# 2D FEM-DEM modeling of ice-inclined structure interaction

*Janne Ranta*
*Postdoctoral Researcher*
*Department of Mechanical Engineering, Aalto University*

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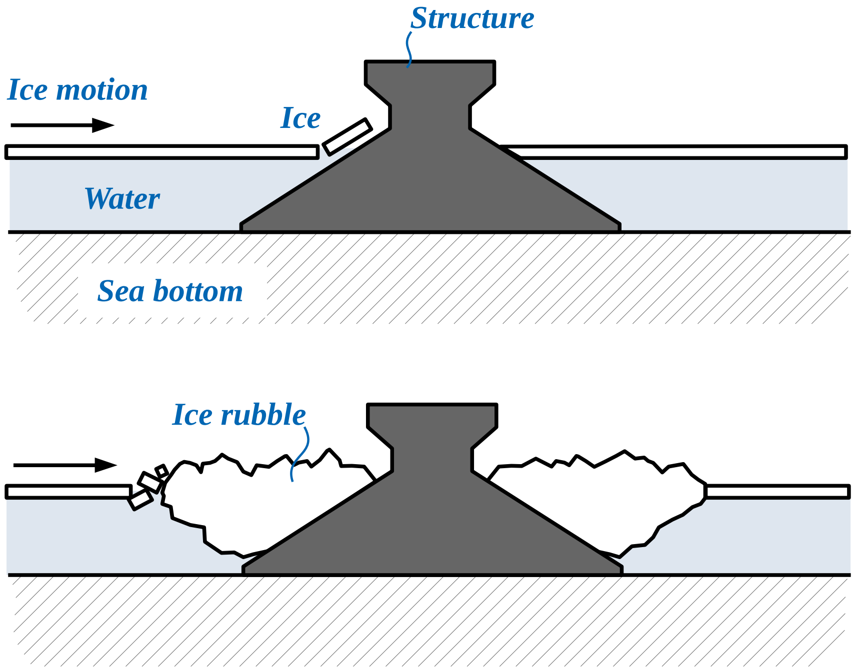
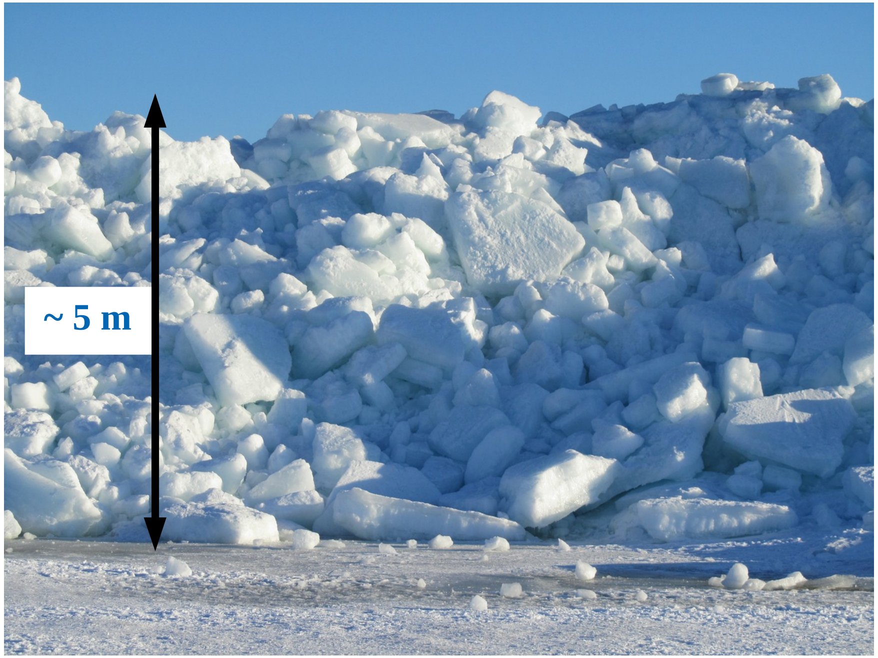
*Aalto University*

# The ice-structure interaction problem and ice rubble



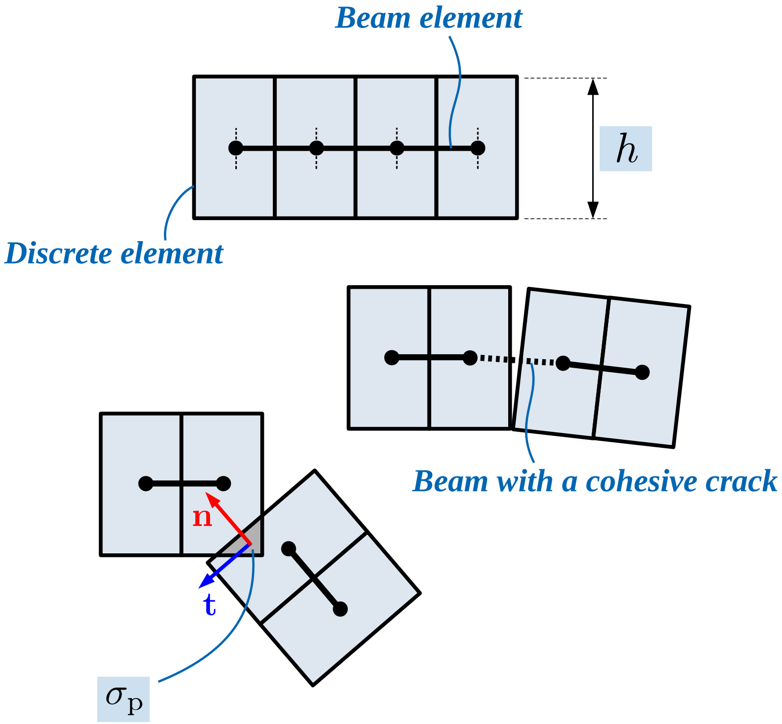

Figures adapted from the book by T.J.O. Sanderson (1988)




Ice rubble pile at the shoreline of the Gulf of Bothnia (16th Apr 2017, J.R.)

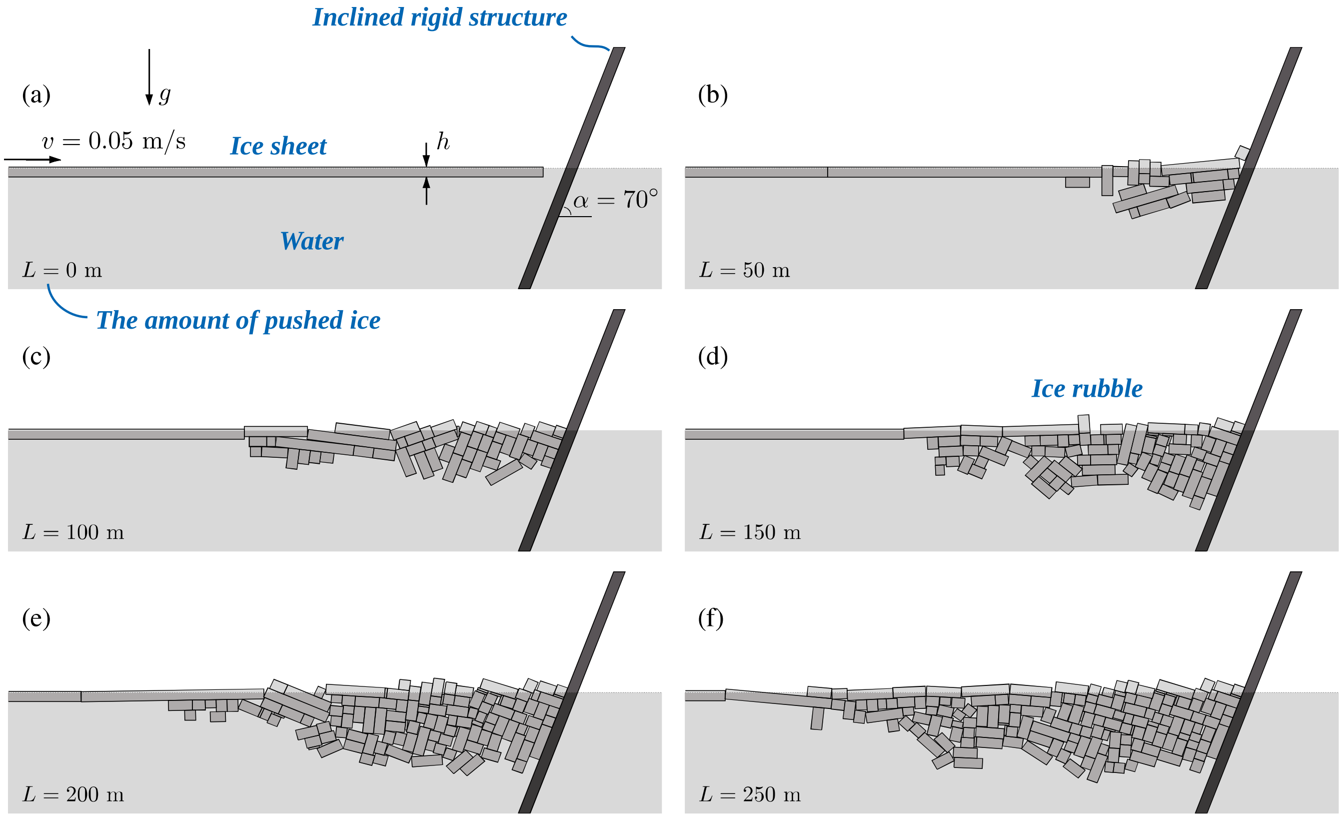
# The tool for modeling the ice-structure interaction

- Numerical 2D FEM-DEM model
  - Developed, verified, and validated by the Aalto ice mechanics research group (long-term work)
- Model features (schematic description)
  - Beam finite elements for elasticity
  - Cohesive crack model for describing the ice failure
  - Discrete elements to account for the geometry, contacts, and fluid effects (buoyancy and drag)
- Large-scale response of the system is determined by the mentioned small scale features



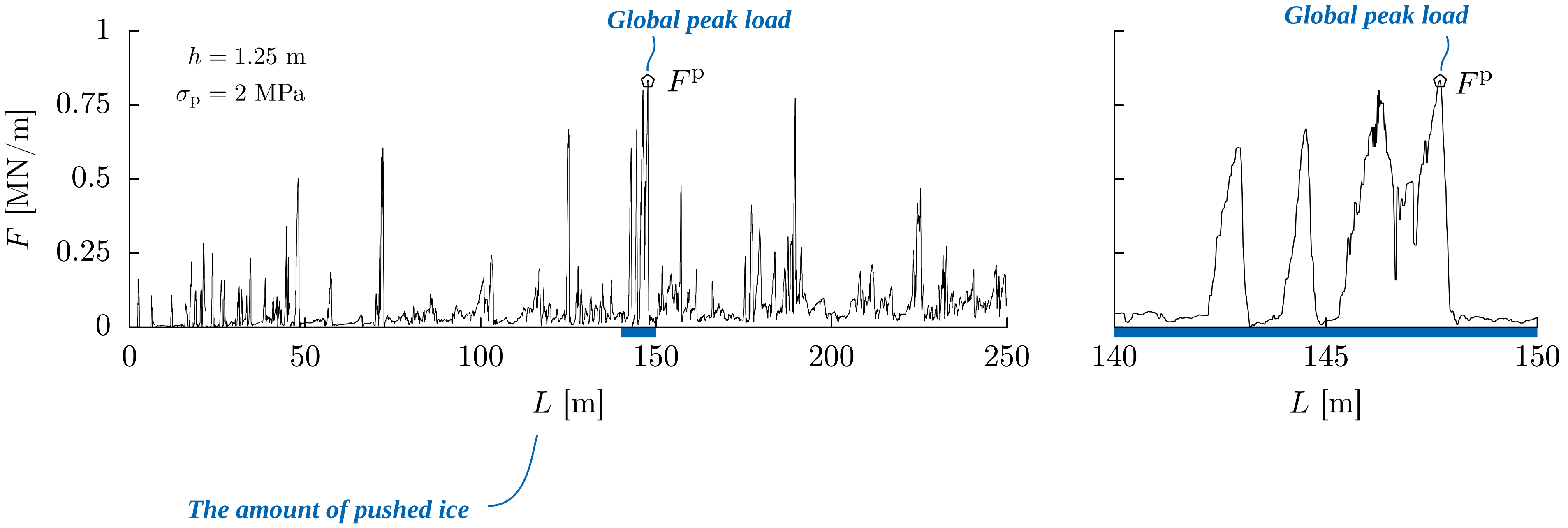

*The **plastic limit** parameter limits the normal contact force*
*The Coulomb **friction** model limits the tangential contact force*

# Studied case: Ice-inclined structure interaction

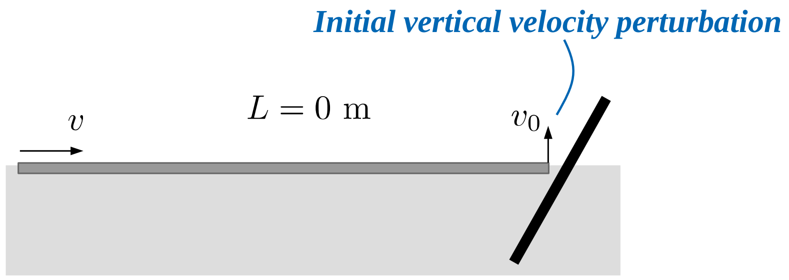


# Animation

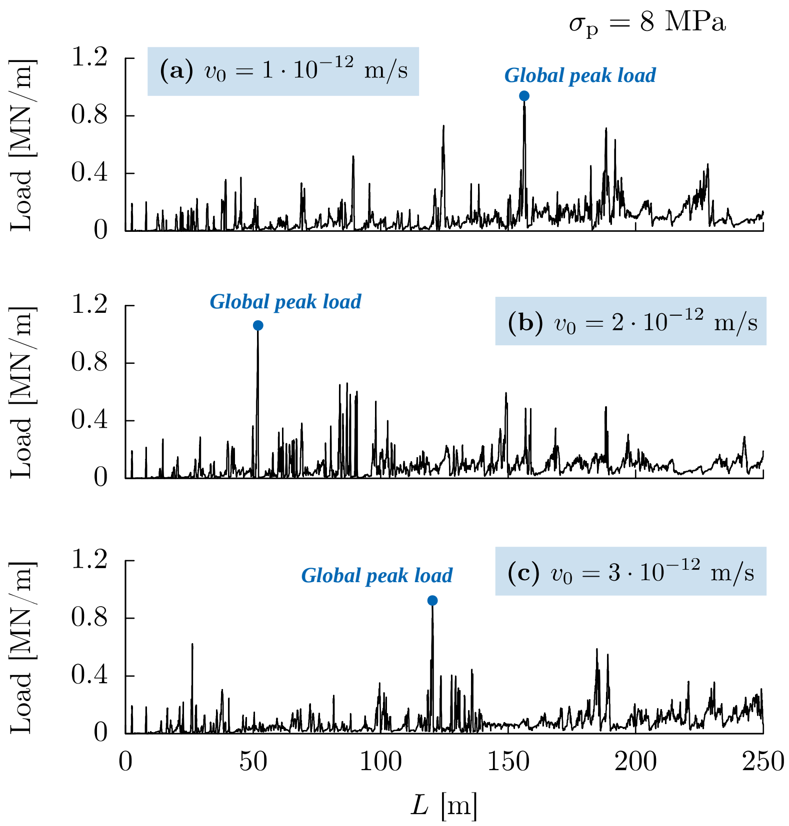
# Typical Force Record and Peak Load Observation



# Sensitivity to Initial Conditions

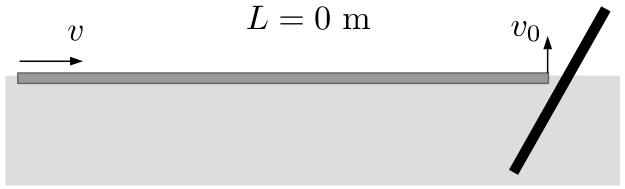


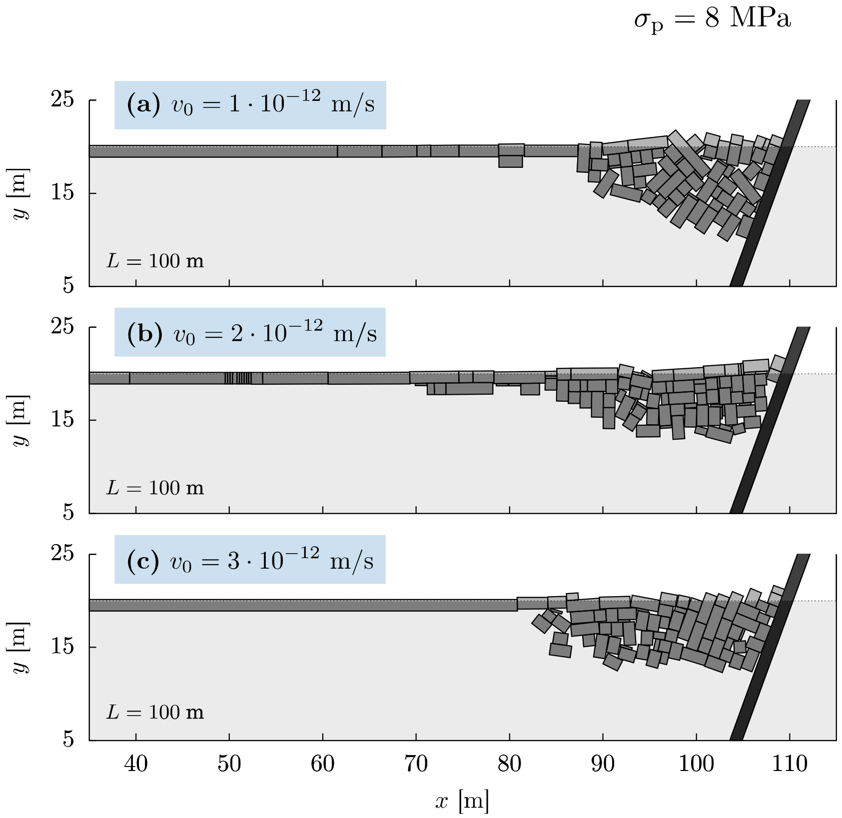

- The model is deterministic but very sensitive to initial conditions
- Repeated simulations with only slightly different initial conditions yielded different load outputs
- This sensitivity was used to produce large number of independent and identically distributed load observations



# Sensitivity to Initial Conditions

- Naturally, also ice floe arrangements were different in initial condition perturbed simulations



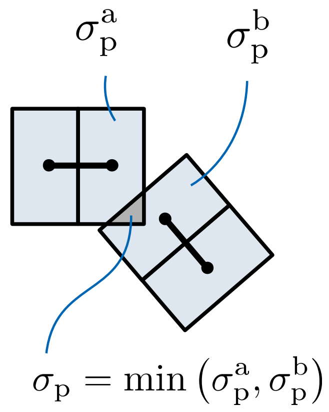
# Simulation Sets

| Set | $h$ [m] | $\sigma_p$[MPa] | $v_0$ varied |
|---|---|---|---|
| S1 | 0.5 | 1 | yes |
| S2 | 0.5 | 2 | yes |
| S3 | 0.875 | 1 | yes |
| S4 | 0.875 | 2 | yes |
| S5 | 1.25 | 1 | yes |
| S6 | 1.25 | 2 | yes |
| S7 | 1.25 | $\mathcal{U}(1,2)$ | no |
| S8 | 1.25 | 8 | yes |

- 50 repetitions in each set
- 400 simulations in total

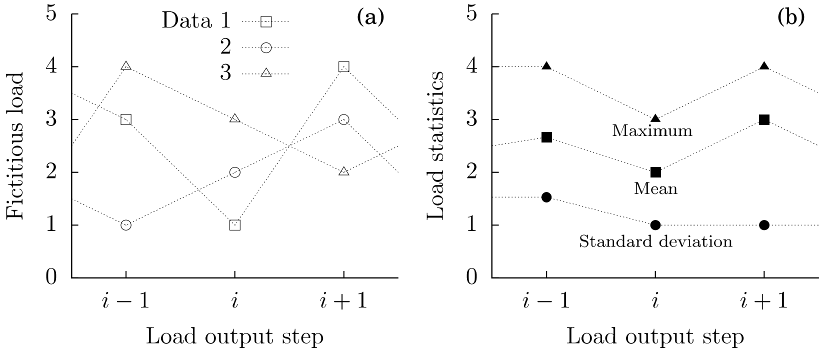
***Non-homogeneous ice***

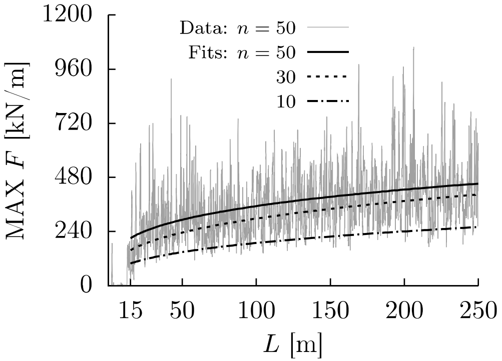
***Plastic limit varied discrete element-wise***



# Failure Process Statistics

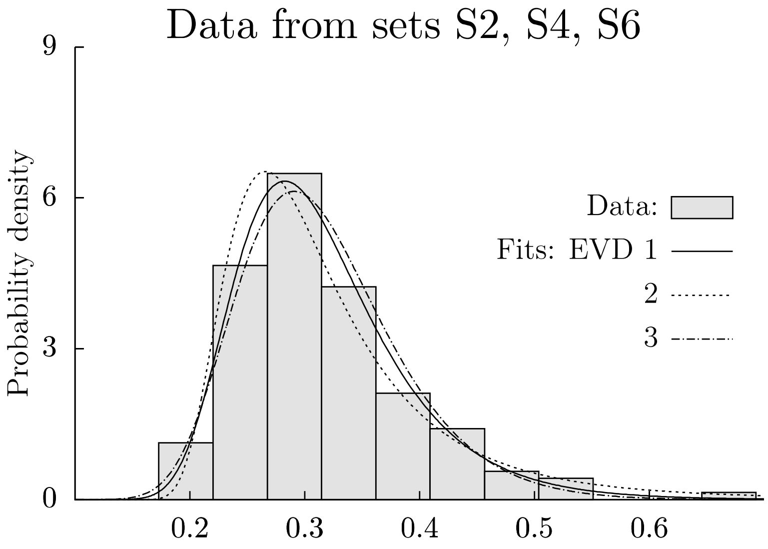
- Ice load histories were not stationary
- Statistics were calculated using concurrent load observations from repeated simulations
  - Mean, standard deviation, and maximum statistics increased throughout the process with increasing $L$
  - Coefficient of variation (STD/MEAN) decreased with increasing $L$
- Also, concurrent maximums increased with increasing number of simulations ($n$)



# Peak Ice Load Statistics

- A dimensionless buckling load factor $\Lambda$ was used to normalize the peak load data
- In general, the Gumbel distribution (EVD type 1) fitted well on the data
- The large scatter in normalized data mainly stem from the complex ice-structure interaction process (ice sheets were homogeneous)
- According to the used normalization, the peak loads are strongly dependent on the ice thickness

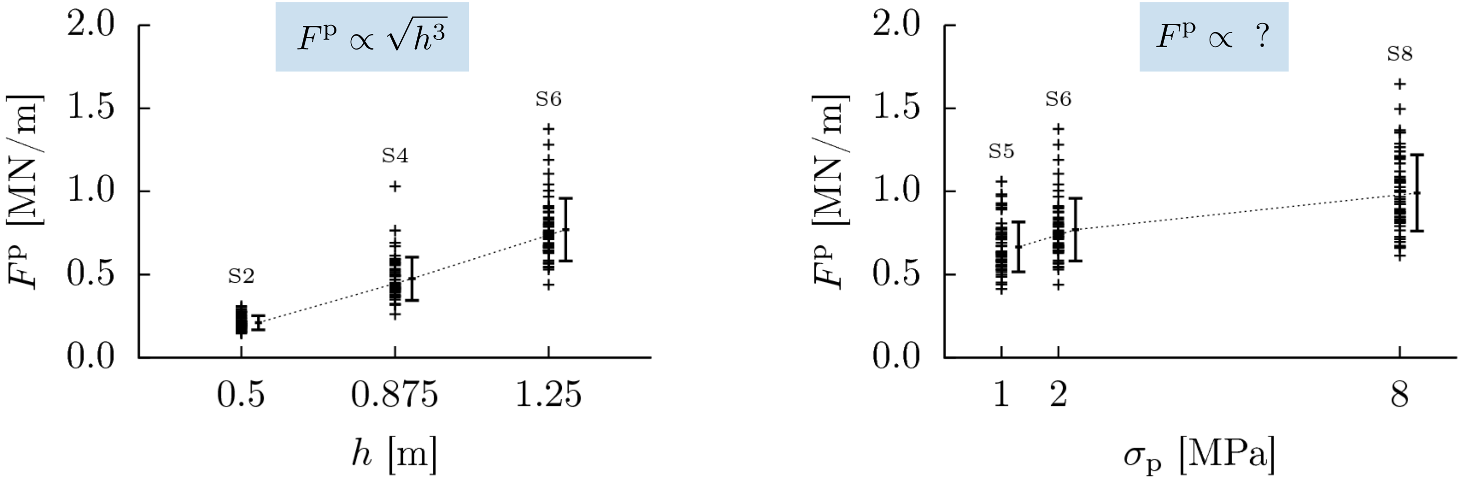



$$\Lambda = \frac{F^{\mathrm{p}}}{\sqrt{kEI}}$$

$$F^{\mathrm{p}} \propto h^{3/2}$$

# Parameter Effects

- In the data, the effect of the ice thickness was strong
- Plastic limit parameter affects peak loads as well but this effect is minor



# Summary

- In the study, full-scale ”experiments” were conducted by using numerical simulations
- Large number of simulations provided data for studying statistics and mechanics of ice loads
  - A benefit of simulations is that all ice properties are known exactly (full control on the system)
- In general, data showed large scatter
- Despite of the large scatter, some relationships between ice loads and the used model parameters (ice parameters) were found
  - Peak loads were strongly dependent on the ice thickness
  - Peak loads were observed to depend on the compressive strength as well but this effect was relatively weak

# Publications

- Ranta, Polojärvi
  - Limit mechanisms on peak ice loads: Local ice crushing
    Submitted to Marine Structures.
- Ranta, Polojärvi, Tuhkuri
  - Limit mechanisms on peak ice load: Ice buckling
    *2018 in Cold Regions Science and Technology.*
  - Ice loads on inclined marine structures – Virtual experiments on ice failure process evolution.
    *2018 in Marine Structures.*
  - Scatter and error esimates on ice loads – Results from virtual experiments.
    *2018 in Cold Regions Science and Technology.*
  - The statistical analysis of peak ice loads in a simulated ice-structure interaction process.
    *2017 in Cold Regions Science and Technology.*