First-year ridge loads on Norströmsgrund lighthouse

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Ocean, Coastal & River Engineering

NRC OCRE

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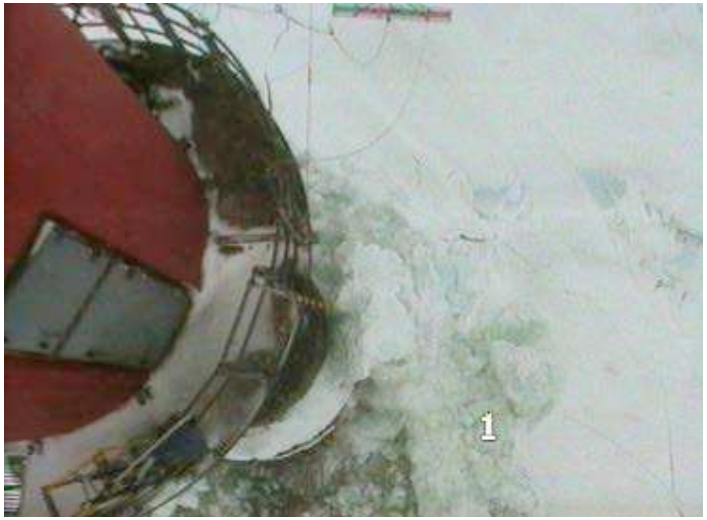
First-year ice ridge loads at Norströmsgrund lighthouse: Overview

- Why study ice ridges and loading?
- Norströmsgrund as a platform for investigation (LOLEIF and STRICE)
- Details of selected ridge interaction events
- Local and global loads on structure
- Comparison with global loads predicted using ISO 19906 Standard



Ridged ice interaction with lighthouse on 4 April 2003 at 17:35; courtesy of STRICE project

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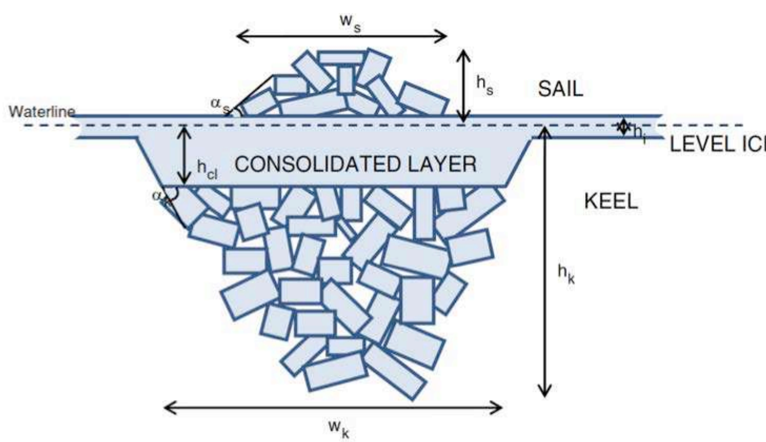
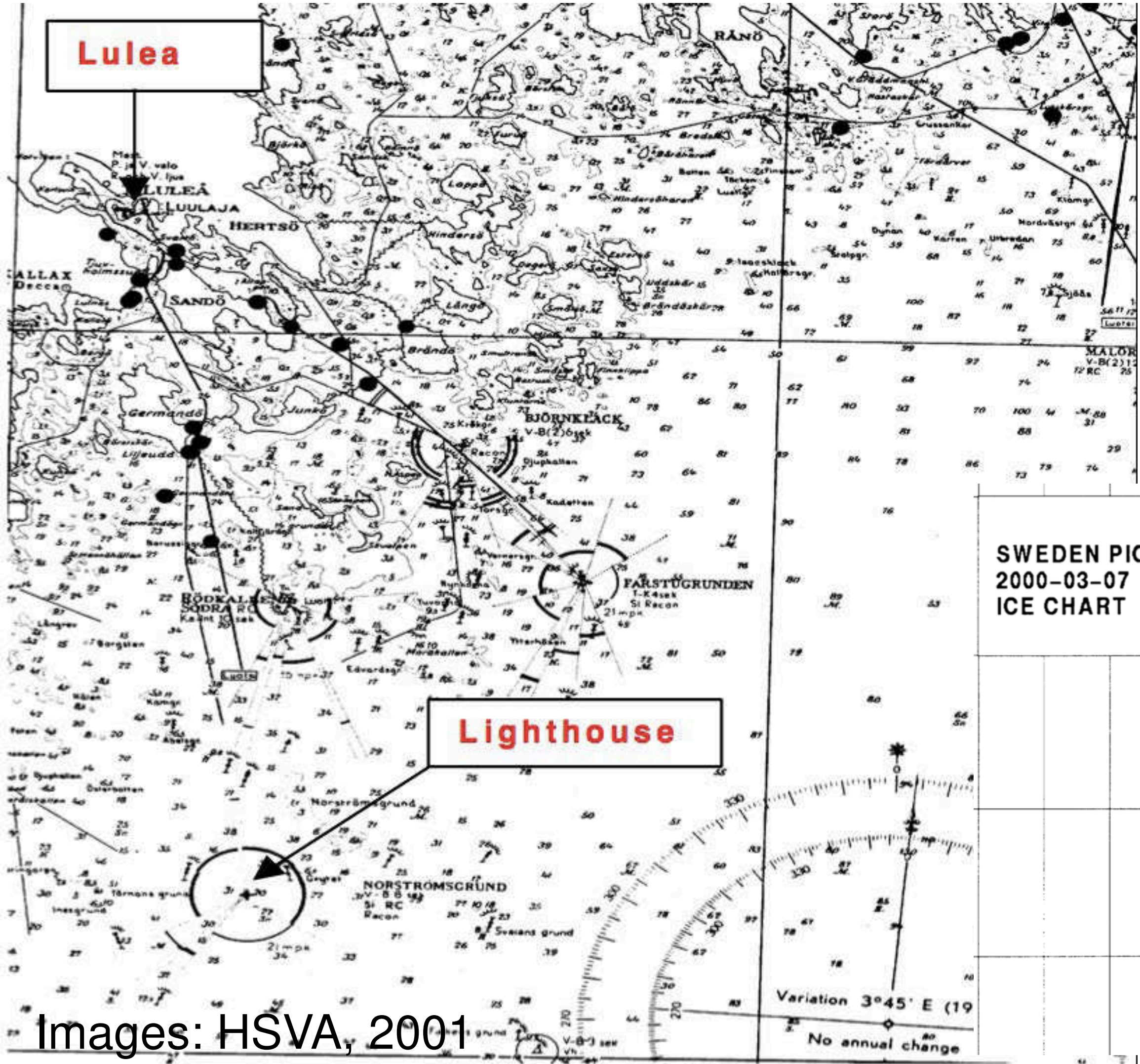
Application of ridge properties for load calculation

- *For offshore structures:* total ridge thickness and ridge strength for multi-year ridges; consolidated layer thickness, keel properties (friction angle, porosity, cohesion) and possibly ridge width for a first-year ridge
- *For the shipping industry:* ridge size and consolidated layer thickness
- *For subsea installations:* keel properties (depth, geometry, consolidation and cohesion)

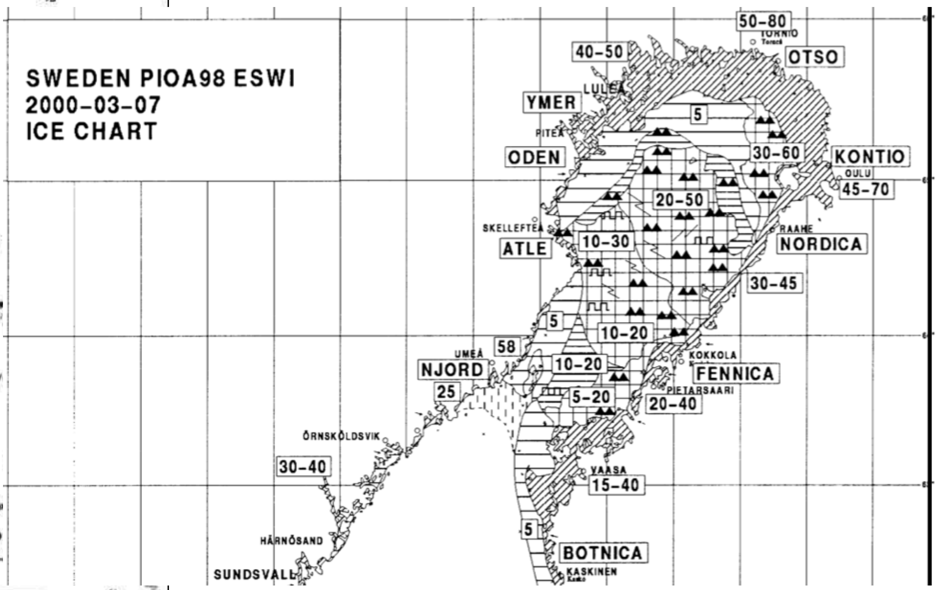


Strub-Klein & Sudom, 2012

Norströmsgrund lighthouse location and ice conditions



Images: HSVA, 2001



- Ice from February – April
- Average level ice thickness up to ~ 0.6 m
- Ridges with keels up to 8 m, or greater

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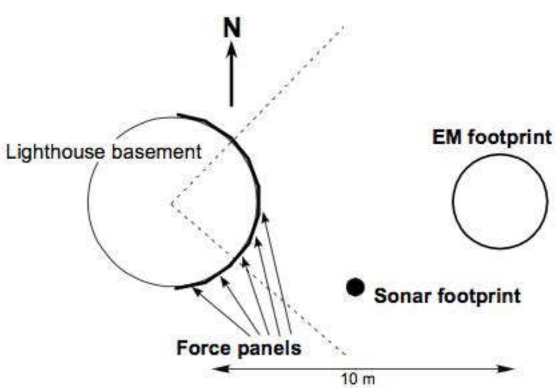
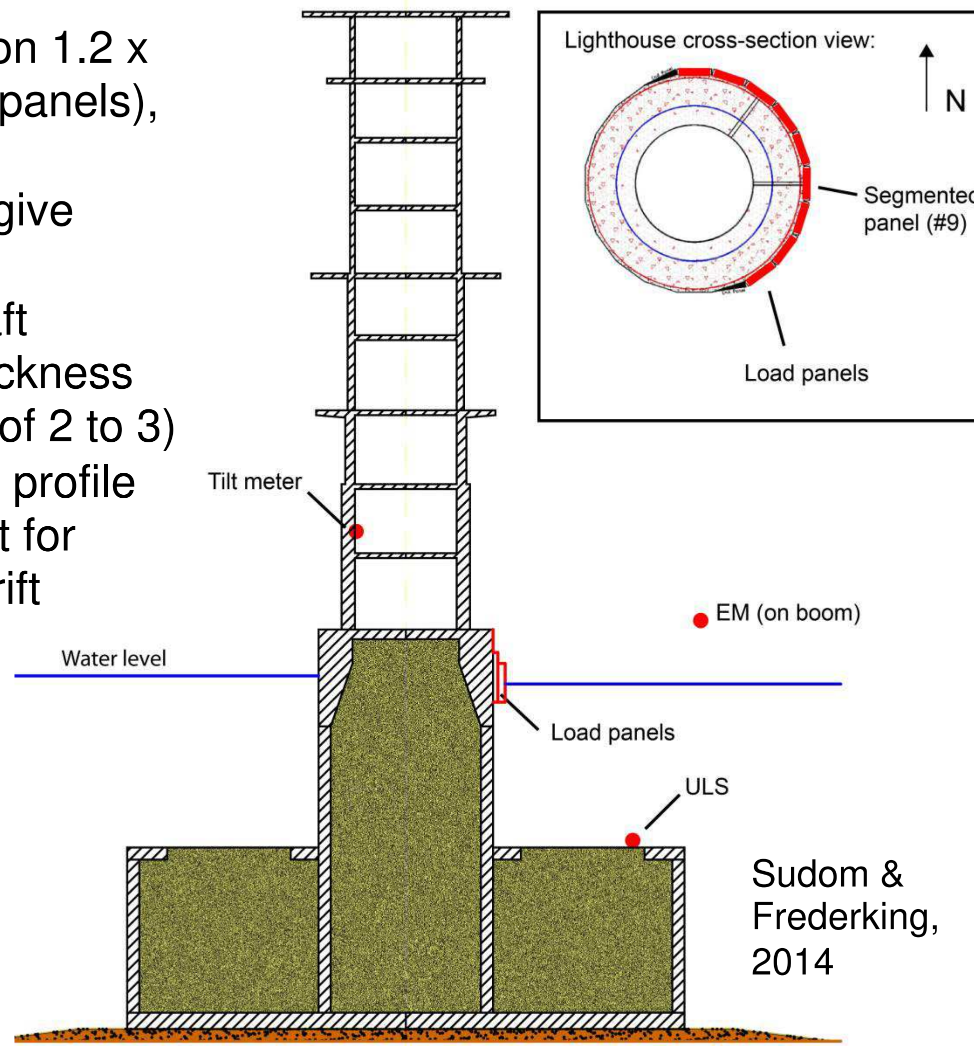
Norströmsgrund lighthouse instrumentation for LOLEIF and STRICE projects

- Nine load panels measuring total load on 1.2 x 1.6 m areas (one with 8 segments/sub-panels), covering 162°
- Tiltmeter measuring angular change – give indication of keel loads?
- Upward-looking sonar (ULS) for ice draft
- Electromagnetic (EM) device for ice thickness (underestimates keel depth by a factor of 2 to 3)
- Laser and sonic devices for ice surface profile
- Ice observer log books – very important for notes on ridge interaction events, ice drift direction and other details



Haas & Jochmann, 2003

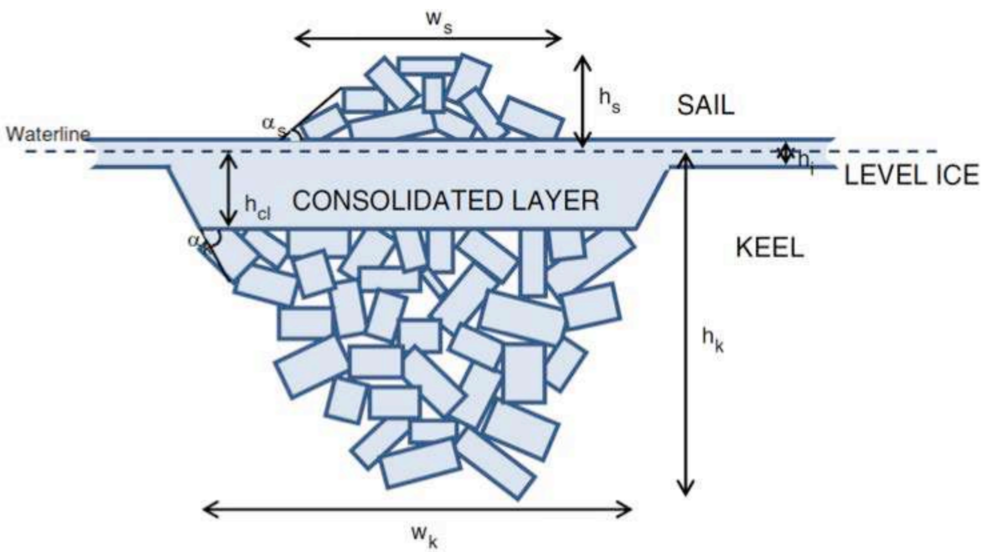


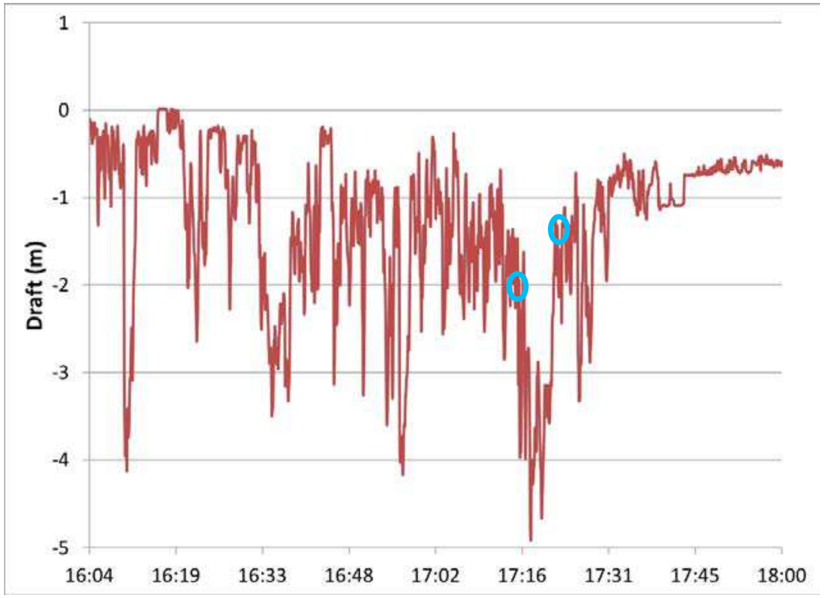
Sudom & Frederking, 2014

Selection of events for detailed analysis

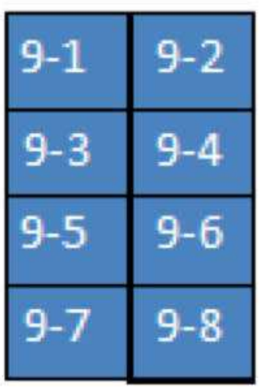
- Ice observer notes
- Keels as measured by ULS (≥ 4 m) or EM (≥ 2 m)
- Period of level ice before or after ridge
- Loading from east or east-northeast, so that panels captured most of load
- Availability of tilt data (2002 – 2003 only)

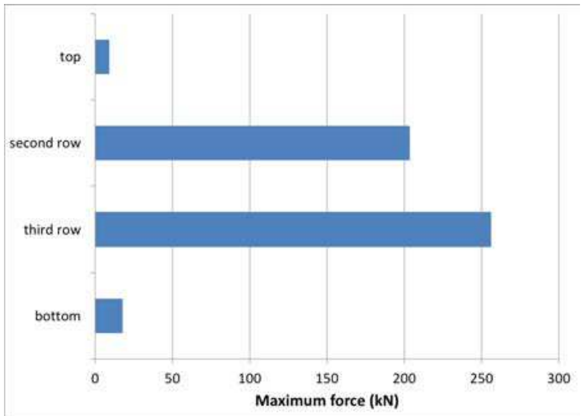
1 Apr 2000 event: ice draft (from ULS) and estimation of consolidated layer thickness





Panel 9





- In some cases can estimate CL thickness
- Keel pressures much lower than those from CL

Figure top left: Strub-Klein & Sudom, 2012
All other figures: Poirier et al., 2014

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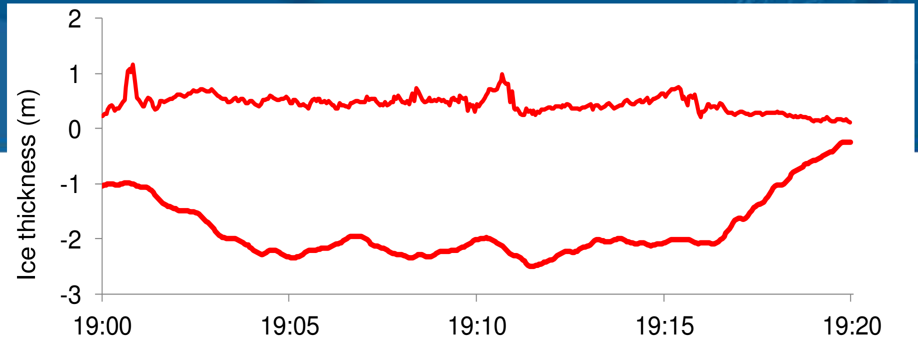
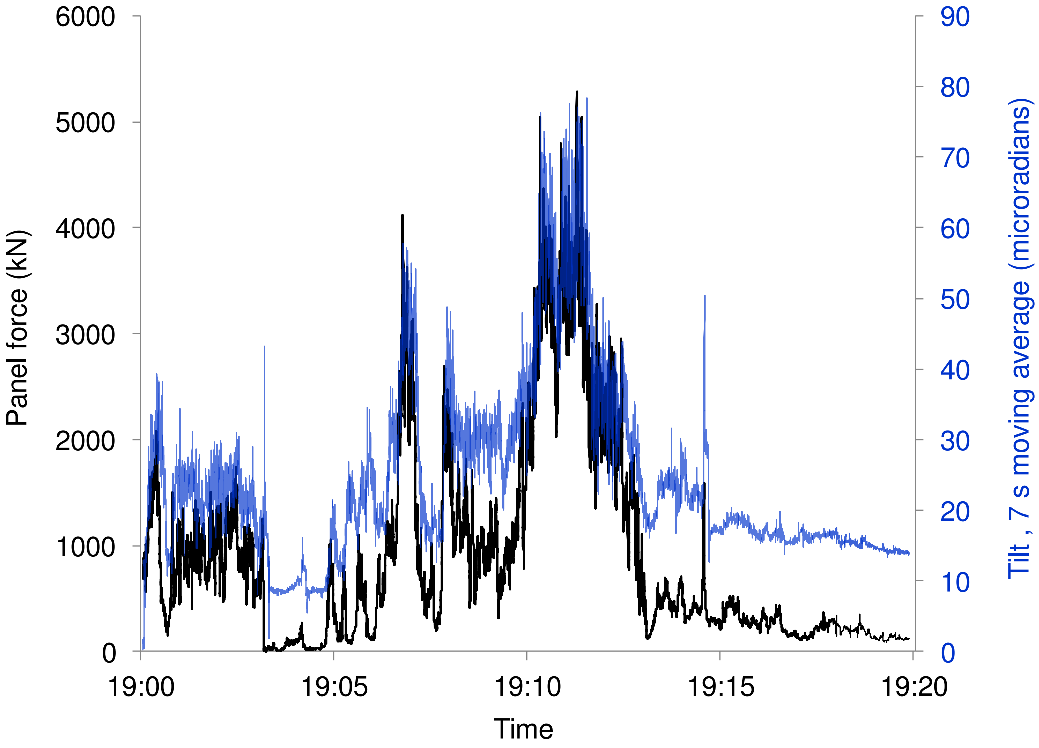
9 May 2002

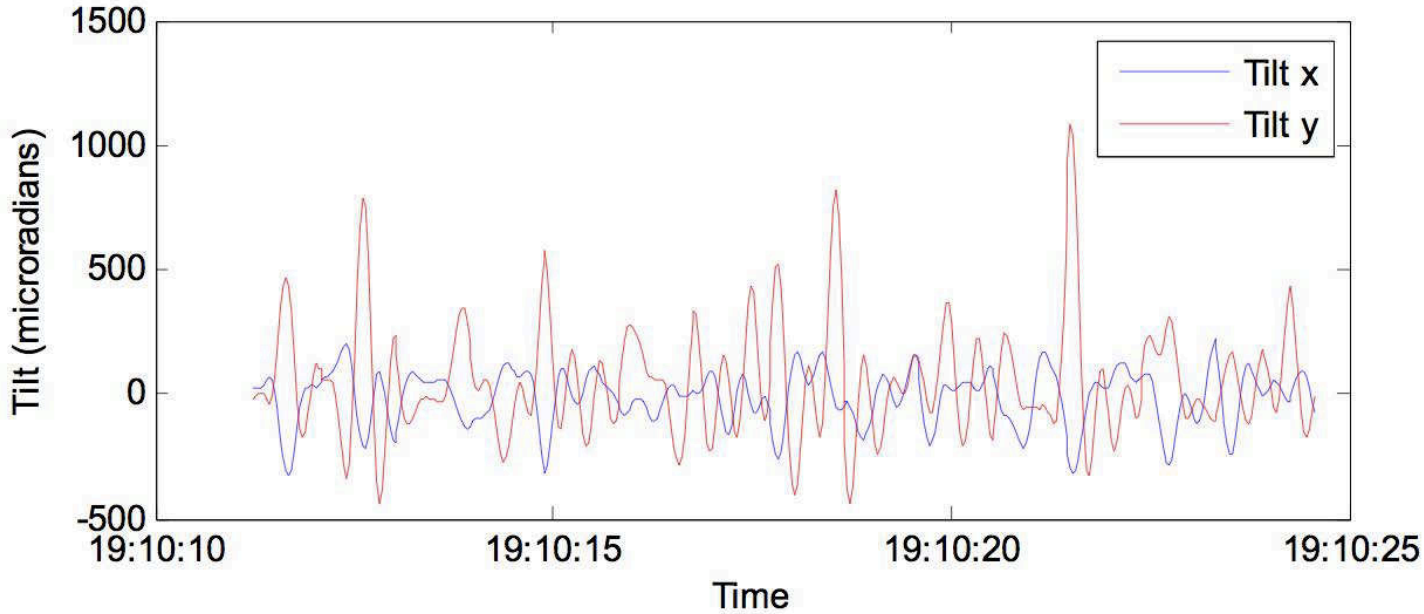
- Large ridge field; dynamic event
- Ice draft from EM
- CL up to 1.2 – 1.5 m thick
- Some sail/upper load missed, but little keel load missed
- One of highest load events measured by panels (5.5 MN)
- Good correlation of tilt and panel loads, when tilt is filtered with moving average
- If 12 kN/μradian conversion factor (Frederking 2005) is applied, peak global load is >13 MN





Figures: Sudom & Frederking, 2014

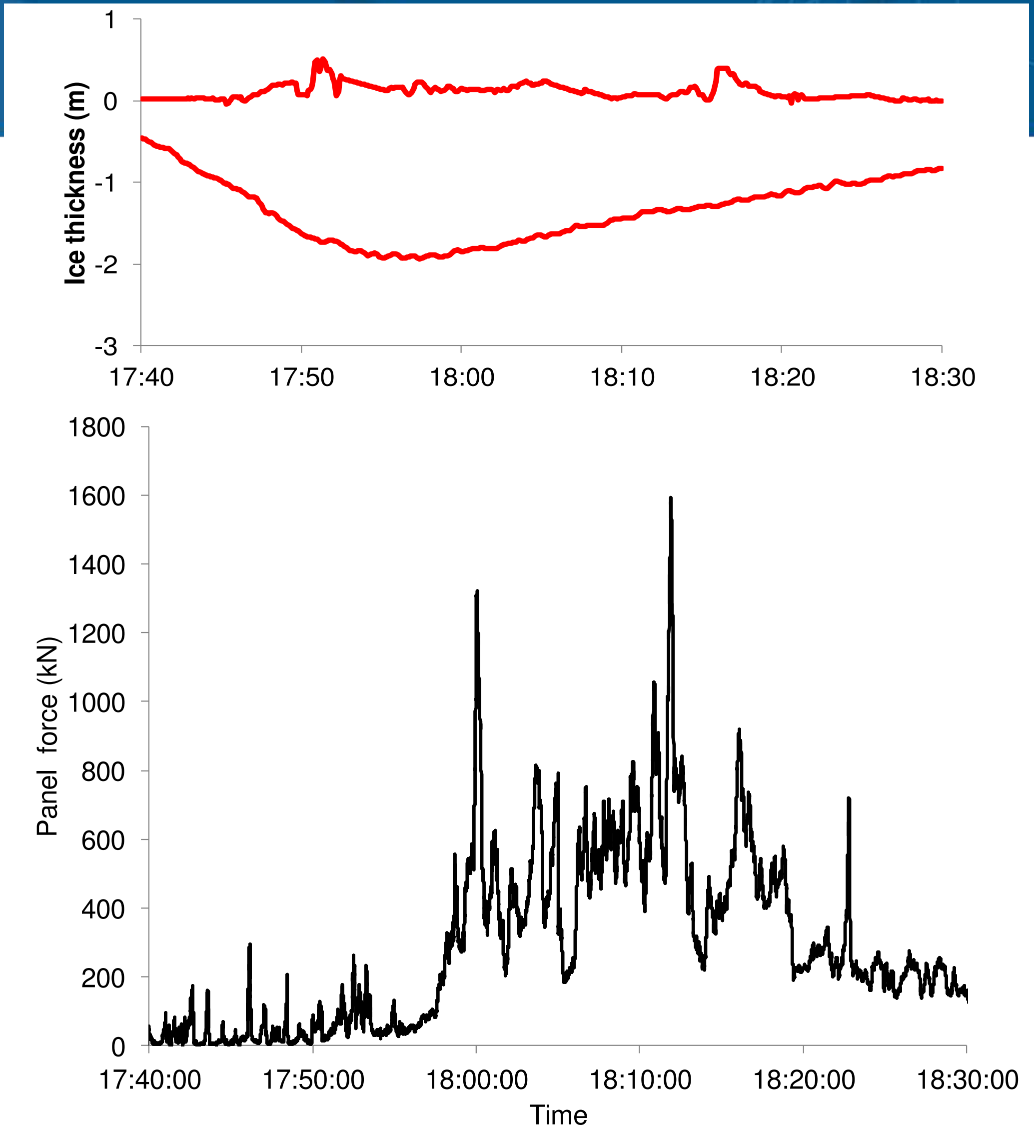
9 May 2002: tilt analysis



- Oscillations of the raw tilt data during 15 seconds of the peak event load in the x (to the north) and y (to the west) directions.
- Spectral density analysis shows 2 dominant frequencies ~ 0.8 Hz and 2.7 Hz.
- VBB (1989): for the fundamental structural (cantilever) mode of the lighthouse, the predominant frequency of vibration is about 2.32 to 2.35 Hz; the lighthouse amplifies its own vibrations.
- Tilt data may be unsuitable for dynamic loading events.

3 Apr 2002

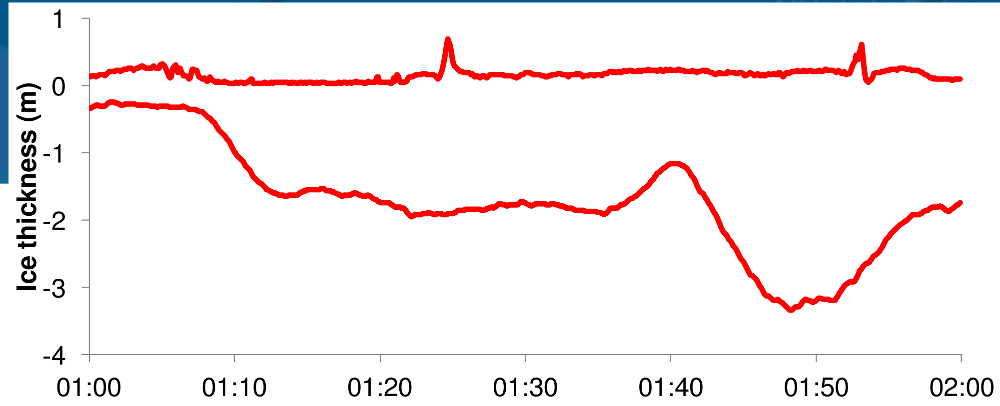
- Single ridge; slow loading event
- Consolidated layer (CL) estimated at 1.1 m
- Some keel load missed (high loads on lower panels) and load on south side
- Should be good event for checking tilt; tilt load should be higher than panel load
- Tilt load (converted) is only ¼ of panel load

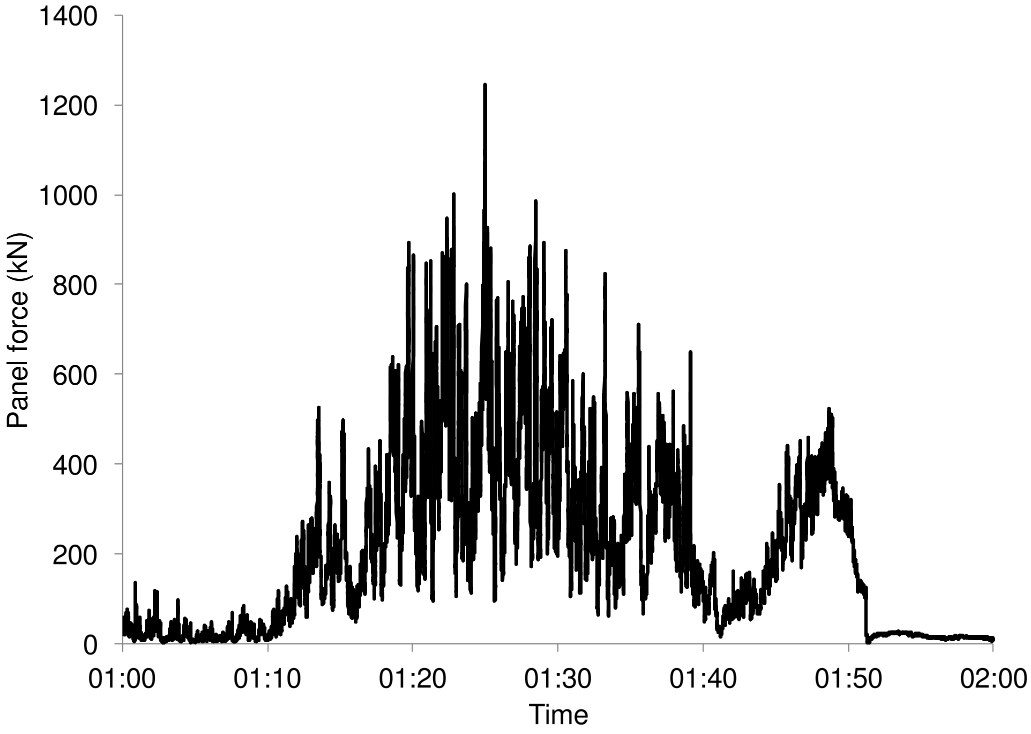


Figures: Sudom & Frederking, 2014

4 Apr 2002

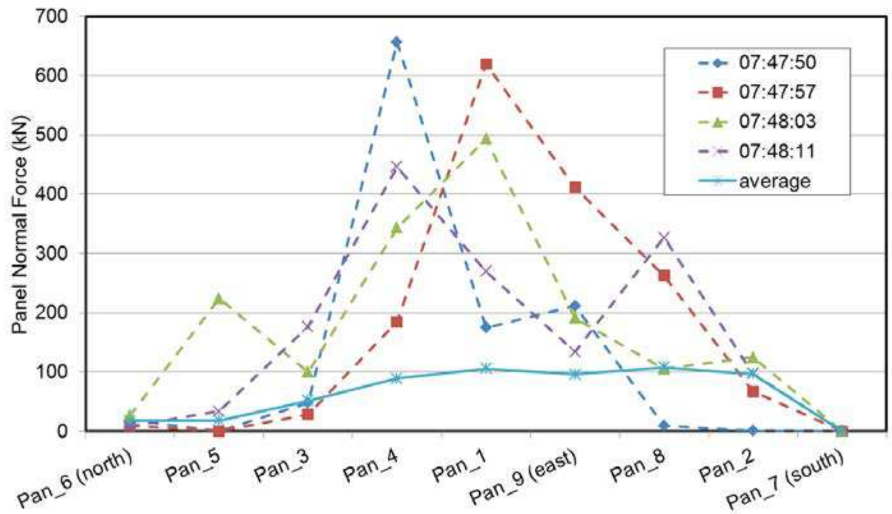
- Ridge field with 2 distinct keels
- First event had shallower keel but higher loads (was full keel captured by EM footprint?)
- Segmented panel indicates that some load was missed below panels
- Some load on southern part of lighthouse may also have been missed
- Level ice load same magnitude as ridge load
- Tiltmeter indicates low load levels

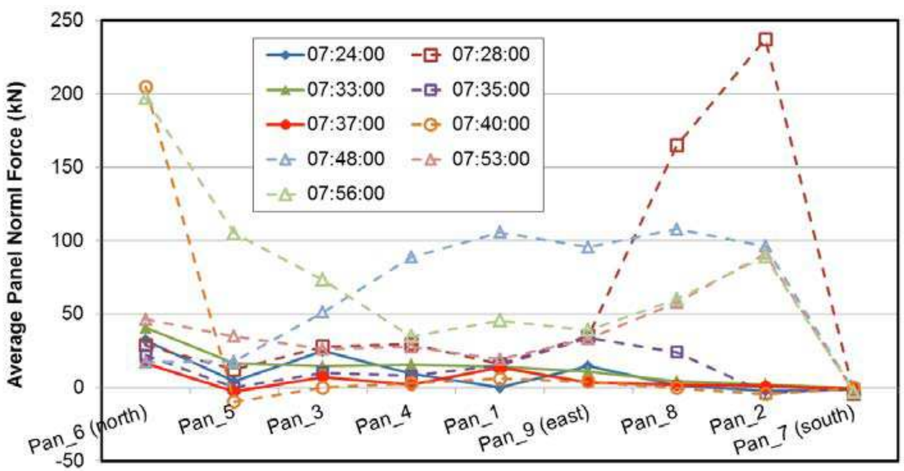




Figures: Sudom & Frederking, 2014

6 Mar 2002: horizontal distribution of ice ridge pressures





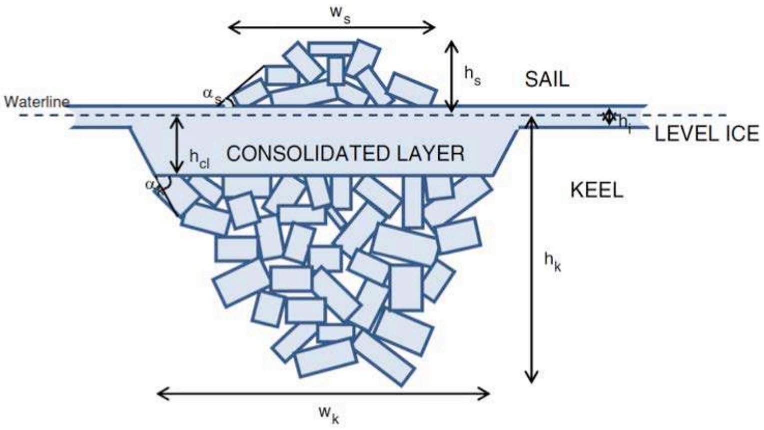
Figures: Frederking, Sand & Sudom, 2014

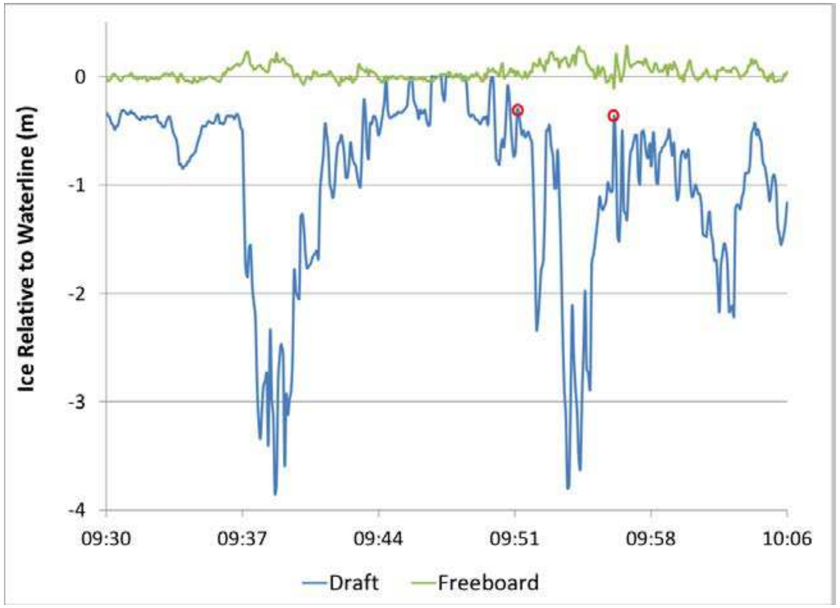
- Top: ice forces measured on individual panels at various points in time during one day of unconsolidated rubbled ice interaction (somewhat parabolic distribution)
- Bottom: average loading on panels during various events (15 to 60 s durations)

Global loads measured by load panels and inferred from tilt meter

- For the ridge events studied, global loads of 1.2 to 5.5 MN were measured by the panels → ridges and ridge fields cause the highest loads experienced on the lighthouse
- Panels often miss part of load
- Ice loads from parent (surrounding) level ice sheet were 0.5 to 1.4 MN
- In general, ridged ice loads are 2 – 5 times higher than those from the parent level ice sheet (for both the panels and tiltmeter)

Load contribution from loose rubble or ridge keel

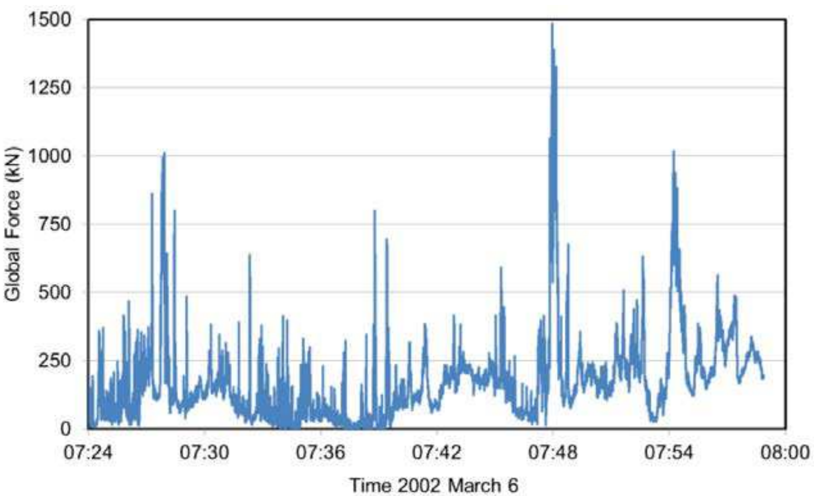


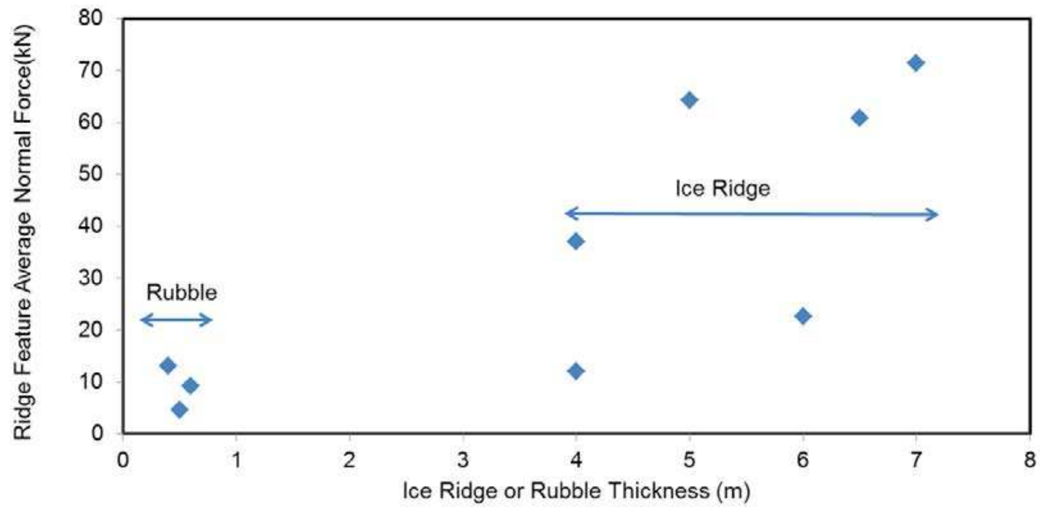


- Panels capture most of consolidated layer (CL) load, but what about keel load?
- In some cases the segmented panel indicates negligible loads on the lower subpanels => keel load is much lower than that from CL
- For keels of 4 m or greater depth, load contribution is still significant

Figure, top: Strub-Klein & Sudom, 2012
Bottom: Poirier et al., 2014

Load contribution from loose rubble or ridge keel

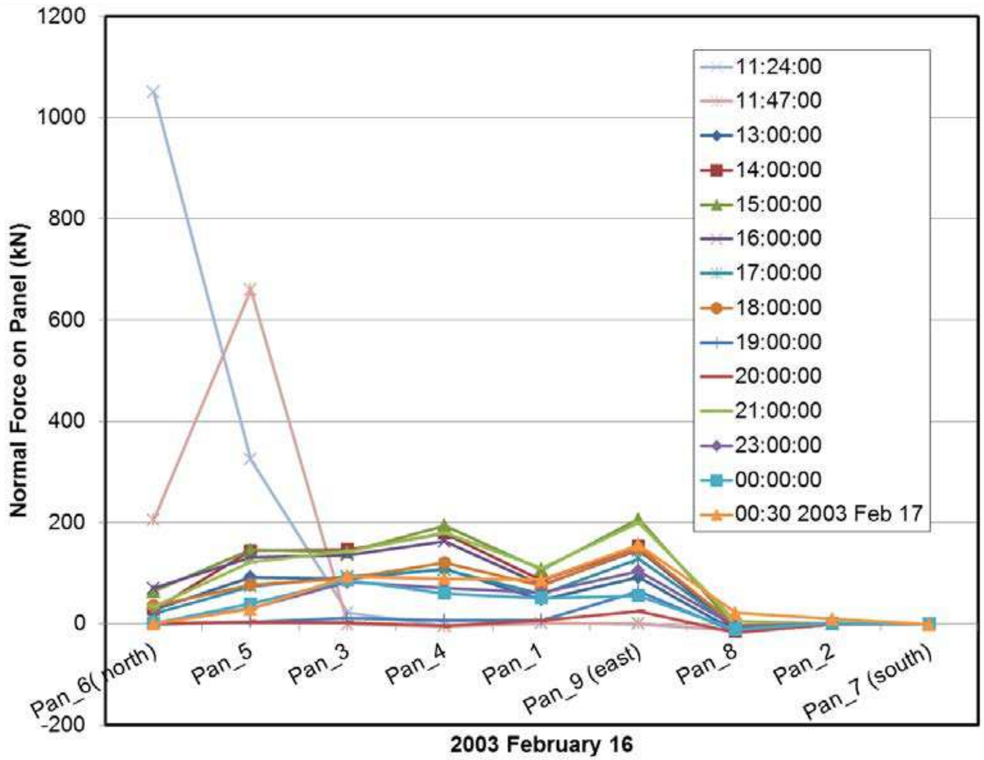




Figures: Frederking and Sand, 2014

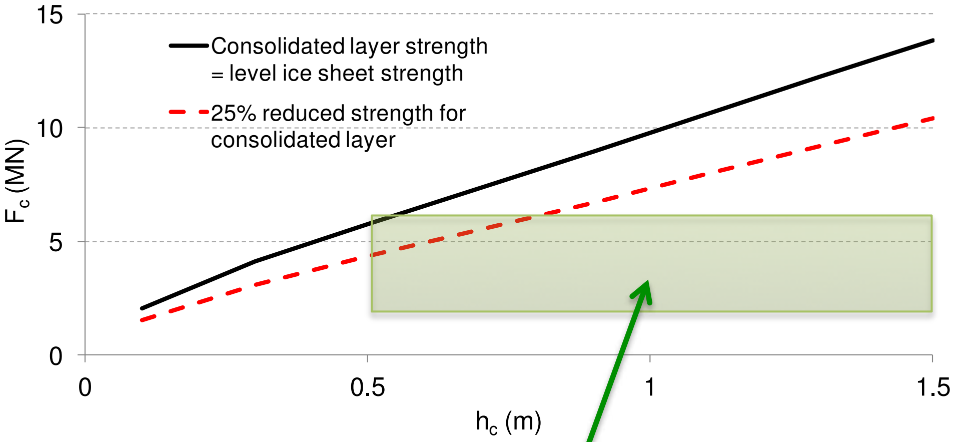
- 6 March 2002: structure interaction with broken ice rubble results in lower loads than with ridges
- Average normal force over panels for time periods of interaction Small consolidated layer likely for ridges
- Water level 0.23 m above top of panels, so panels mostly capture keel load
- with known features gives indication of an average glob

16 Feb 2003: Horizontal distribution of ice rubble loads around lighthouse circumference

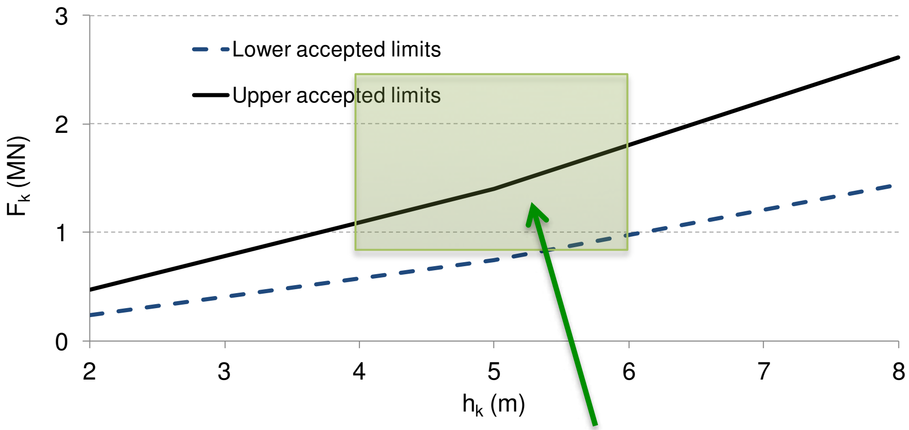


- Early season events – consolidation unlikely
- Rubble loads could be similar to those from unconsolidated keels
- Ice forces measured on individual panels at various points in time during one day of unconsolidated rubbled ice interaction (somewhat parabolic distribution)

Comparison of global loads predicted using ISO 19906 Standard, and range of possible input parameters



Range of measured values at Norströmsgrund from several dozen ridge events



Interpreted values from one February day of unconsolidated ridge/rubble interaction at Norströmsgrund, based on peak rubble loads at waterline extrapolated over keel depth and assuming linear load decrease with depth

- For consolidated layer: ISO 19906 uses an empirical equation for level ice crushing; takes into account the ice pressures measured at Norströmsgrund
- For keel: ISO 19906 uses Dolgopolov (1975) analytical method for load calculations, which treats the structure as having a flat face; modifications for cylindrical structure would be useful
- More work on keel loads needed – little field data available. Canadian experience: Molikpaq data indicates fairly high FY ridge keel pressures (0.3 MPa, double the value calculated above); Confederation Bridge data indicates negligible keel loads (but for conical shaped piers)

Acknowledgments

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Thank you

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