Ice actions in harbours and coastal infrastructure

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Ice in Norwegian waters

- Often light ice conditions
  - Thin ice
  - Limited occurrence
  - Difficult to predict
- Limited driving forces
  - Small ice area in fjords and in harbours
- Which scenario should we design for?

Ice crushes (limit stress) or not?

$$F_{crush} \approx h_i \cdot w \cdot F \; > F_{wind-driving} \approx \rho_a \cdot C_d \cdot A_i \cdot u_a^2$$

- Ice thickness – h_i=0.5 m
- Structure width – w=10 m
- F – ice factor (different in N400, ISO19906, CSA, …) = 1MPa

- Air density – 1,3 kg/m^3
- Air-ice drag coefficient – C_d=0.002
- Ice area - A_i
- Wind velocity - u_a =20 m/s

$$A_i < \frac{F}{\rho_a C_d u_a^2} h_i w \approx 5\mathrm{km}^2$$

Scenarios

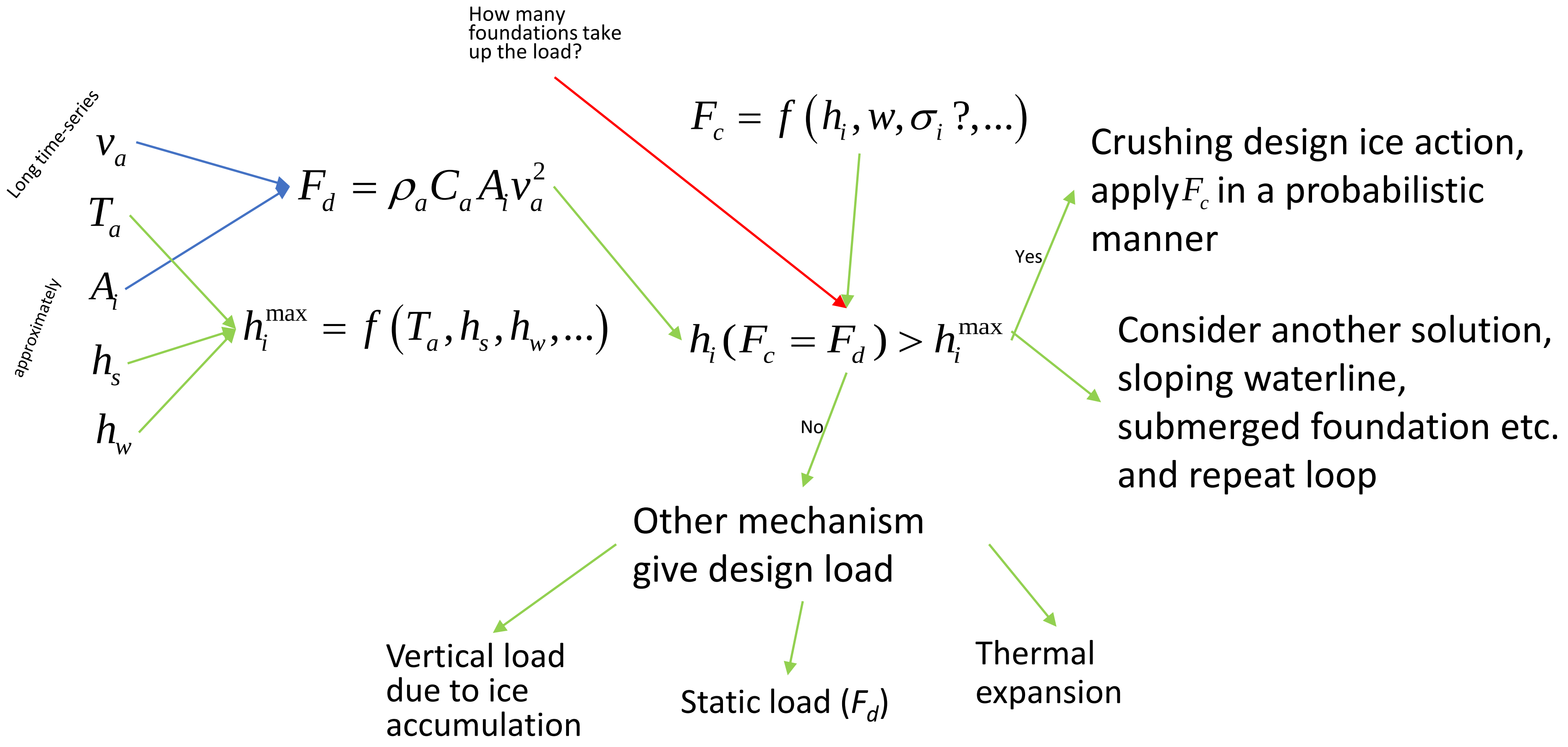
- Need to estimate the probability for different scenarios
- Ice crushes against structure gives highest load (F_{crush} – limit stress)
- Ice action limited by wind and ice area ($F_{wind\ -\ driving}$ – limit driving forces)
- Thermal expansion of ice
- Vertical loads – ice accumulation etc.

- Evaluate probability for different scenarios – bridge design (sloping foundation, submerged foundation, …)

Parameters and variables

- Main input variables:
    - Air temperature, T_a
    - Wind velocity (speed + direction), v_a
    - Ice area – fecth for wind and current, A_i
    - Snow precipitation, h_s
    - Water depth and tides, h_w
- Structural parameters
    - Width and shape in water line
    - Dynamic characteristics
- Parameters
    - Air-ice and water-ice drag, C_a and C_w ->field data for validation of surface roughness
    - Air and water densities, ρ_w and ρ_w
    - F (ice strength ,σ_i, C_R)->field data for validation?
- Calculated variables:
    - Ice thickness, h_i ->field data for validation
    - Driving forces from wind (and current), F_d ->full-scale data for validation
    - Crushing forces (limit stress for example ISO19906), F_c ->full-scale data for validation

Flow scheme for ice action on structures with limited driving forces



Ice thickness – vital parameter

- Simple formulas exist- two vital uncertainties
  - When does the ice form?
  - How much snow?
  - Thin ice more difficult to predict
- Local knowledge important – Ocean is vital!
- Ice forms
  - Locally
  - Elsewhere and drift into harbour

Ice action from thermal expansion of the ice 1

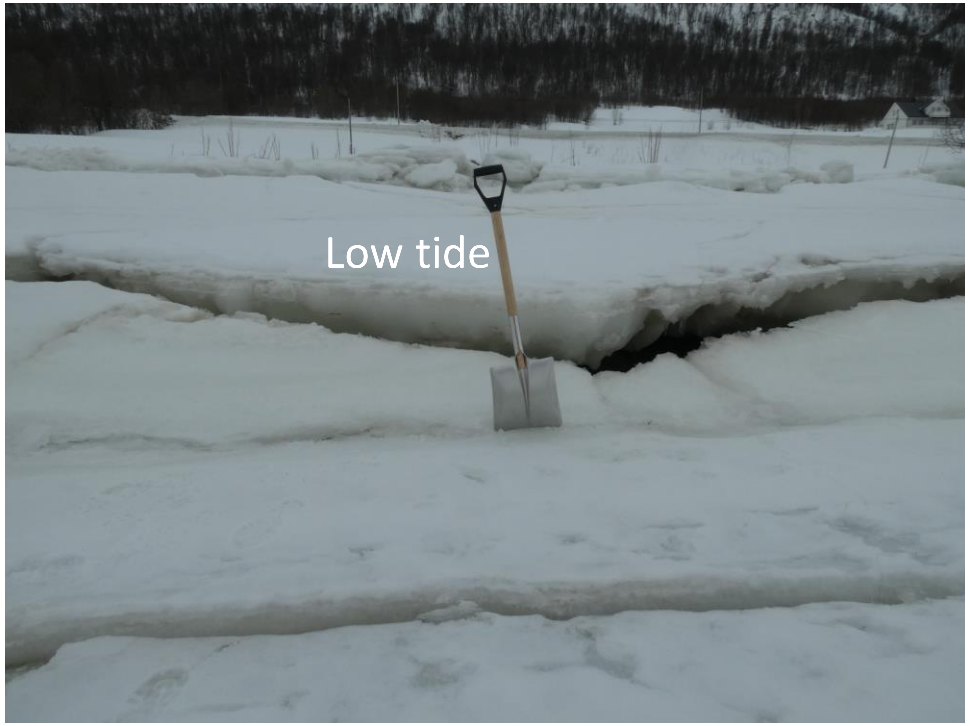
- Most important for air temperature increase without much snow cover.
- What is the 50-year ΔT_a and corresponding ice thickness for cases with no, or little snow?
- Expand in all directions
- Time-scales
  - Temperature penetration has one time-scale given by heat transfer
  - Mechanical response through combined elastic-visco-elastic and creep has another time-scale
  - The combination of these give the response of the ice cover.

Ice action from thermal expansion of the ice 2

- Ice salinity
  - Saline sea ice has a smaller thermal expansion coefficient than freshwater ice. It may even be negative, but this is not clear.
  - Ice often quite fresh (from river outlet)
- Snow cover
  - How does the snow cover give the ice surface temperature
    - Submerged ice
    - Not submerged ice
- Boundary conditions
  - Vertical water level variations
    - Amplitude in relation to ice thickness
    - Frequency in relation to the time-scale
  - Friction on the beach/coastline makes the thermal load worse in the longest direction.

Coastal ice observations

- Friction ice-land can be important



Conclusions – Ice actions in Norwegian harbours

- Light and in-frequent ice conditions
- Limited driving forces
- Two main question
  - What is the probability of ice occurrence?
  - Can ice crush?
- Other mechanisms
  - Give lower ice load
  - More complicated to estimate