying “I started at the right time in the Arctic Engineering and oil business in the early 1970’s because it was wanted and needed.”**
- **What I didn’t say in the book is , “And I retired from the Arctic Engineering and oil business at just the right time – when Obama and Trudeau forgot that it was wanted and needed and all but killed it.”**
- **Just a bit of dark humour to start off the presentation.**

Introduction

- **The Shakespearean quote from Hamlet, "To be or not to be" is the question that stuck in my mind as I began to put this book together.**
- **Will our Arctic Engineering continue to be, will it be lost, and if not lost, will it be used?**
- **Huge sums of money, energy and human talent developed new and innovative methods of testing, experimenting and working with ice.**

Introduction

Dan

You don’t get nowhere easy – we flew to Labrador Pack ice in a French Helicopter the Puma.

Introduction

- **Climate change may be with us, oil may not be popular,**
- **Ice is still a material that exists in extensive regions of our world.**
- **And, in my mind will continue to exist for all future time.**
- **It will always figure into the exploration, transportation and construction of sites that define our human experience.**
- **It will always have to be ‘worked’ with to help humans live.**

Introduction

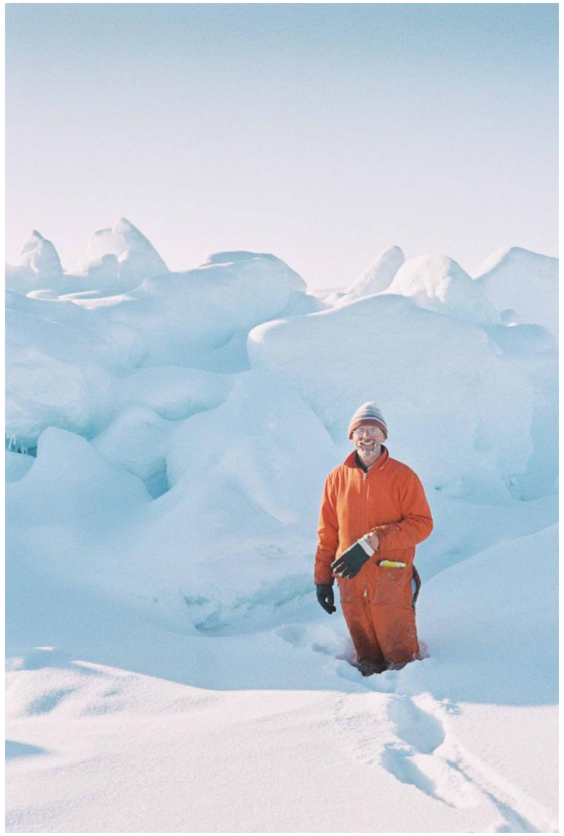
- **Ice - We cannot ignore this aspect of our world.**
- **To use our world responsibly, practically and innovatively has been the human goal for centuries.**
- **Ice is part of our world and will continue to be.**
- **The works described herein are appropriate tools to continue the valuable human experience of moving forward.**

Introduction

- **I, with many dear friends, have spent a life time:**
  - **learning about ice, examining it close up, accepting its dangers, testing it, designing it and constructing with it.**

Off shore Labrador Ice Testing In 1978 - The Lady Johnson II off Labrador. Not sure which calmed our nerves more in the very wild North Atlantic - our very experienced Captain Harrison Johnson or the Alcohol served by his brother Morrisey, who kept us full of scotch and rum while we literally shot through the storm filled passage into St. Johns.

Introduction



Bill Graham, at the edge of a pressure ridge, “If only I had brought my snowshoes”

Introduction

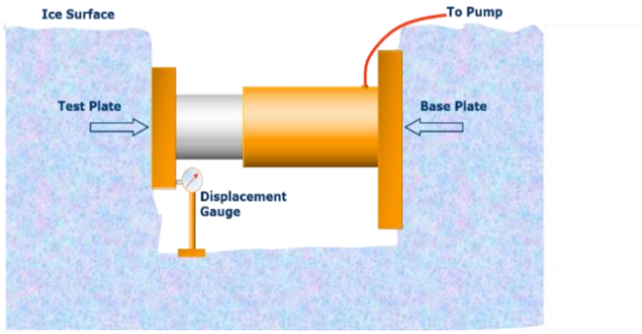
Bill Graham and John Bastian, “Will this auger get through the entire ice thickness?”

Introduction

- **My hope is that this work is not lost to future generations.**
- **This book provides a summary of:**
  - **techniques,**
  - **lists of research papers**
  - **project summaries**
- **I hope this book can help to keep this engineering in front of and available for future generations.**

Ice Strength Tests

Pit tests
Early on in our research testing was basic – but very useful



Pit Test

- **The pit tests for unconfined compressive strength were definitely the easiest, most reliable and readily interpreted and yielded a lot of data on basic ice strength.**
- **My role in the tests was to assist with their execution and then to work to interpret the results and to report them to the client.**
- **This was called a Flaky pit test – because the ice would flake off.**
- **Did this the first time in Fort George to unload mining equipment off a frozen in barge – the French foreman asked, “good Glace” (Good Ice)**

Ice Strength Tests

- **The Borehole Jack is a prime example of innovations.**
- **We know of cases where it is being replicated now, over 40 years since it was first developed.**
- **In 1974, we needed a tool to quickly measure the in-situ engineering strength and stiffness properties of ice;**
- **properties needed by engineers to estimate ice forces on smaller structures and ice load bearing capacity.**
- **Up to this time, the strength of ice could only be determined from ice cores, which were taken into a laboratory for testing.**

Ice Strength Tests – The Borehole Jack

The Borehole Jack was patterned after other tests:

- **The Menard pressure meter used for soils - was not strong enough for ice.**
- **The Goodman Jack, used to test rock - had too short a stroke – fell apart in the hole during the tests.**
- **We spent months developing the Borehole Jack capabilities.**

Ice Strength Tests – The Indenter

- **The most significant and difficult work that GEOTECH successfully undertook was the execution of the Medium Scale ice crushing tests at Pond Inlet NWT in 1984**
- **A large grounded Iceberg was used for the compression test.**
- **From early 1983 to spring 1984, intense discussion, coordination and test equipment design and construction took place – no small engineering feat in itself.**
- **Meetings in Dallas, Salt Lake City, Calgary and Ottawa preceded the actual work – I became well known in North America's airports.**

Ice Strength Tests – The Indenter

- **Iceberg tests (confined compression) at Pond Inlet**
- **Development of the indenter – a major task to allow large scale in-situ strength tests**
- **Months of design and detailed fabrication of this state of the art, and one of a kind equipment took place – in a welding shop in Calgary.**

Detlef Rook (left) Joe Kenney (right)
This indentor is taller than a human, so huge that it was shipped in pieces and assembled on site.

Ice Strength Tests – Indenter at Pond Inlet

No small task – into a huge iceberg 4 tunnels were excavated to receive the Indentor. We worked off solidly frozen ice cover in Pond Inlet. 10% of the ice berg is visible, 90 % is under water and grounded

Ice Strength Tests – Indenter at Pond Inlet

The tunnels up close. Notice the bob cat – the tunnel is big enough for it to enter.

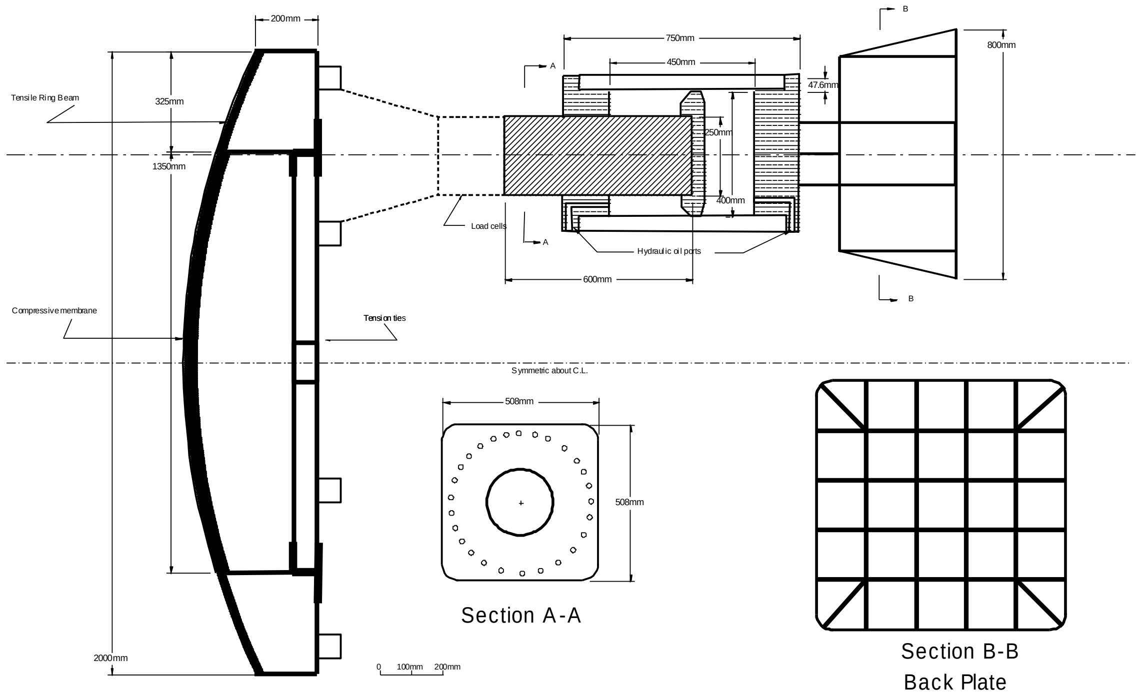
Ice Strength Tests – Indenter at Pond Inlet

A work in progress -two helpers hand excavate the tunnel. The sides had to be cut vertical, parallel and reasonably true to receive the Indentor.

Ice Strength Tests – indenter at Pond Inlet

The indenter in place and providing test results. 65,000 lb. of test apparatus and equipment were flown to Pond Inlet and delivered to this iceberg location.

Ice Strength Tests -Indenter with Actuator



Schematic of Indenter with Actuator and base plate set across tunnel

Ice Strength Tests - Impact Tests at Pond Inlet

Tunnel No.	TEST DATE	TEST NO	TEST CATEGORY
1	84-05-02	1	0.02 m^2
1	84-05-04	2	0.10 m^2
1	84-05-06	3	0.10 m^2
1	84-05-13	4	1.00 m^2
1	84-05-14	5	3.00 m^2
2	84-05-10	1	0.5 m^2
2	84-05-10	2	0.5 m^2
2	84-05-17	3	0.1 m^2
2	85-05-17	4	0.02 m^2
2	84-05-19	5	1.00 m^2
3	84-05-15	1	1.0 m^2
3	84-05-16	2	3.0 m^2
3	84-05-18	3	0.5 m^2
3	84-05-18	4	0.5 m^2
3	84-05-19	5	0.02 m^2
4	84-05-21	1	1.00 m^2
4	84-05-21	2	3.00 m^2
4	84-05-22	3	3.00 m^2
4	84-05-22	4	0.10 m^2
	84-05-22	**5**	**0.10 m^2**

- **4 Tunnels were hand excavated – 10 ft x 10 ft x 50 ft length**
- **4 tests were conducted per tunnel**
- **A total of 20 servo controlled tests on the confined compressive strength of iceberg ice at medium to large scale**

Building Structures with Ice

- **Typical Projects Reviewed**
  - **Wharf out of frozen mine waste**
  - **Ice roads and runways – floating and grounded**
  - **Floating ice pads – flooded and sprayed**
  - **Pipe Lines under Ice**

Frozen Mine Waste Wharf (Cominco)

- ***Polaris zinc mine was an underground zinc mine on Little Cornwallis Island in the Canadian territory of Nunavut (Northwest Territories).***

- ***The mine was located 1,120 kilometres (700 mi) north of the Arctic Circle, and 96 kilometres (60 mi) north of the community of Resolute.***

- ***The Polaris mine closed in July 2002 following more than twenty years of zinc production***

Frozen Mine Waste Wharf (Cominco – Cont’d)

Location Maps and Summary of Cominco Mines History

	Nunavut (Northwest Territories)
Country	Canada
Coordinates	75° 23′ 24″ N
	096° 54′00″ W
Products	Lead, Zinc
Production	21,000,000 tonnes (ore)
Financial year Life of mine History	
Opened	1981
Closed	2002
Owner Company	Cominco
Year of acquisition	1964

North Polar Region

Polaris Location

Ice Roadways and Airstrips

Hydraulic Pump flooding an airstrip, powered by an IMP, a tracked vehicle.

Ice Roadways and Airstrips

Runways were successfully constructed on floating ice:

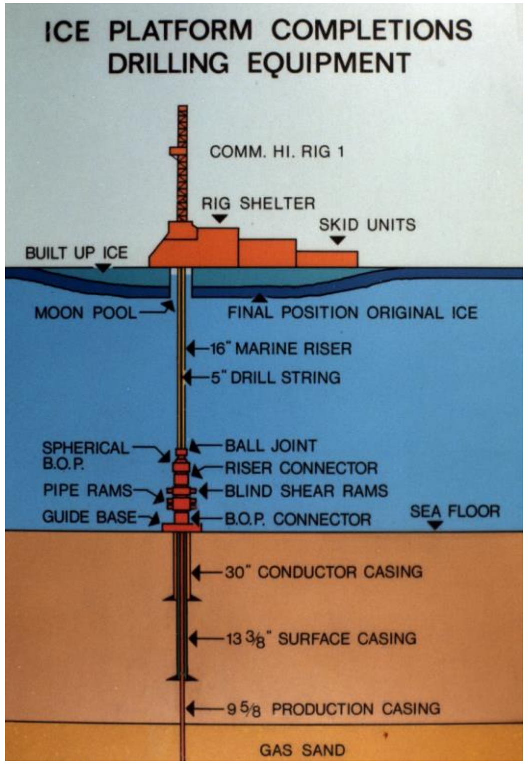
- **The runways supported 80 to 100 C-130 Hercules aircraft landings bringing equipment and supplies during a drilling rig move. And continued to bring fuel and drilling supplies.**
- **Its maximum take off weight was 175,000 lbs.**

Ice Roadways and Airstrips

Not Everything Worked Perfectly

- **Failures were usually the result of carelessness, overconfidence and truckers getting off the designed roadway.**
- **This is the Wrong Way to do It.**
- **I did not design this road.**

Offshore Drilling from Floating Thickened Ice



Rig on Off Shore Floating Ice Platform:
Test drilling throughout the winter, the hole was plugged and abandoned; then the equipment was moved out.
The Load Imposed =1600 tons (static + dynamic + moving equipment)

Actual Drilling Rig on Ice Platform

Flooding Operations

Flooding a floating ice platform using electrical submersible pumps in insulated wells.
As the flooding progressed the structure on the left would sink to about 6” of freeboard.

Flooding Operations and Final Set Up

From this (Forming Ice by spraying) **To this (Mars, in Alaskan Waters)**

The sites were huge and required, storage, work space, living quarters and equipment mobility – 20 acres

Holes in the Ice Bring Visitors

Any port in a storm – or how to ‘seal’ a friendship – provide an air hole.

The first ice platform – Hecla N-52 –

Never forget the latent heat of Arctic sea water >> than that of Normal Sea Water due to its ice content.

- **The final design thickness of the first ice platform in 1973, Hecla N-52, was a negotiated maximum thickness with Panarctic's partner Tenneco and their consultant.**

- **Our calculations had determined a maximum required thickness of 12 ft or 3.5 m**

- **This would satisfy safety against breakthrough and loss of freeboard due to creep deflection.**

The first ice platform – Hecla N-52 –

Never forget the latent heat of Arctic sea water is >> than that of Normal Sea Water due to its ice content.

- **Approximately 90 percent of floating ice is below water,**
- **So the thickened ice would have a freeboard, or above water dimension, of about 1.2 ft or less than half a meter.**
- **Tenneco's consultant did a calculation, based on tank tests (flawed) performed at Resolute Bay,**
- **They argued that the maximum thickness would have to be greater, about 17 ft (5.2 m)**

The first ice platform – Hecla N-52 –

Never forget the latent heat of Arctic sea water which is >> than that of Normal Sea Water due to its ice content.

- **Panarctic had already begun to build the platform**
- **We knew that, with the equipment and resources available, this thickness could never be achieved.**
- **In addition, Tenneco's consultant specified that warm water should be used for the first one or two floods to ensure bonding to the existing sea ice.**

The first ice platform – Hecla N-52 –

Never forget the latent heat of Arctic sea water which is >> than that of Normal Sea Water due to its ice content.

- **A boiler was shipped to site and sea water pumped through it to heat the flood water.**
- **The sea water pumped directly from under the sea ice cover already had ice crystals in it.**
- **Thus the boiler was simply supplying latent heat to melt the crystals and the temperature of the flood water was not raised even 1 degree.**

The first ice platform – Hecla N-52 –

Never forget the latent heat of Arctic sea water which is >> than that of Normal Sea Water due to its ice content

- **This warming effort was abandoned**
- **The boiler was pulled off to the construction edge where the tubes froze and had to be repaired later.**
- **Flooding continued using gasoline powered auger pumps, the same pumps that had been used at an earlier project at Fort George.**

The first ice platform – Hecla N-52 –

Never forget the latent heat of Arctic sea water which is >> than that of Normal Sea Water due to its ice content

- **The Hecla N-52 well was successfully drilled during the winter and spring of 1974.**
- **There were no failures and the freeboard remained positive.**
- **In later years the design allowable elastic stress was re-established at 50 psi and later at 70 psi or 500 kPa.**
- **Moral – Test properly, use common sense, and prove theories ahead of time.**

Ice Testing Personnel Posing

Ray Young, Dan Masterson & Manos Kazakopoulos at Hecla N-52,
Picture taken by Bob Frederking of NRC

Pipeline Construction under the Ice

Once oil or gas was discovered, transportation by pipeline had to be provided from offshore

Moving huge blocks of ice to make way for the trench – Drake F-76 – offshore Melville Island.

Pipeline Construction under the ice

Somewhat standard pipe laying – except keep the ice clean or experience thawing.

Closure – What did we accomplish

***Exploration and examination techniques*.**

- **New exploration models were developed from the old.**
- **Extensive testing was carried out on sea ice, pack ice, and icebergs.**
- **New methods of sampling were improvised that give excellent samples to test.**
- **Major cutting in to the sides of ice structures was done to allow engineers to examine, test and sample ice.**
- **Existing testing procedures borrowed from soils, concrete and steel were tried and successfully modified to fit the new material, ice.**
- **This involved extensive use of machinists, welders and hydraulics specialists to develop the innovative testing equipment described in this book – that can be and was used again and again.**

Closure – what did we accomplish

***Exploration and examination techniques*.**

- **The Borehole Jack is a prime example:**
  - **We know of examples where it is being replicated now, over 40 years since it was first developed.**
- **Now there is documentation in this book, in work files and published papers:**
  - **There is good evidence of the practicality of the methods devised, which can be used on any project.**

Closure – what we accomplished

Empirical equations and calculations developed.

- **Existing equations for stress, strain and failure of materials were readily available.**
- **These research and construction projects allowed those to be modified and adapted to specific ice conditions.**
- **This work has resulted in national codes of practice specifying the requirements for safe and successful structures.**

- **With this wealth of knowledge, like many applications in engineering, practical experience and a sixth sense about structural properties was needed..**

Closure (To Be or Not to Be)

- **My book describes some of the work, the risk, and the associated difficulties encountered in the Arctic:**
- **to accumulate useful ice crushing pressures.**
- **To determine load bearing data.**
- **Experience related to ice impacting offshore structures and load capacity of floating ice.**
- **The tests were conducted at large scale, rendering the data obtained directly useful for design. No longer did we have to scale up small scale laboratory test results using theory.**

Closure (To Be or Not to Be)

- **The work done from the 1970’s to the 2000’s was accomplished by pioneers who took established engineering knowledge and applied it to ice in new and unique ways.**

- **They took it one step further using it in practical applications in the most difficult of surroundings.**

Closure (To Be or Not to Be)

- **This work was done for oil and gas exploration and for various reasons may not be used in the near future to aid in the development of those resources.**

- **But the testing, the calculations, the understanding, the parameters and the implementation of it in ice design are universal in their applications.**

Closure (To Be or Not to Be)

- **I am proud of the work that those acknowledged in my book have done.**

- **Their work will go on and on and be used by generations of engineers, contractors and environmentalists to make the Arctic a liveable area.**

- **None of this work was easy.**

Closure (To Be or Not to Be)

- **It was necessary to balance human safety, environmental concerns,**
- **With production costs, political interest, corporate ideals**
- **All with people skills – those people worked for decades in a harsh world to become successful managing ice in a way that would set the future standard.**
- **Those involved gave their all to accomplish immense tasks despite the odds.**
- **While this book details their work on several fronts and summarizes accomplishments, the details and mathematics can be found in published papers listed in the book.**

Closure (To Be or Not to Be)

- Thank you for inviting me to present my book, a life time of work.
- You can purchase a copy of it on line from
  - Cambridge Scholars Publishing
  - www.cambridgeshcolars.com
  - Go to physical sciences and scroll down.
  - Publisher has offered for SNAME in Calgary, on line order cost,
    - 55.19 British Pounds plus shipping ($96.00 CAD plus shipping)
    - Regular price is 68.99 British pounds plus shipping ($120.00 CAD plus shipping)
- Or if you have cash, I have ten copies and can sell you one today at my author price of $75.00 CAD – shipping included