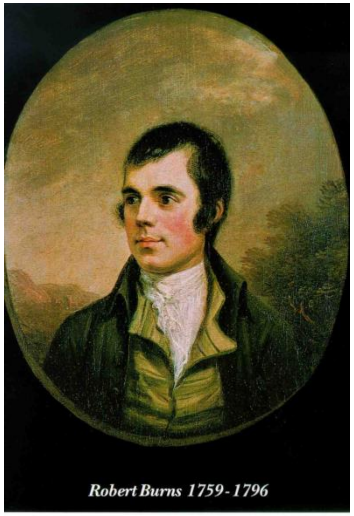
From the blades of jet engines to the blades of wind turbines
or
A journey in Engineering
recognizing that

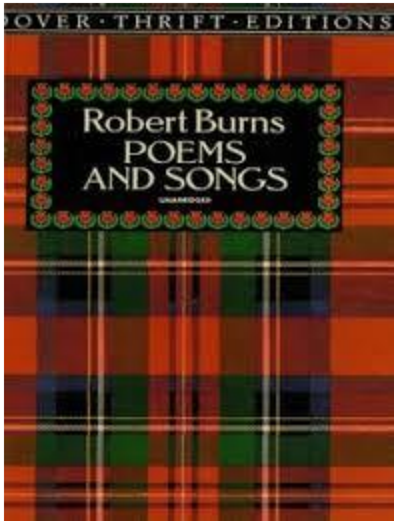
"The best laid schemes of mice and men gang oft agley"
Robert Burns – born Jan 25th 1759

(For those who are Scottish dialect challenged)
(The best laid plans of mice and men often go astray)

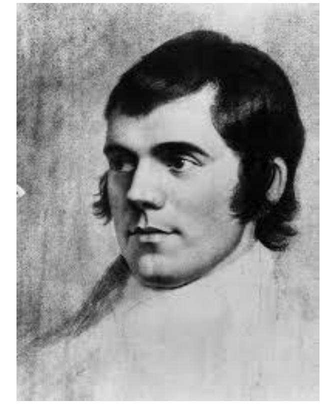


Ken Croasdale
Address to SNAME Calgary

January 16 2018



Robert Burns



Considered by the Scots to be the best poet ever

- Even as a Sassenach (English) – I tend to agree !
- Born Alloway, Ayrshire, on 25th January 1759 (Hence Burns' Suppers on Jan. 25th)
- Died Dumfries, Ayrshire, only 37 years later.
- He wrote in the Scottish dialect – not Gaelic – which was limited to The Highlands
- Even though a form of English it can be hard to understand !
- He was a farmer and later an exciseman – poetry was his passion.
- He was ploughing his fields one day and his plough destroyed a mouse nest. He felt sorry for the mouse and wrote "To a Mouse"
- The message being that well-made plans sometimes don't go according to plan ! As we all know !

"To a Mouse"
Robert Burns

Small, sleek, cowering, timorous beast,
O, what a panic is in your breast!
You need not start away so hasty
With hurrying scamper!
I would be loath to run and chase you,
With murdering plough-staff.

I'm truly sorry man's dominion
Has broken Nature's social union,
And justifies that ill opinion
Which makes thee startle
At me, thy poor, earth born companion
And fellow mortal!

I doubt not, sometimes, but you may steal;
What then? Poor beast, you must live!
An odd ear in twenty-four sheaves
Is a small request;
I will get a blessing with what is left,
And never miss it.

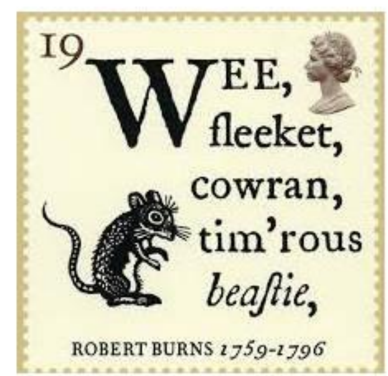
Your small house, too, in ruin!
It's feeble walls the winds are scattering!
And nothing now, to build a new one,
Of coarse grass green!
And bleak December's winds coming,
Both bitter and keen!

You saw the fields laid bare and wasted,
And weary winter coming fast,
And cozy here, beneath the blast,
You thought to dwell,
Till crash! the cruel plough past
Out through your cell.

That small bit heap of leaves and stubble,
Has cost you many a weary nibble!
Now you are turned out, for all your trouble,
Without house or holding,
To endure the winter's sleety dribble,
And hoar-frost cold.

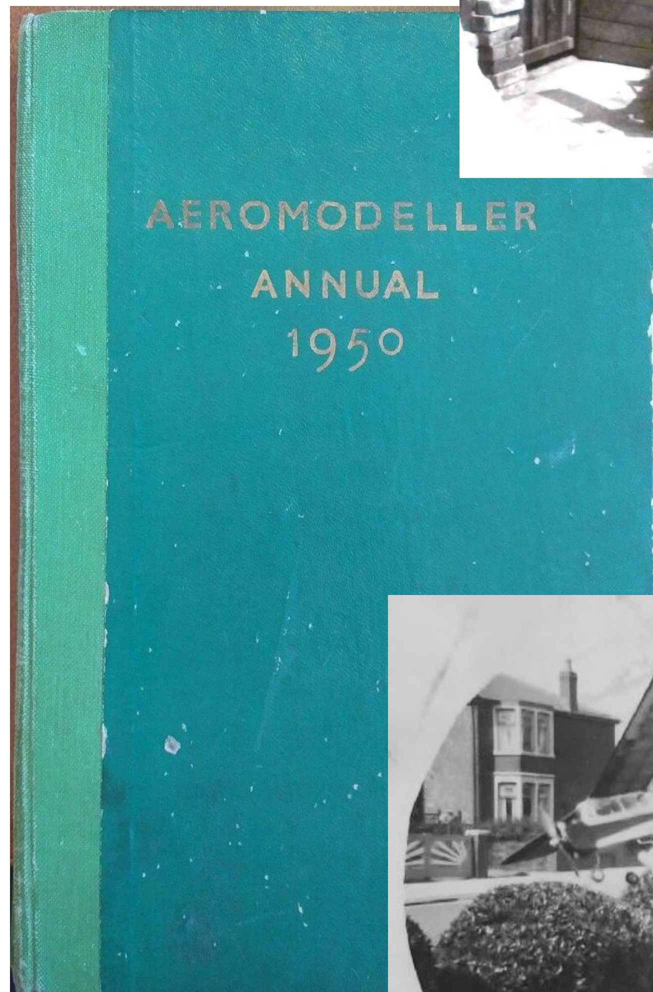
But Mouse, you are not alone,
In proving foresight may be vain:
The best laid schemes of mice and men
Go often askew,
And leaves us nothing but grief and pain,
For promised joy!

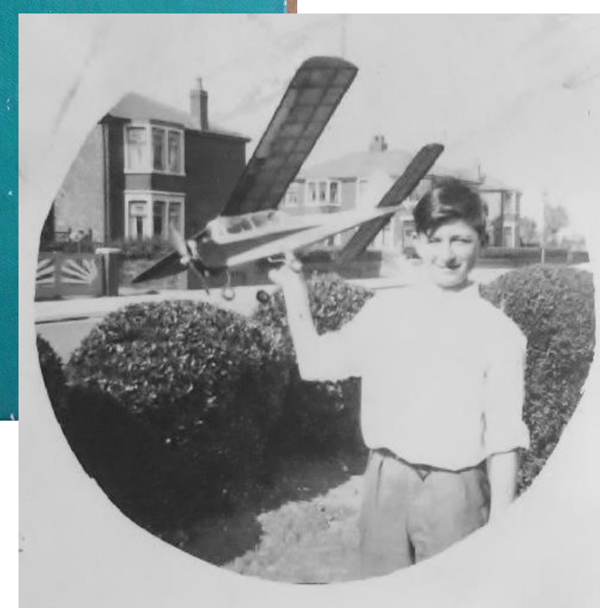
Still you are blest, compared with me!
The present only touches you:
But oh! I backward cast my eye,
On prospects dreary!
And forward, though I cannot see,
I guess and fear!



My start in Engineering

- I was pretty good at physics and math in school – and at that time thought poetry was for sissies
- I was also passionate about designing and building model aeroplanes.
- So I left school as early as possible and took up an apprenticeship with a local aircraft company (1955).
- My “best laid plan" was to be a “Famous Aircraft Designer”



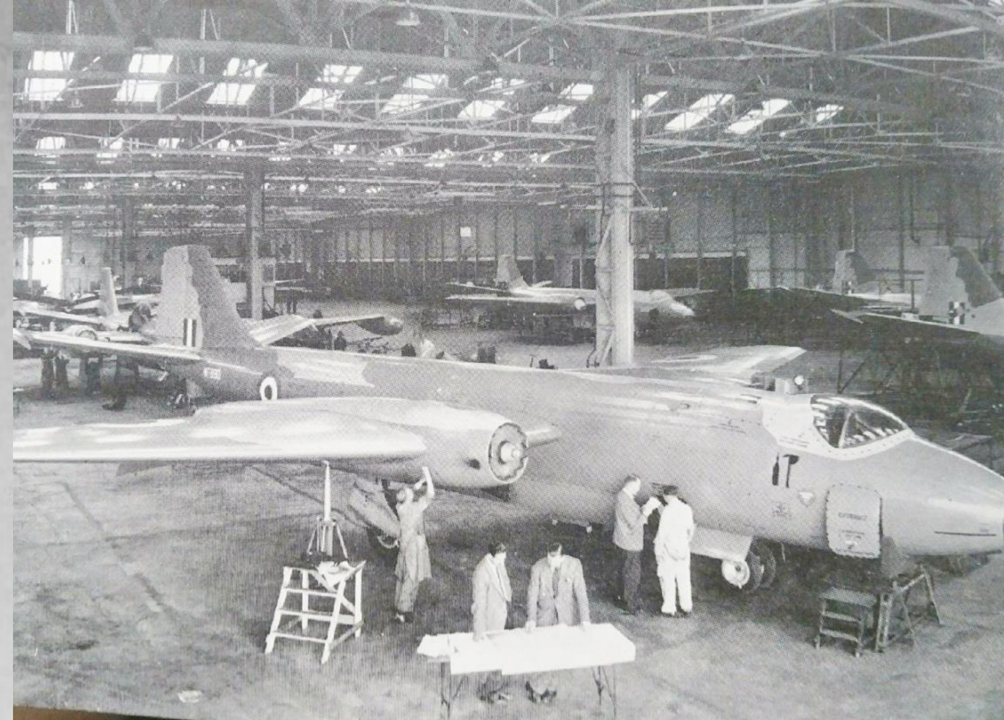


I became a student
Apprentice - for 5 years

CAREERS IN AERONAUTICAL ENGINEERING

with

THE ENGLISH ELECTRIC COMPANY LIMITED



The Canberra !
The first British
jet bomber
after WW2.
Set several
transatlantic
records in the 50s.
I helped build them
in the factory in
Preston 1955 - 57

Aeronautical engineer

- I studied engineering part time for 2 years and then full time for another 2 years to obtain a degree in Aeronautical engineering (External) from the University of London (1959)
- I transitioned into a structural engineer analyzing aircraft structures.
- FE methods were just being pioneered but you were expected to solve stress levels from first principles.
- Lightning Fighter – I analyzed parts of this aircraft's structure

Early disillusionment & changes

I was one of about a 100 stress engineers working on one aircraft – in a big office – I could not see the big picture !

Also not happy about working on military projects

My plan to be aircraft chief designer – went aft agley !

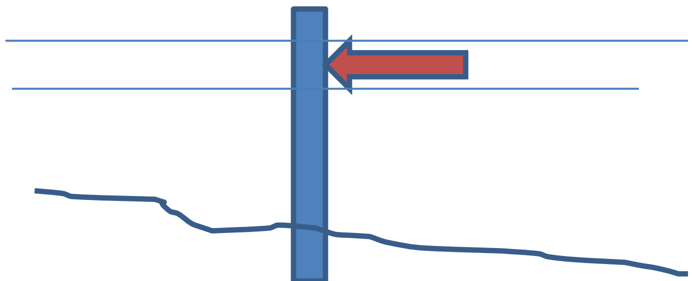
So we came to Canada !

How did I learn Arctic Engineering

- I joined Imperial in 1968 – not even to work on Arctic topics – more on materials and production engineering in their small R&D Lab in Calgary
- In 1969 Imperial was looking at ways to drill offshore in the Canadian Beaufort. The geology looked good and there had been a big Arctic oil discovery in adjacent Alaska (at Prudhoe Bay)
- The specific problem assigned to me was to instrument some test piles for ice loads (my prior work on aircraft structures was good background)
- I did literature searches on ice forces to help me figure that out

Test pile vs indenter

- Problems with test piles in the Beaufort in 1969 were:
- Little known about the soils (how deep to drive the pile ?)
- Ice pressure to design for was unknown
- In shallow water, the ice was landfast and might not move very much – no data
- Going to deeper water required deeper penetration into the sea floor but with no equipment to drive the piles immediately available
- I suggested pushing a pile shape through the ice. The world's first indenter test for ice crushing research



- Advantages of an indenter
- Not dependent on nature to get relative movement
- This can be varied (slow and fast)
- Using hydraulic rams could provide over-capacity relatively easily
- Can build quickly in the South
- No expensive installation equipment needed

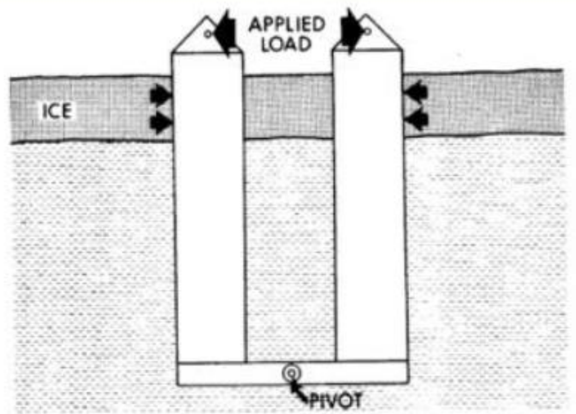


Figure 1. Operating principle of Nutcracker testers.

Slides of Nutcracker project and subsequent indenters

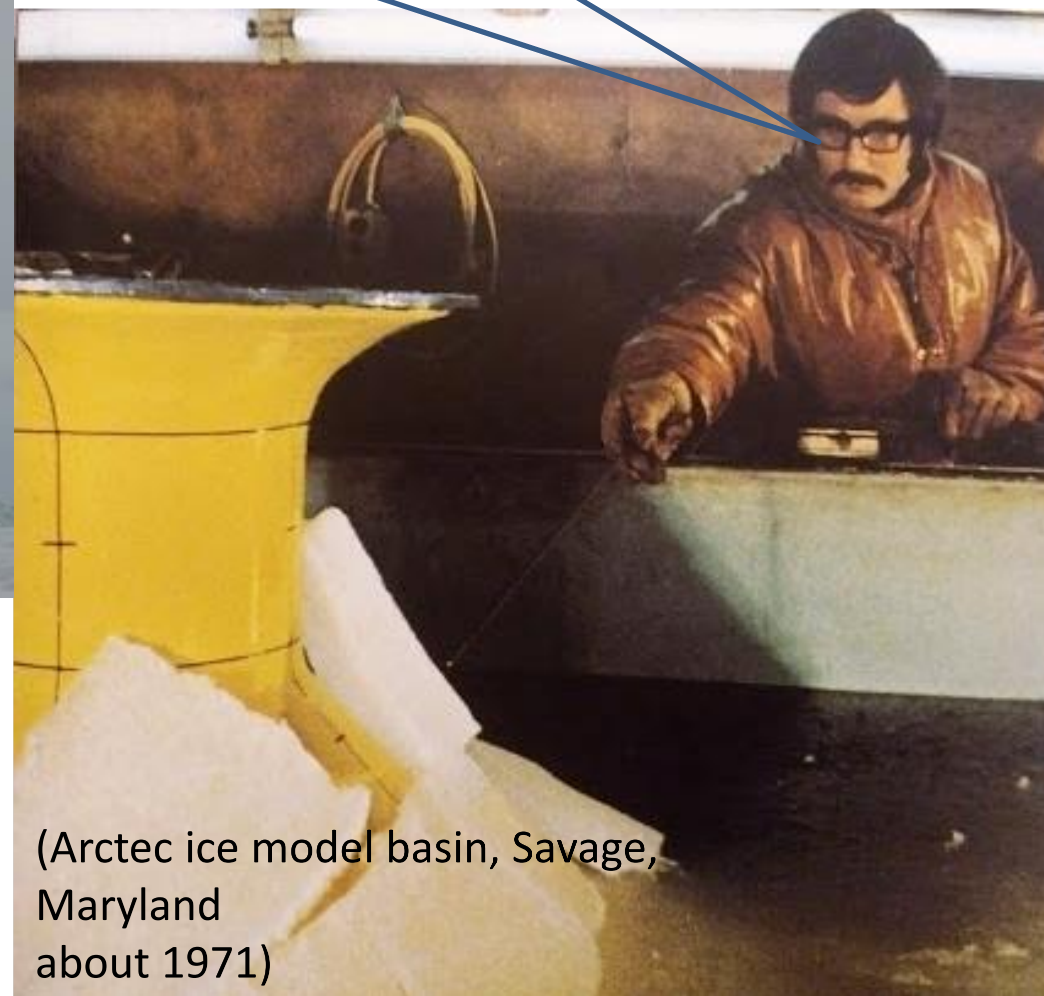

Leaving Calgary, 1969

Tuktoyaktuk, Canada 1970

ICE-STRENGTH TESTING at locale of the "Nutcracker" devices in Tuk harbor off the Arctic coast is the operation pictured in part, above. Top is a panoramic shot taken by Ron Bell, showing operational shack, right. Lower left, Ken Croasdale, P.R. and T.S., Calgary, poses with Brazil tester, used to gauge strength of ice cores. Lower right is Ron Bell who is coordinating broad program of ice-testing and sea-ice surveying in offshore Arctic.


Eagle Lake, 1972 - 76

Exciting stuff – I think my “best laid plan” now is to become a famous Arctic ice engineer !!



(Arctec ice model basin, Savage, Maryland
about 1971)

The Canadian Golden Years !

- Halcyon days followed
- Many of us here today worked together on pioneer projects
- Canadian technology was in the forefront
- Some of this knowledge was also applied to non-oils and gas projects such as Confederation Bridge

- **Artificial islands**
- **Caisson islands**
- **MODUs (Molikpaq, SDC)**
- **Floating drilling in ice**
- **Kulluk**
- **Icebreakers – Kigoriak, Terry Fox**
- **R&D - Hans Island experiments**
  - Esso Basin – world' largest
- **PanArctic off ice drilling**
- **Spray ice islands**
- **Russia – Sakhalin design criteria and more**
- **Kazahkstan – Kashagan platforms & pipeline design criteria**
- **ISO 19906 – Canadian leadership**
- **Iceberg management**

So what happened to the "best laid plans" for Arctic engineering in Canada ?

- Not the greatest geology ! (Despite Jack Gallagher's claims !)
- Environmental & political opposition delays projects
- Oil price collapse (several times!)
- Arctic moratorium by Trudeau and Obama
- Russian sanctions – cut off significant consulting business for many of us
- The political push to a lower carbon world
- The growth of renewables (for whatever reason !)

Does that mean our skill-set has “gang agley” ?

I hope not !

- In our Canadian Academy of Engineering report – we suggest small Northern LNG for communities and marine fuel.
- This could also help indigenous employment in those communities
- In my opinion, we should continue to work with other nations who are still developing resources in cold regions. (We should oppose the Canadian Govt. Russian sanctions - I wrote to my MP about this!)
- In Canada harbours and vessels for Arctic resources and tourism will still be needed
- We can join the “renewables” (turbines in ice regions)

Icebreaker

LEEDCo

Lake Erie Energy Development Corporation

The Great Lakes – Oceans of Opportunity

In 2016 we were invited to help with ice design criteria for this project

Fall 2017 POWER-US Technology Workshop

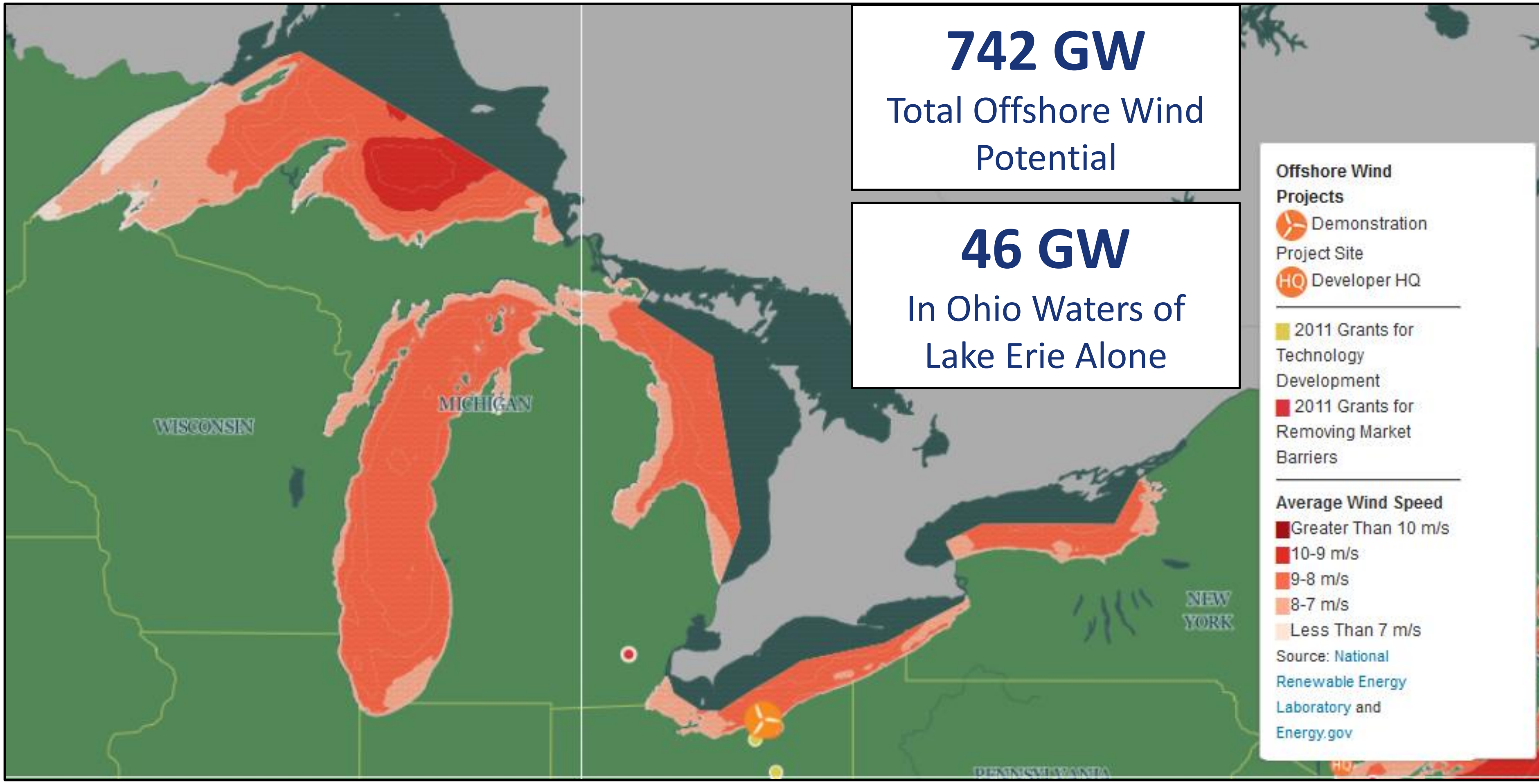
Technology research challenges

The Great Lakes Opportunity

The Great Lakes, Superior, Michigan, Huron, Erie & Ontario
are the largest surface fresh water system on earth,
comprising 20% of the world's fresh water and 90% of the U.S.

The Lakes Have the Resource

Alberta currently produces 1.5 GW of wind power



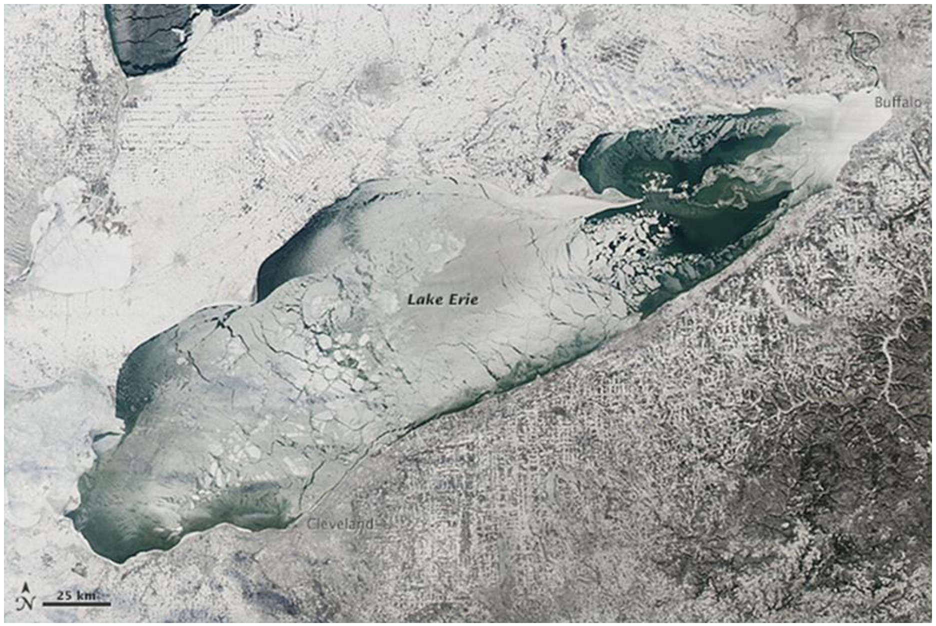
742 GW
Total Offshore Wind Potential

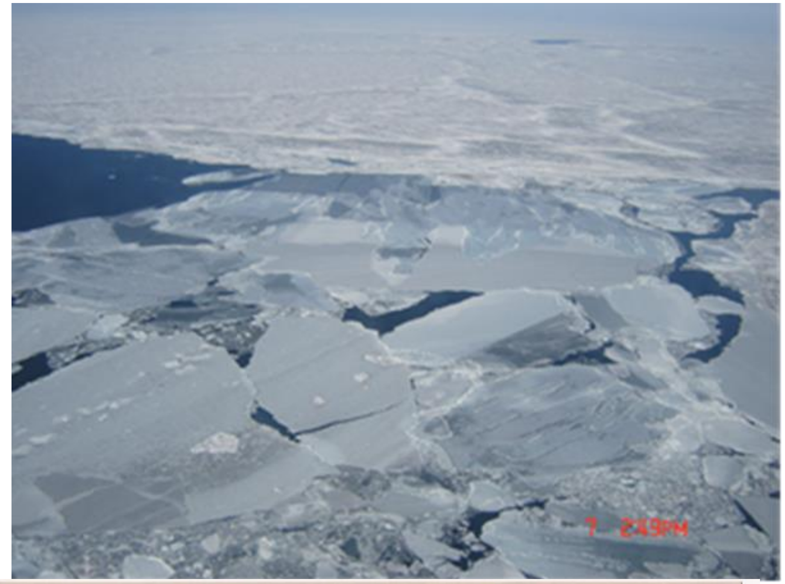
46 GW
In Ohio Waters of Lake Erie Alone

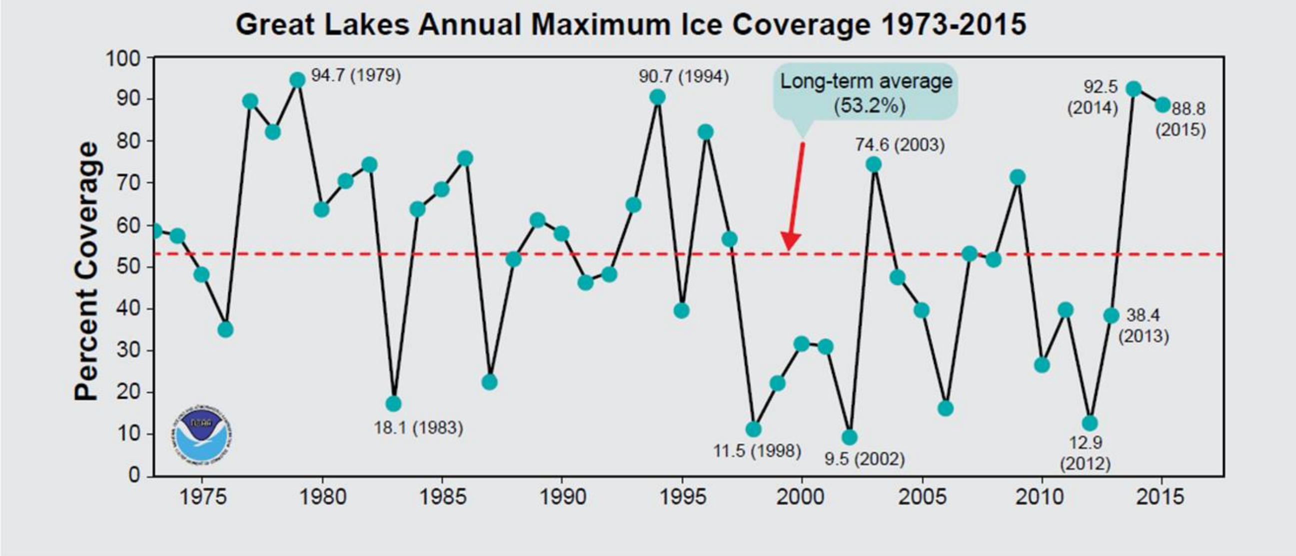
What makes this region unique for turbines in the US ?

One Word – Ice !

KRCA/CMO

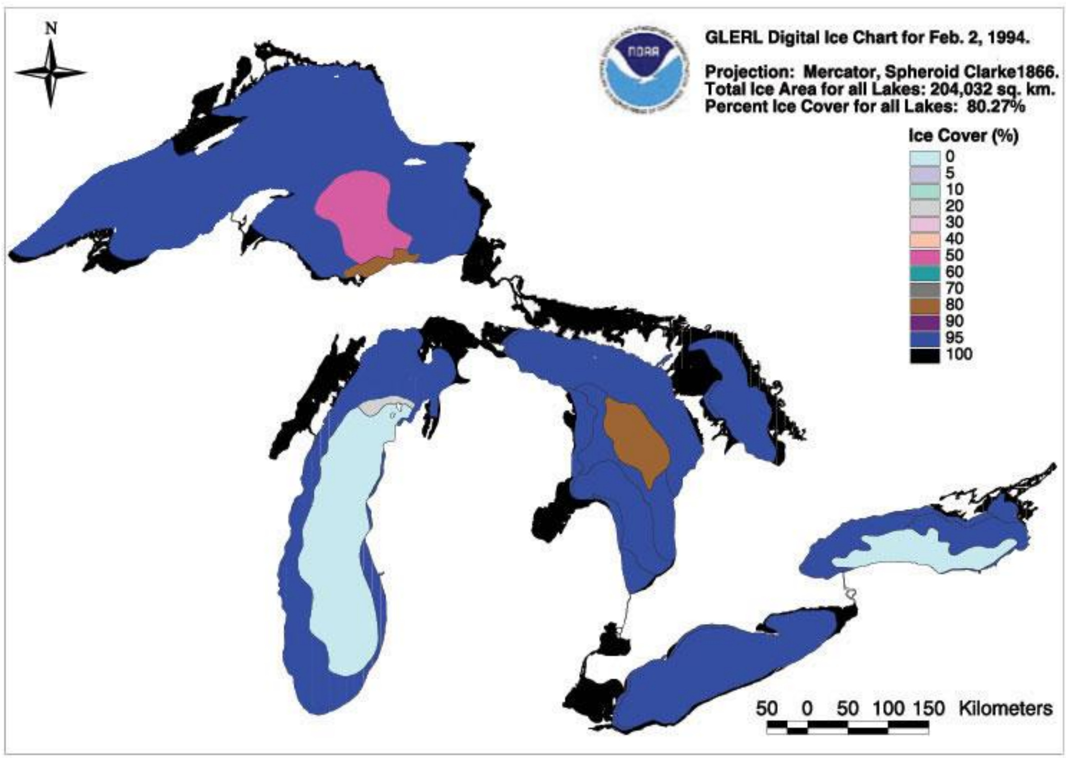






NOAA Great Lakes Environmental Research Laboratory ◆ 4840 S. State Rd. ◆ Ann Arbor, MI 48108 ◆ www.glerl.noaa.gov

Ice cover has a significant annual variability.
But it is prevalent enough to be a technology challenge in wind turbine design and operations



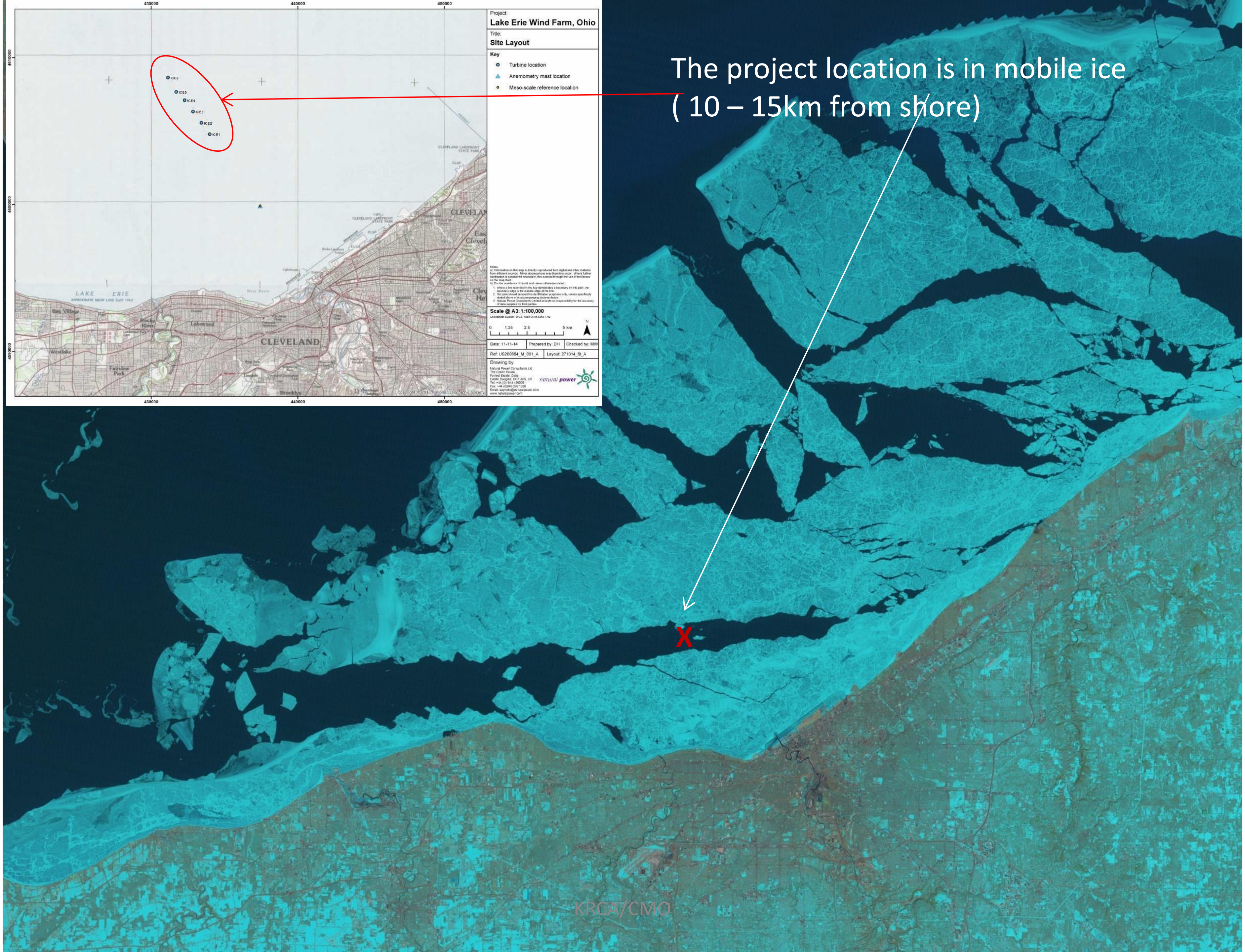
Lake Erie usually has the most ice coverage.
But all lakes can have ice present.
Therefore all turbines in the Great Lakes have to consider ice.

Challenges relating to ice

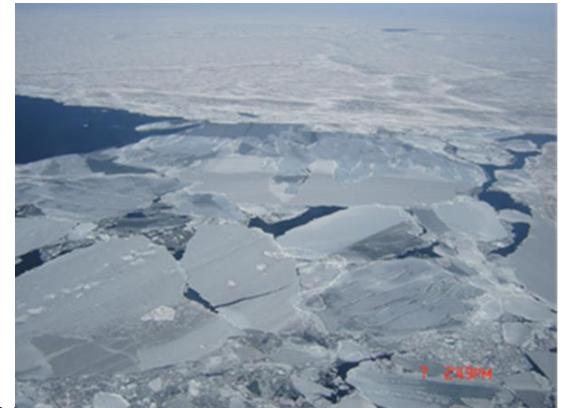
- Predicting and designing for Ice loads – global – cyclic nature – vibrations - fatigue.
- Ice gouging of lake floor – governs depth of cable burial ?
- Effect of turbines on ice environment
- Atmospheric and spray icing
- Access to turbines in winter

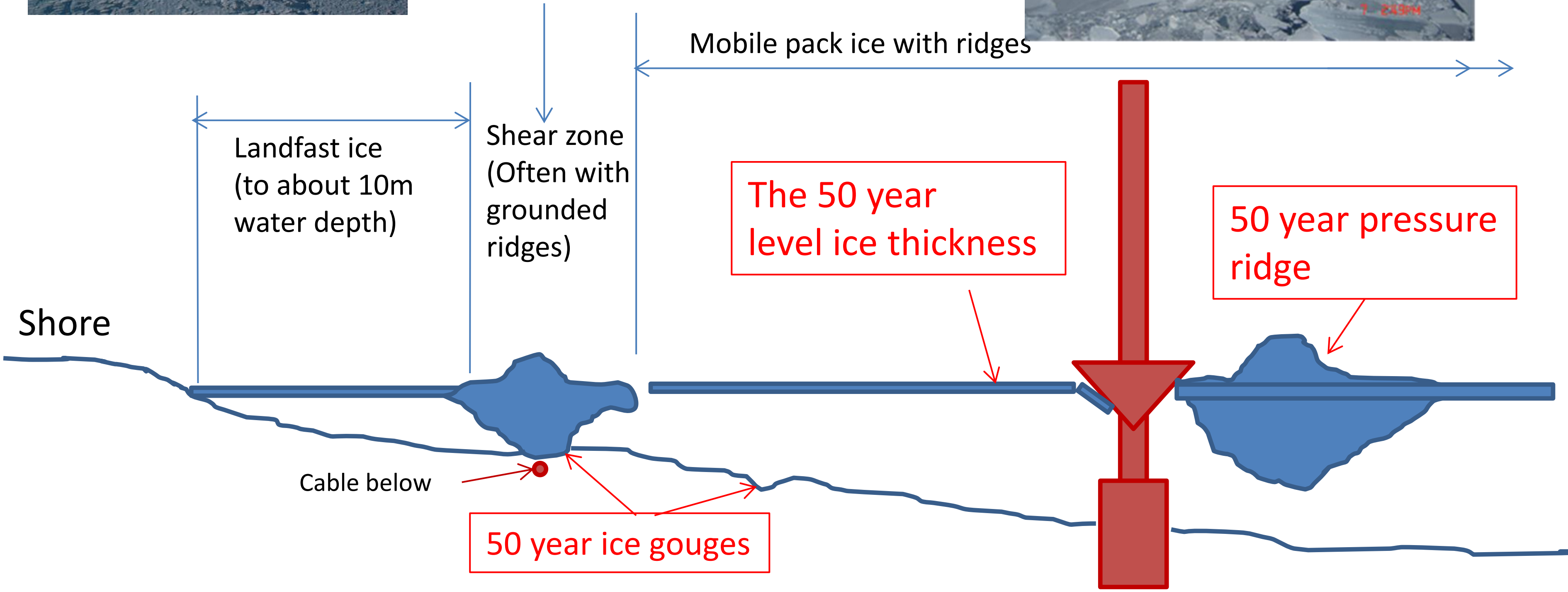
Pori Offshore 1 Wind Farm (Photo: Soumen Hyötotuuli)

Precedent – PORI Project in Finland – but is in Landfast Ice


The project location is in mobile ice
(10 – 15km from shore)
Project:
Lake Erie Wind Farm, Ohio
Title:
Site Layout
Key
Turbine location
Anemometry mast location
Meso-scale reference location
ICE6
ICE5
ICE4
ICE3
ICE2
ICE1
430000
440000
450000
LAKE ERIE
CLEVELAND
Lakewood
Bay Village
Westlake
Rocky River
Fairview Park
Scale @ A3: 1:100,000
Date: 11-11-14
Prepared by: DH
Checked by: MW
Ref: US200854_M_001_A
Layout: 271014_6t_A
Drawing by:
natural power
X
KRCA/CMO

Ice features to be assessed for design

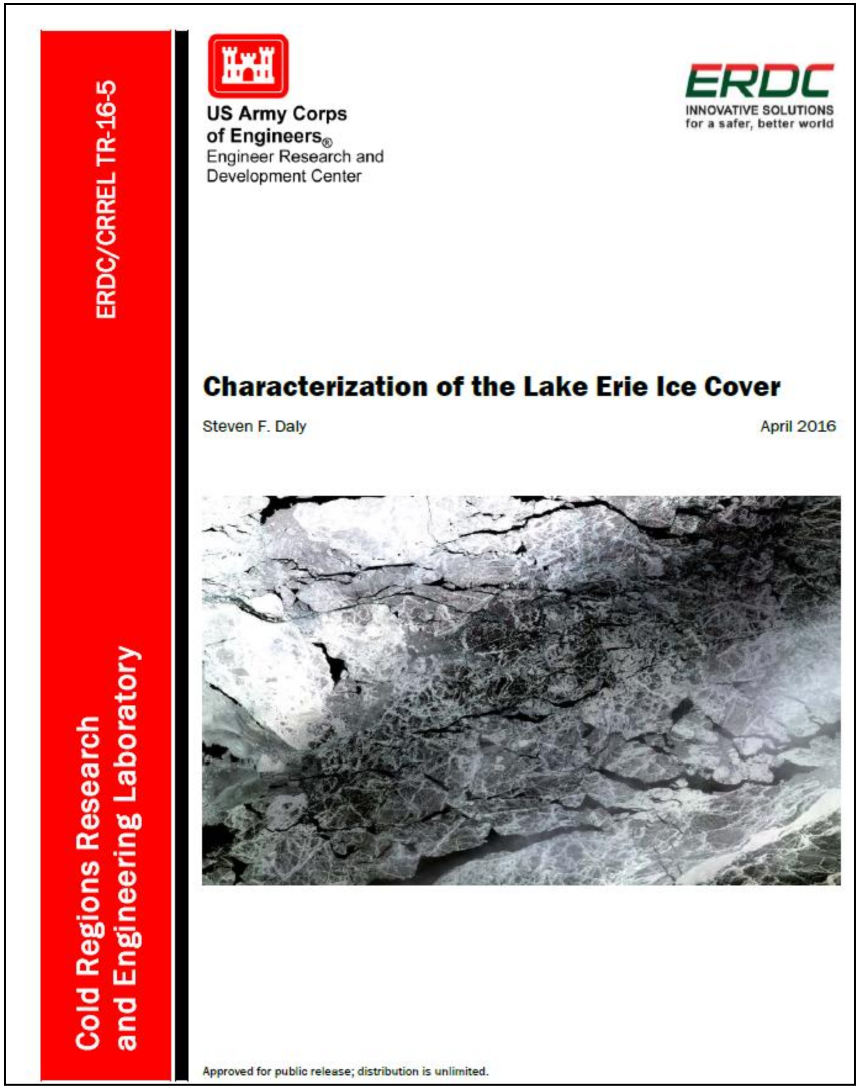




Note: The IceBreaker Project is the first to put turbines in a mobile pack ice zone

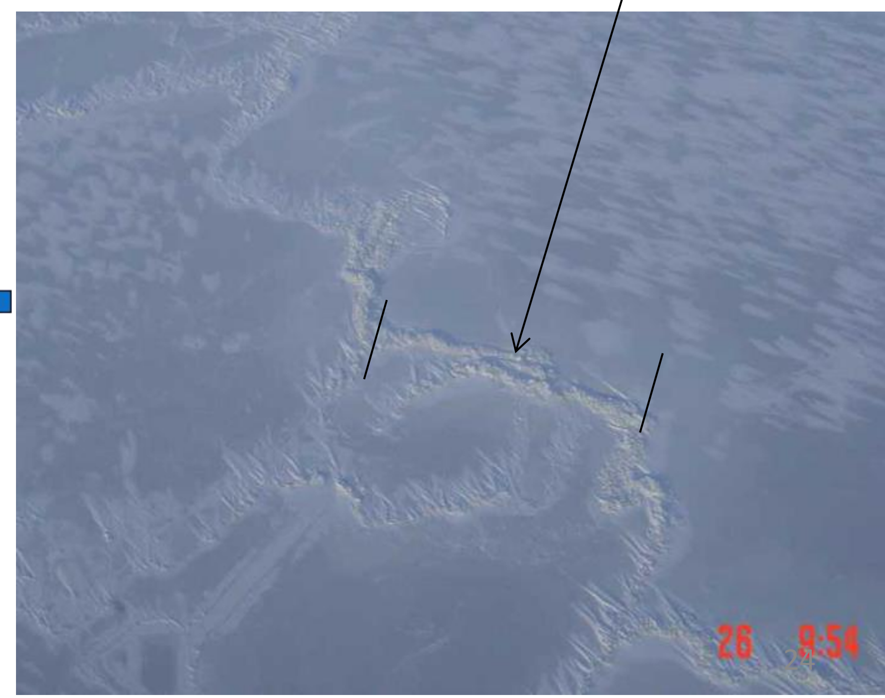
Lake Erie Ice

- Recent study was conducted by ERDC/CRREL on ice conditions – from this -
- 50 year ice level ice thickness is predicted to be 0.6m
- Pressure ridges can have keels extending to sea floor in 18m of water.
- The 50 year ridge is estimated to be an early-forming ridge having a consolidated layer thickness of 1.1m and a keel depth of 16m (see next slide for definitions)

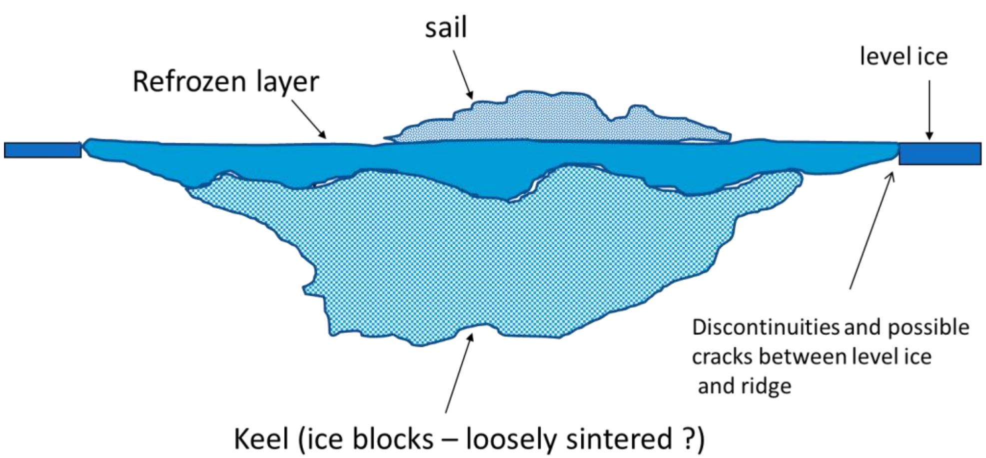


Morphology of a Pressure Ridge

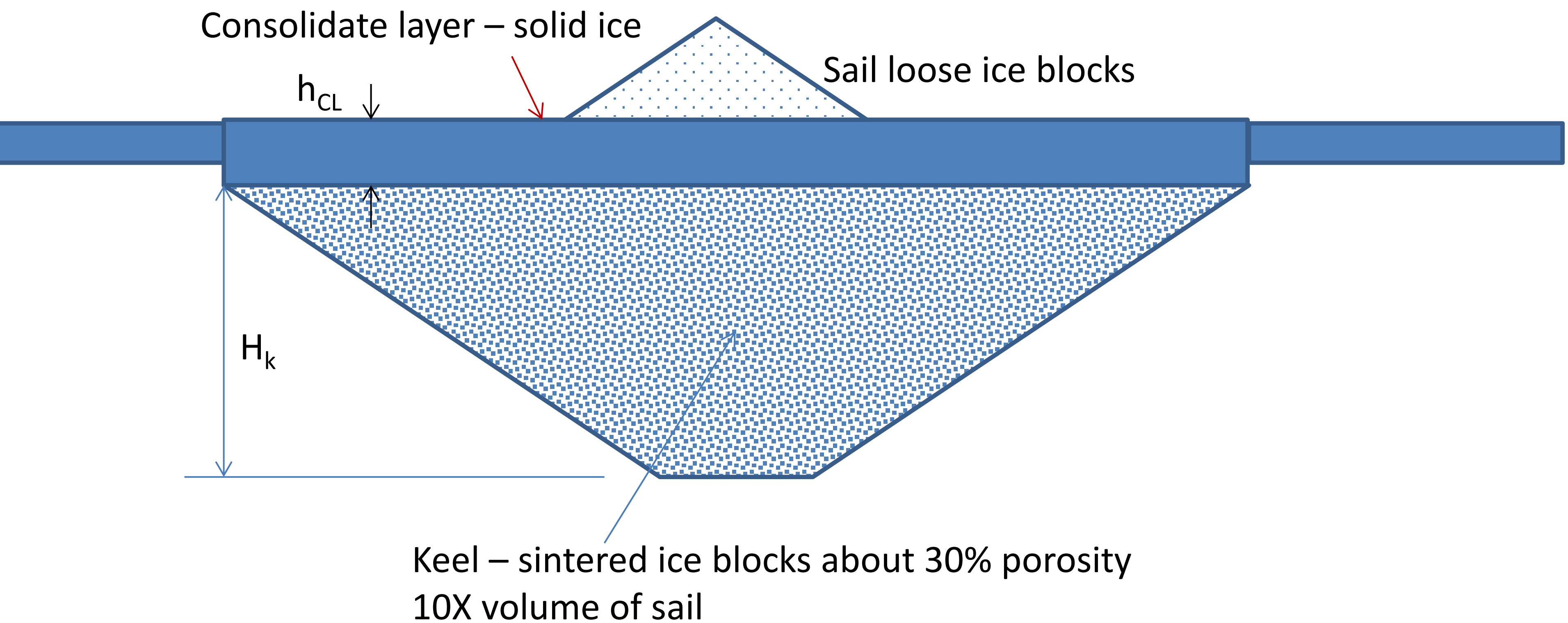
Ridges are idealized as linear features



Typical Ridge X Section



Idealized Pressure Ridge – for calculations

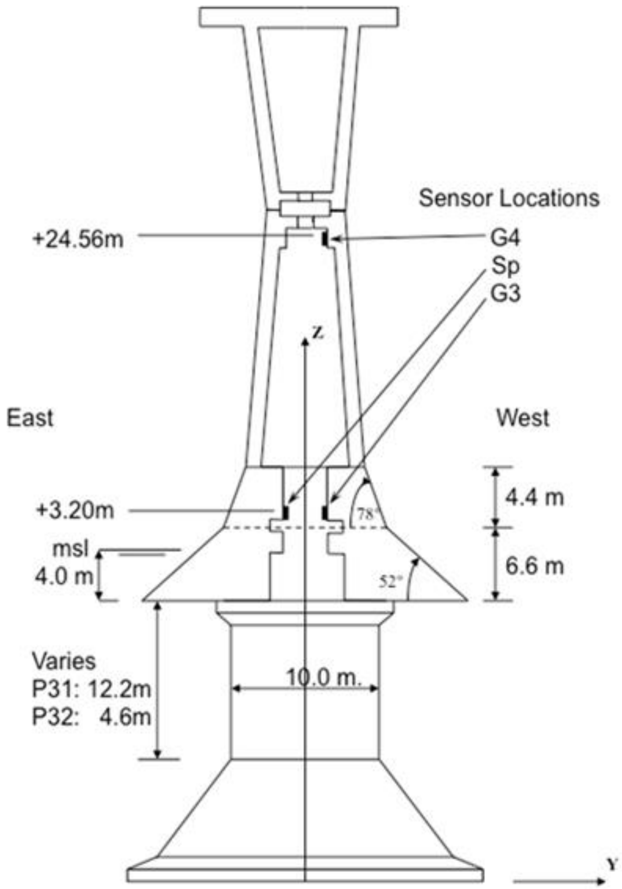


Nominal “50 year” ridges

Case	Hk (m)	hCL (m)
Early ridge	16	1.1
Late ridge	19.5	0.5

Benchmarking with Confederation Bridge – in Canada. Gulf of St Lawrence – connecting the Mainland to Prince Edward Island

12km long – 60 piers



Comparison of Confederation Bridge and Lake Erie wind towers

Parameter	Lake Erie	Confederation Bridge	Ratio
Shaft dia.	5 m	10 m	0.5
Cone dia.	8.5 m (this varies see Table 1.3)	13.5 m	0.63
Keel depth	20 m	20 m	1.0
CL thickness	1.1 m	2.2 m	0.5
Ice strength	fresh	Sea ice	1.0 – 1.3
Friction	0.15	0.3	0.5
Slope angle	60^{0}	52^{0}	1.15

Confederation Bridge 100 year design load is 16.5MN – largest load to date – about 9MN

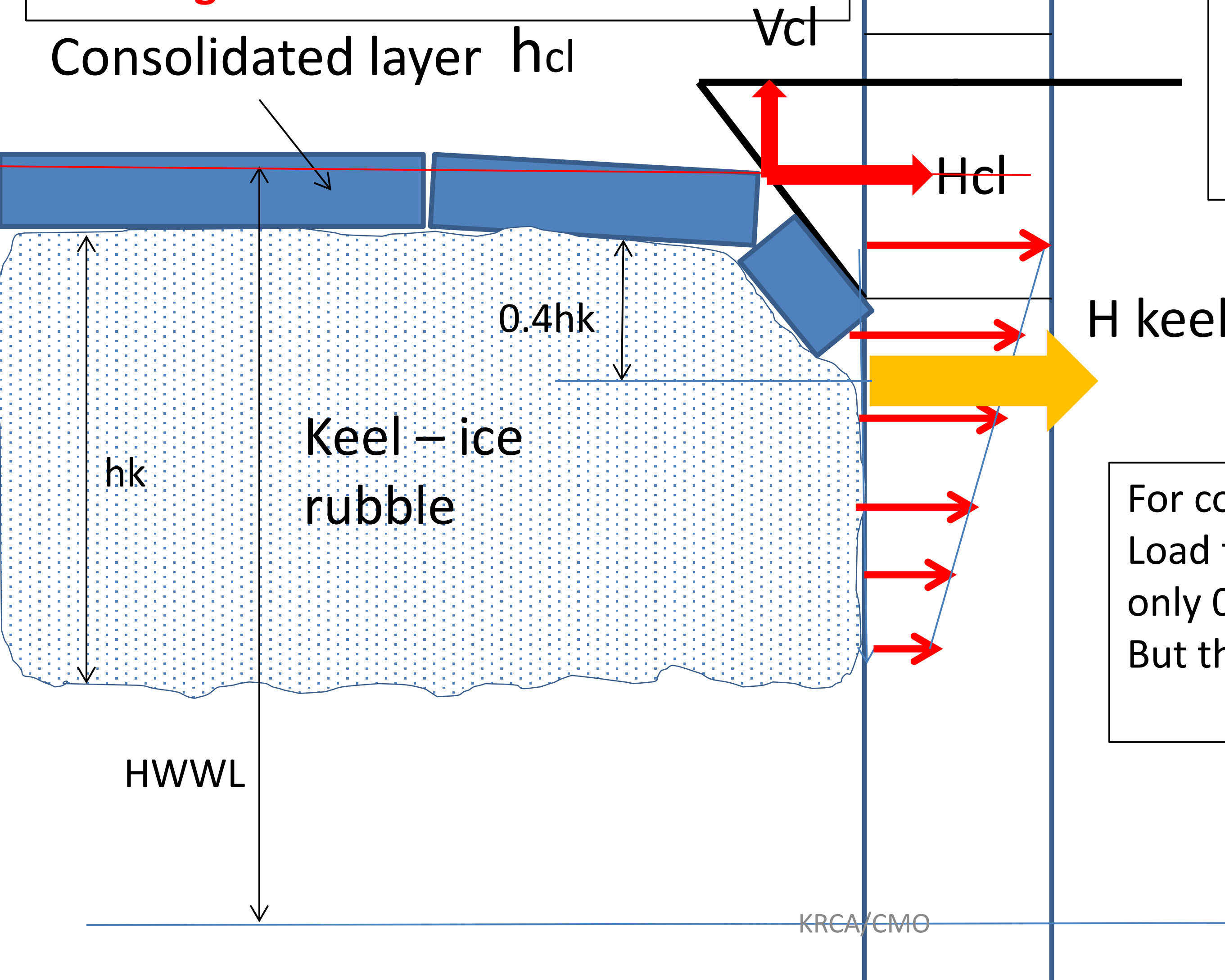
Parametric adjustments on design load
Case A: keel dominated.
Ridge load = 14x0.6 + 2.5x0.28 = 8.4 + 0.7 = 9.1MN
Case B: CL dominated.
Ridge load = 4.5x0.6 + 12x0.28 = 2.7 + 3.4 = 6.1MN

CONCLUSION: Using this method: Corresponding “100 year load” for Lake Erie would be in range 6 to 9MN (For an upward cone).

Up vs Down

- No codes or practice give guidance on first year ridge loads for structures on cones (neither up nor down).
- From an ice perspective, the main reason to favour an upward cone is that there is significant full-scale experience in ridged ice (Confederation Bridge).
- Based on this experience there better confidence in the predicted design loads with an upward cone.
- If only level ice was present, the downward cone has advantages of lower ice loads and would be recommended.
- A downward breaking collar also provides a better access for servicing the turbines.
- For downward cones, the breaking loads of the consolidated layer as it pushed down into a keel is uncertain – a new method has been developed by KRC but not proven.
- For wind turbines with conical collars, the actual keel loads (up or down) are quite similar because the keel is acting mainly on the vertical shaft.

Downward cone – Ridge load.
New method recognizes that downward breaking of hCl is inhibited by keel rubble – which increases the breaking load



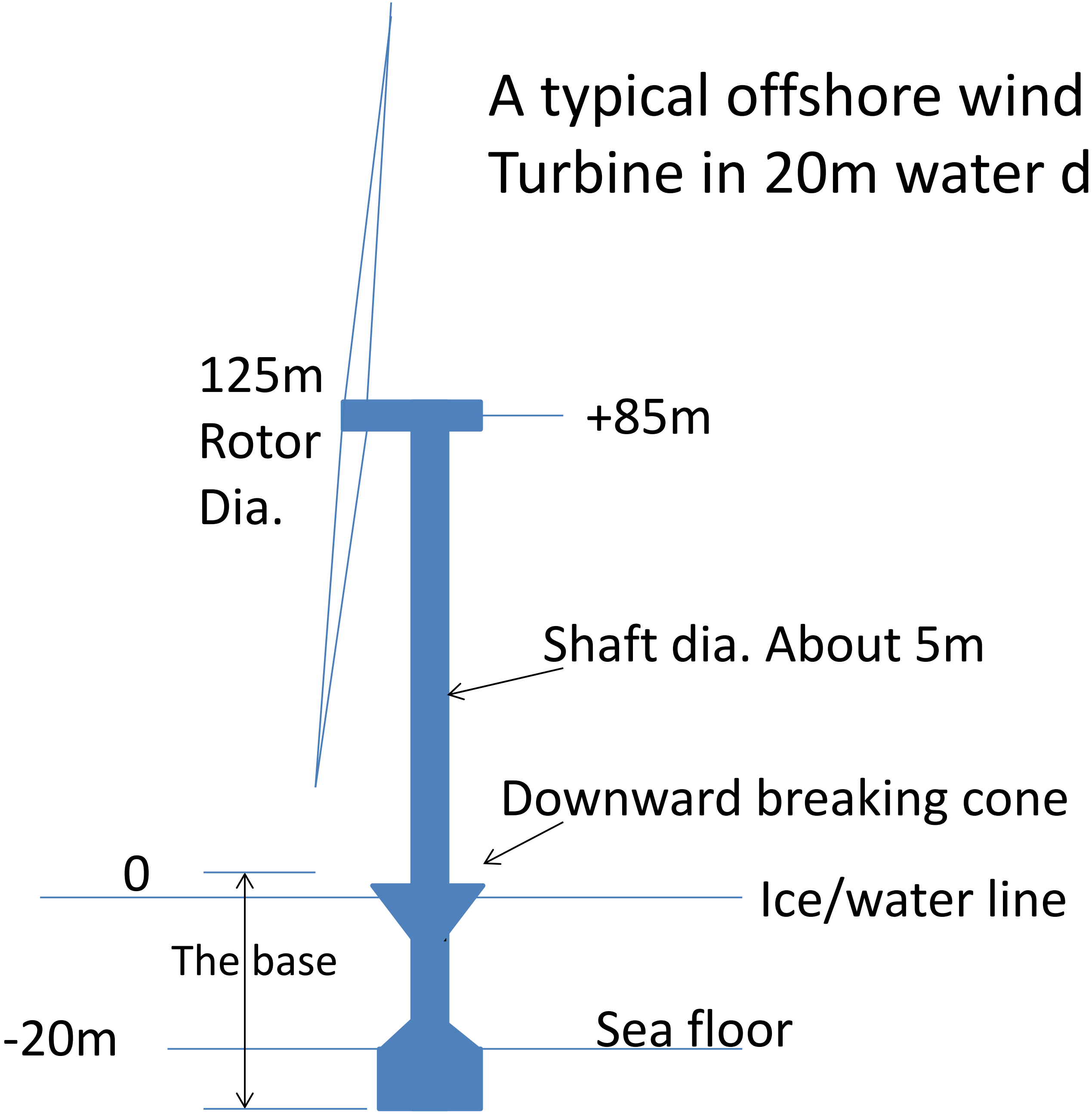
hcl = 1.1m
hk = 16m

Htotal = H keel + Hcl

= 7.4MN

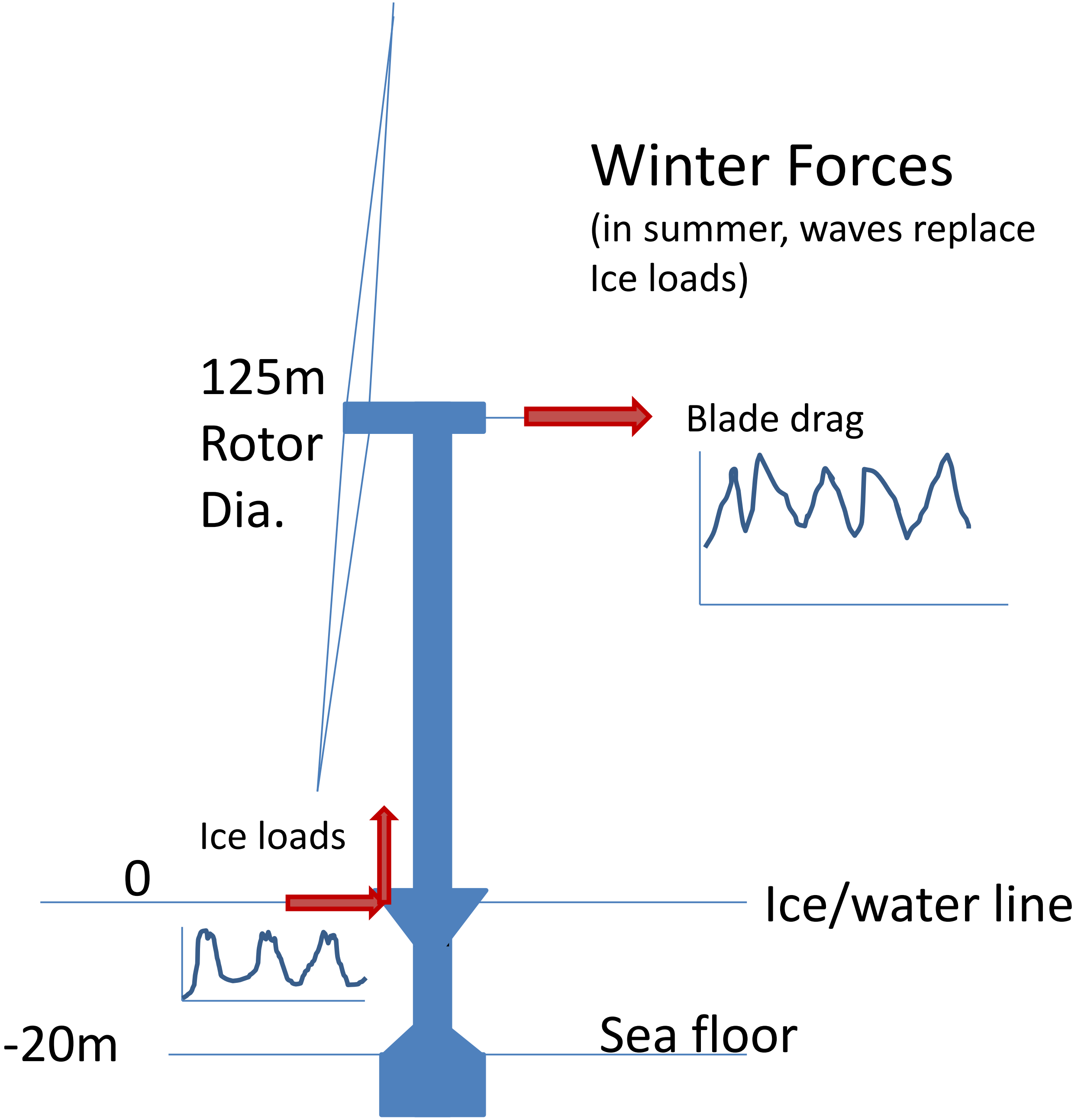
For comparison:
Load from 0.6m level ice is only 0.73MN.
But this can be more dynamic.

A typical offshore wind Turbine in 20m water depth



Winter Forces

(in summer, waves replace Ice loads)



Wind turbines – challenges in design of base and foundation

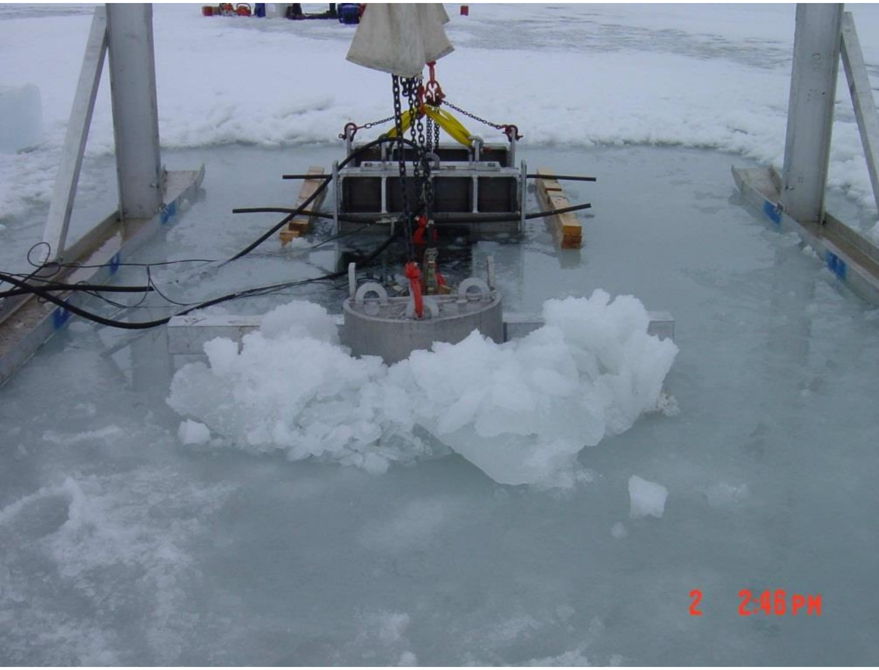
- Wind turbines are slender structures and susceptible to vibrations and fatigue
- The frequency and magnitude of the ice loads are important for design
- Typical first natural frequencies of the structure can be in range of 0.5 to 2.5Hz.
- Ice load frequencies must aim to be below this (by a margin)
- Structural designers of wind turbines require the ice load "signatures" to input into dynamic analyses of the structure (which also include the wind load cycles)

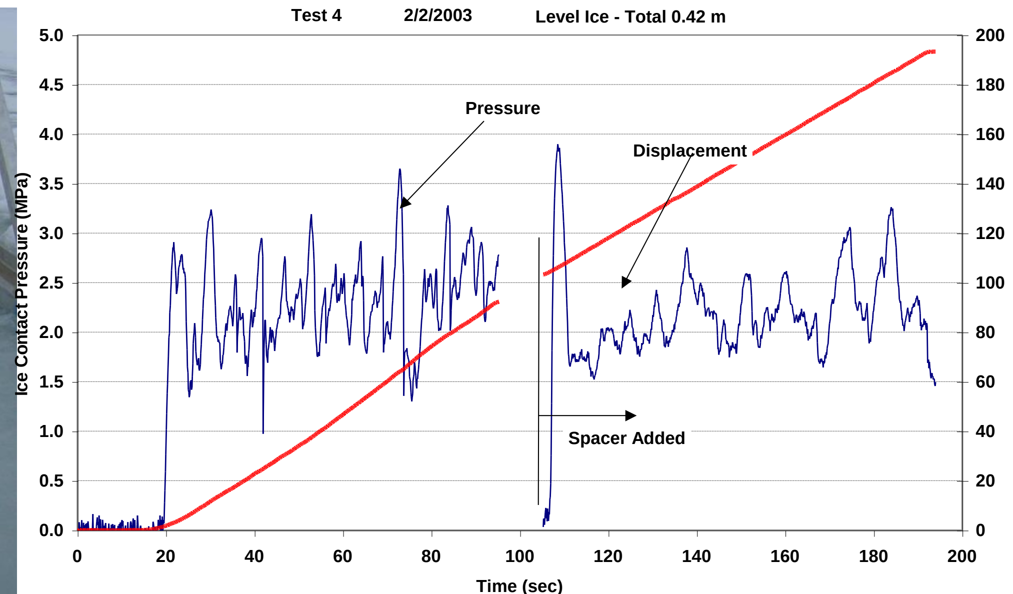
Ice induced vibrations - history

- Vibrations induced by ice destroyed the Kemi 1 lightpier (Maattanen (1977)Maattanen & Hoikkanen (1990)).
- Baltic lightpiers at that time were slender cylinders with minimal damping.
- Less dramatic vibrations have been experienced by vertical-sided bridge piers and Cook Inlet platforms.
- The Molikpaq platform suffered significant dynamic excitations during some ice crushing events.(Jeffries and Wright(1988).
- Small-scale experiments with vertical faces can easily produce vibrations (e.g. Sodhi, 1989).

Simple explanation

- Ice loads are cyclic because of repeated (usually brittle) failures of the ice as it moves against a platform.
- At some ice speeds, the cyclic load frequency coincides with natural periods of the structure.

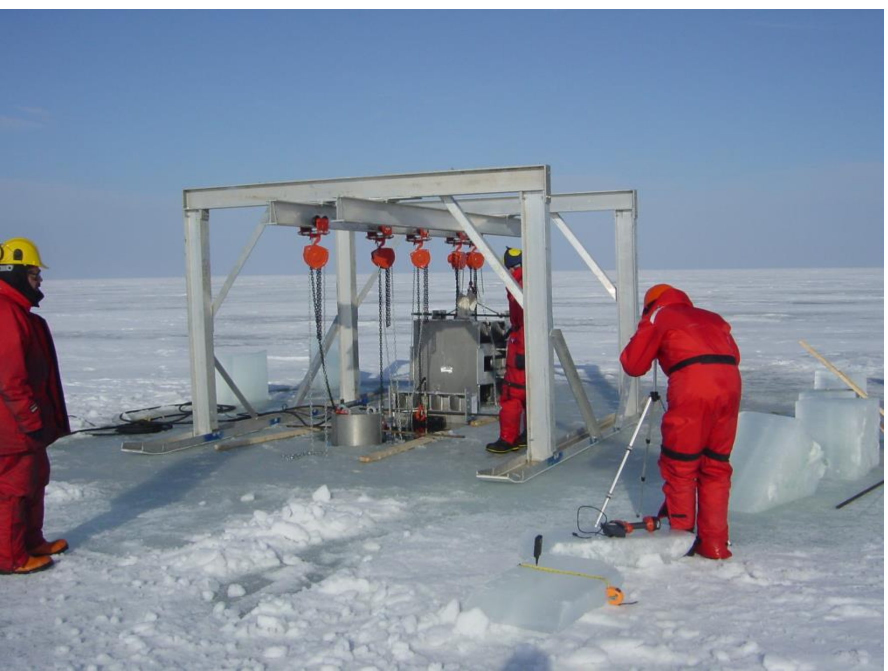




Caspian indentation tests

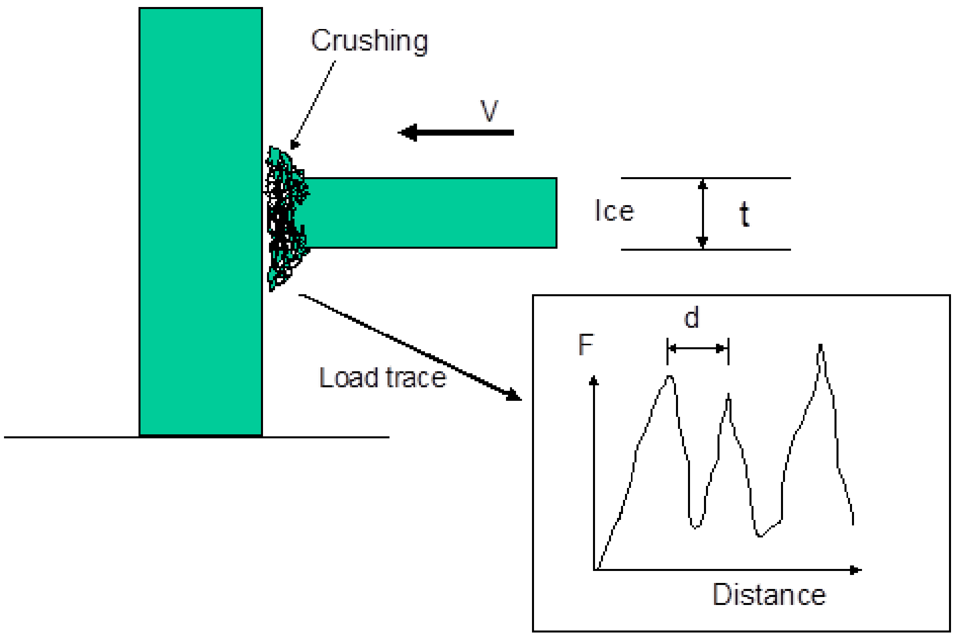
These load traces are typical of ice crushing

Crushing loads are cyclic – troughs are about
half the peaks



Simple concept – cyclic loads

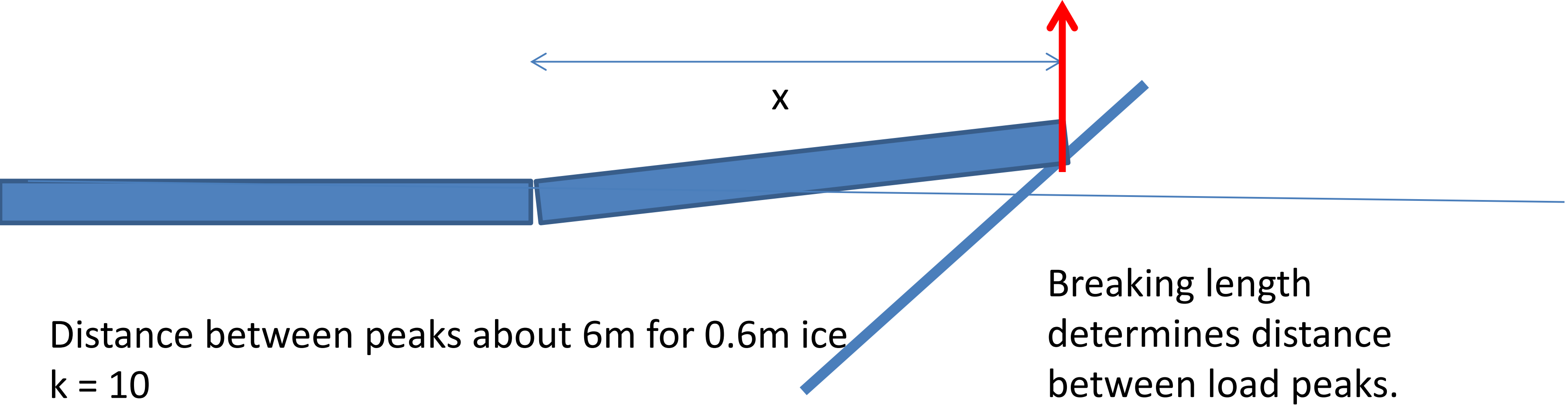
- As ice advances, the crushed area increases and so does the load. At some value of load corresponding to peak strength for the failure mode, the ice fails in a global mode (in the case shown it is spalling) and the load drops.



$$d = kt$$

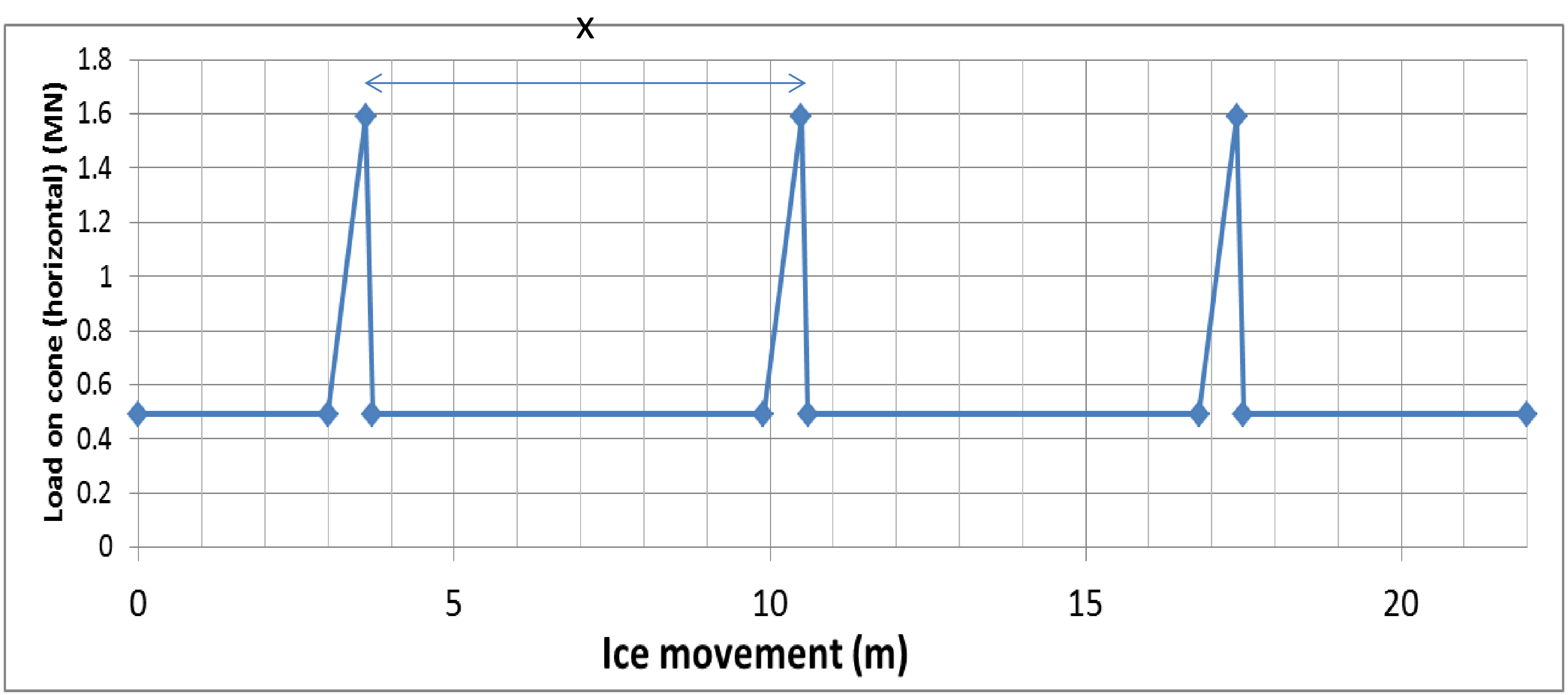
$$\text{Frequency} = v/kt$$

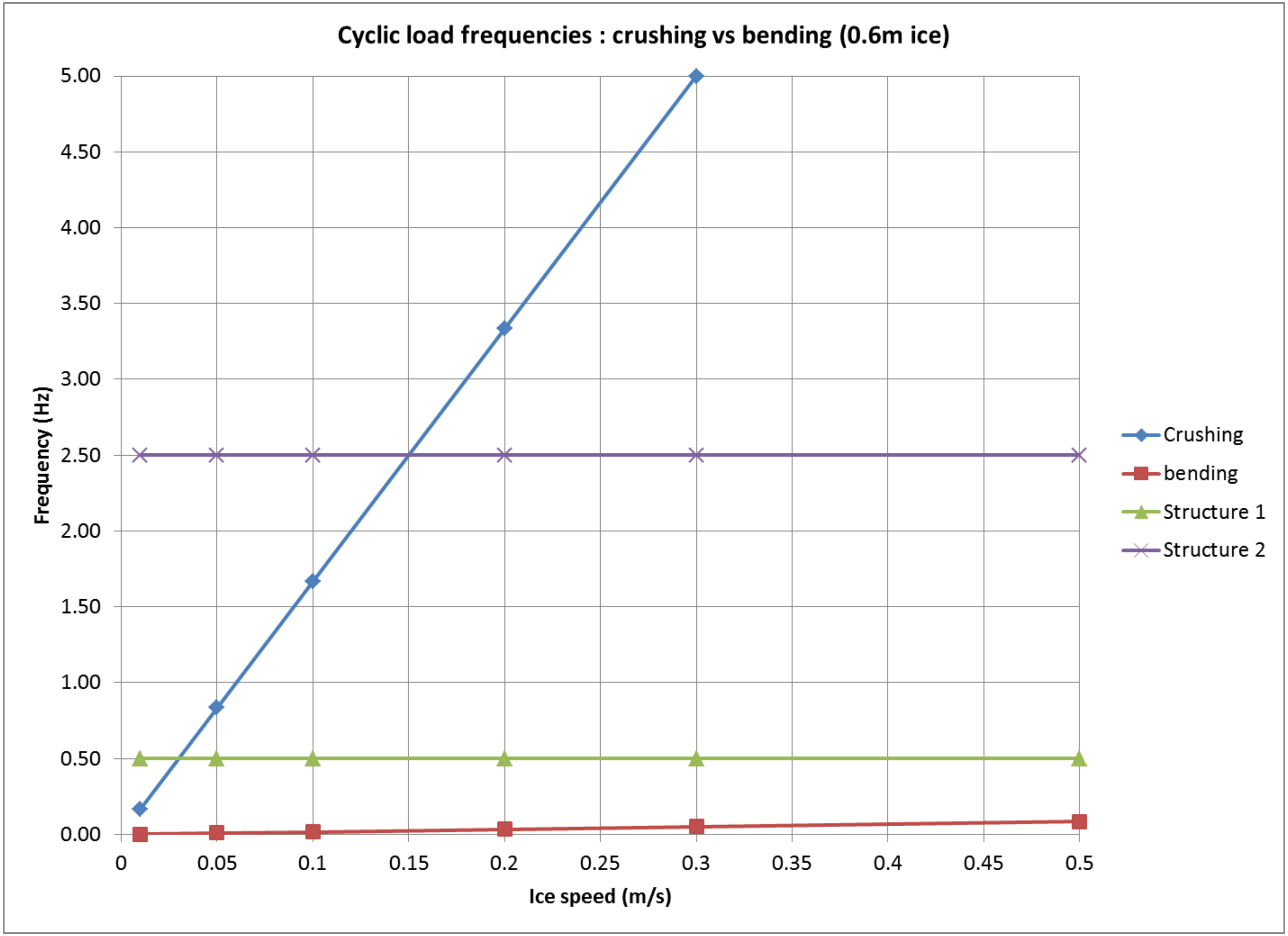
For crushing, k has been assessed from full scale and model test data.
Typical k values in range 0.05 to 0.2
So for v = 0.1 to 1m/s and 1m ice: Frequency in range of 0.5 to 20 Hz
Typical first natural frequencies of a turbine base in range of 0.5 to 2.5Hz.



Distance between peaks about 6m for 0.6m ice
k = 10

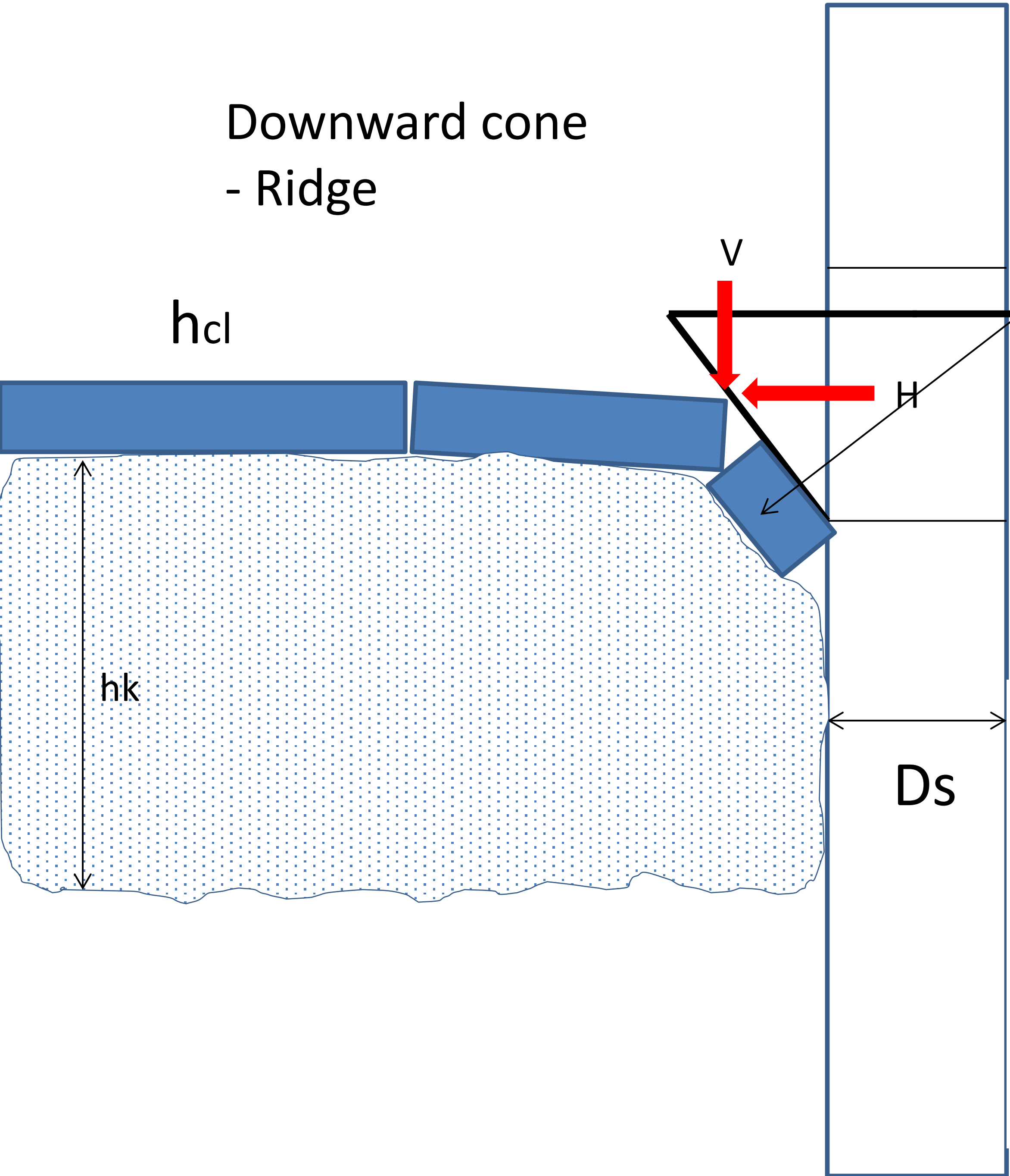
Breaking length determines distance between load peaks. This is a function of h



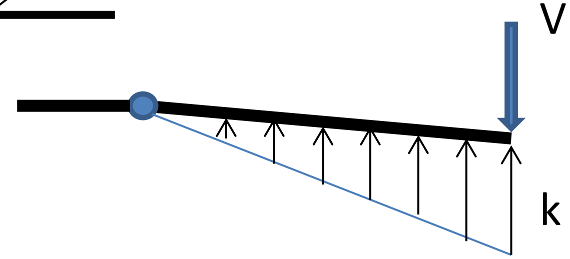


Cyclic load frequencies : crushing vs bending (0.6m ice)
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Frequency (Hz)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Ice speed (m/s)
Crushing
bending
Structure 1
Structure 2

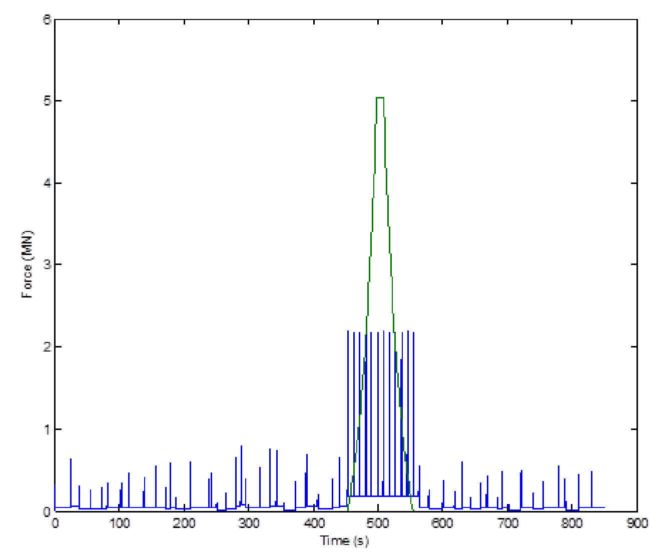
Downward cone - Ridge



Consolidated layer has to pushed down into the keel to fail it



k is uncertain – not simple buoyancy

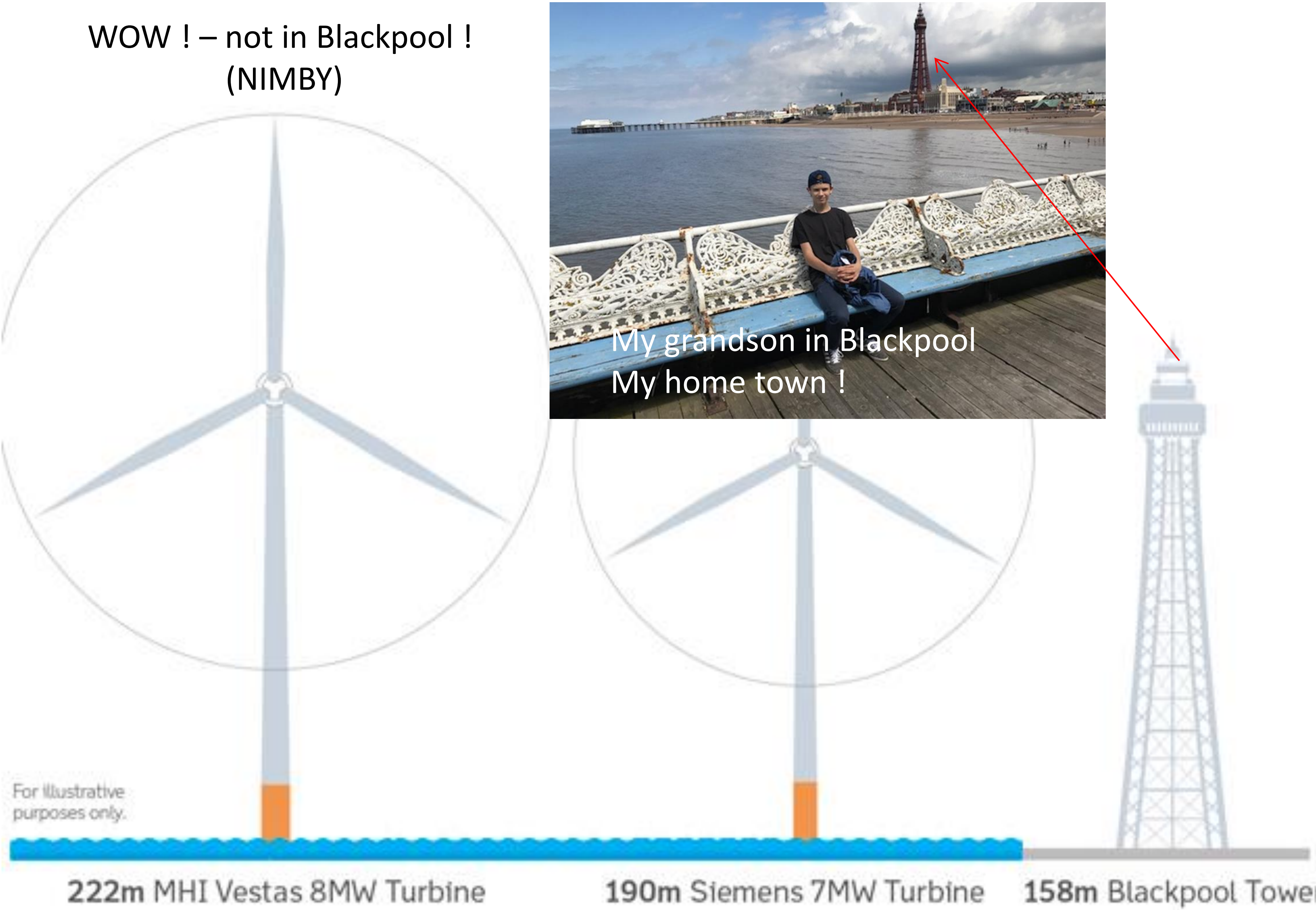


To Sum up – Re Wind Turbines

- The additional technological challenge in the Great Lakes over other US areas is the presence of ice.
- No precedents exist for wind turbines in pack ice
- Pori Project in the Baltic – but it is in landfast ice.
- The LeedCo “IceBreaker” is a pioneer project.
- New methods have been developed and accepted during Verification.
- But continued research on ice issues can help in refining future projects
- Will Canada place turbines in offshore ice–covered areas ?
- Recent costs per kWh are down a lot (3.7c/kWh onshore)
- But we need some flexible base-load generation or storage
- Turbines are becoming very large – see additional slides – being offshore will reduce visual impacts ?


To sum up on “best laid plans”
ROBERT BURNS
BIRTHPLACE MUSEUM
I already implemented my plan to go to Alloway
Next week I plan to eat a
HARVEST
HAGGIS
Nutrition Facts
Valeur nutritive

WOW ! – not in Blackpool !
(NIMBY)



But Paris is OK !!!