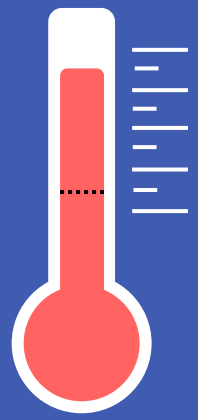
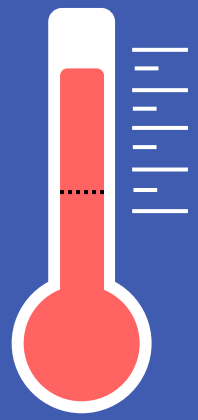
THERMAL ICE PRESSURES ON FLEXIBLE STRUCTURES

Haakon Sundelius



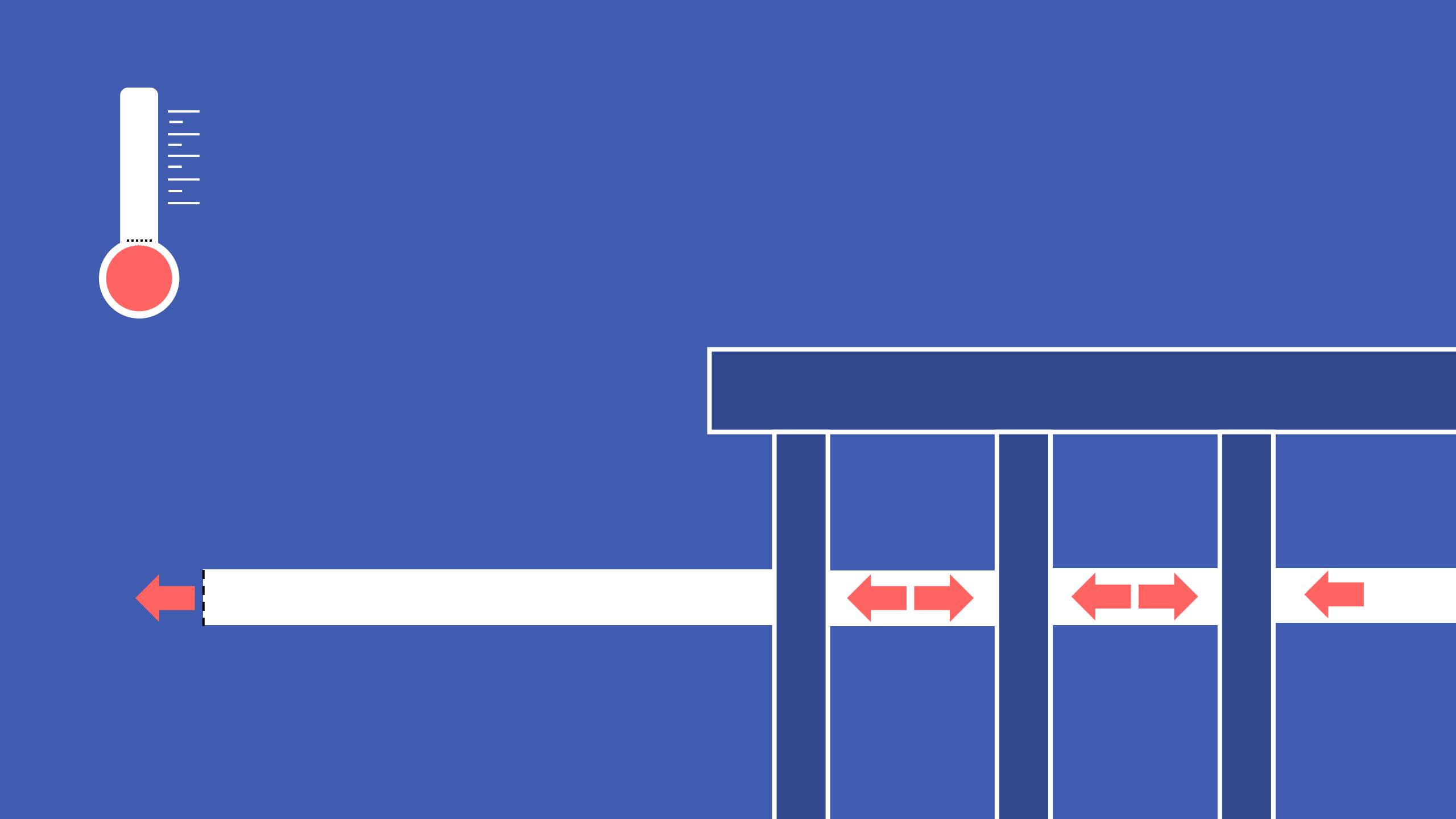
ΔT

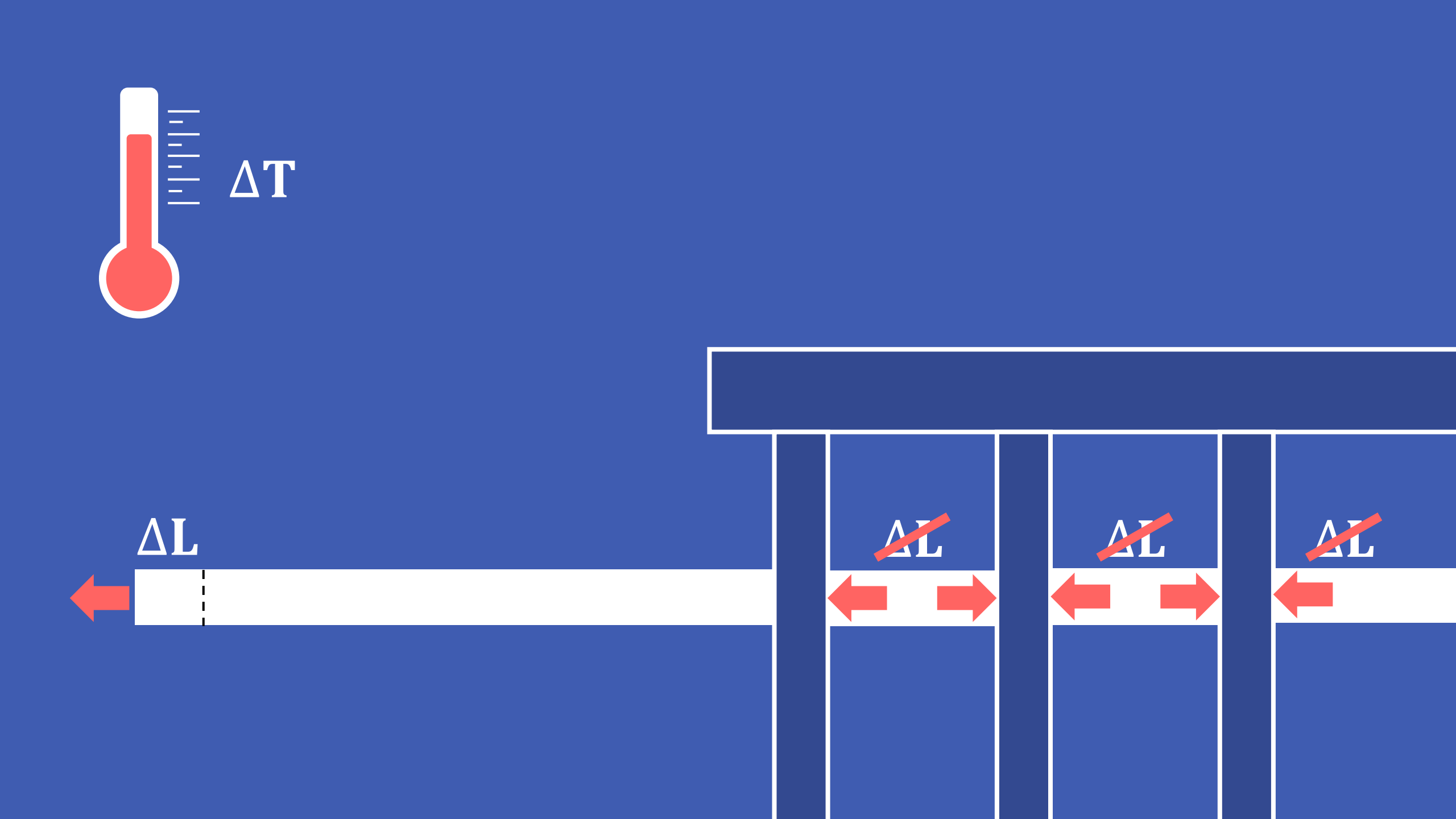
ΔL

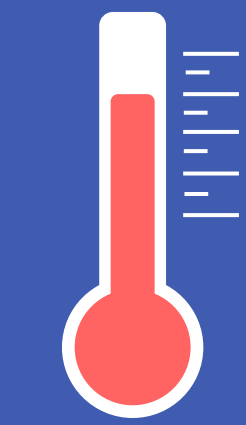


ΔT

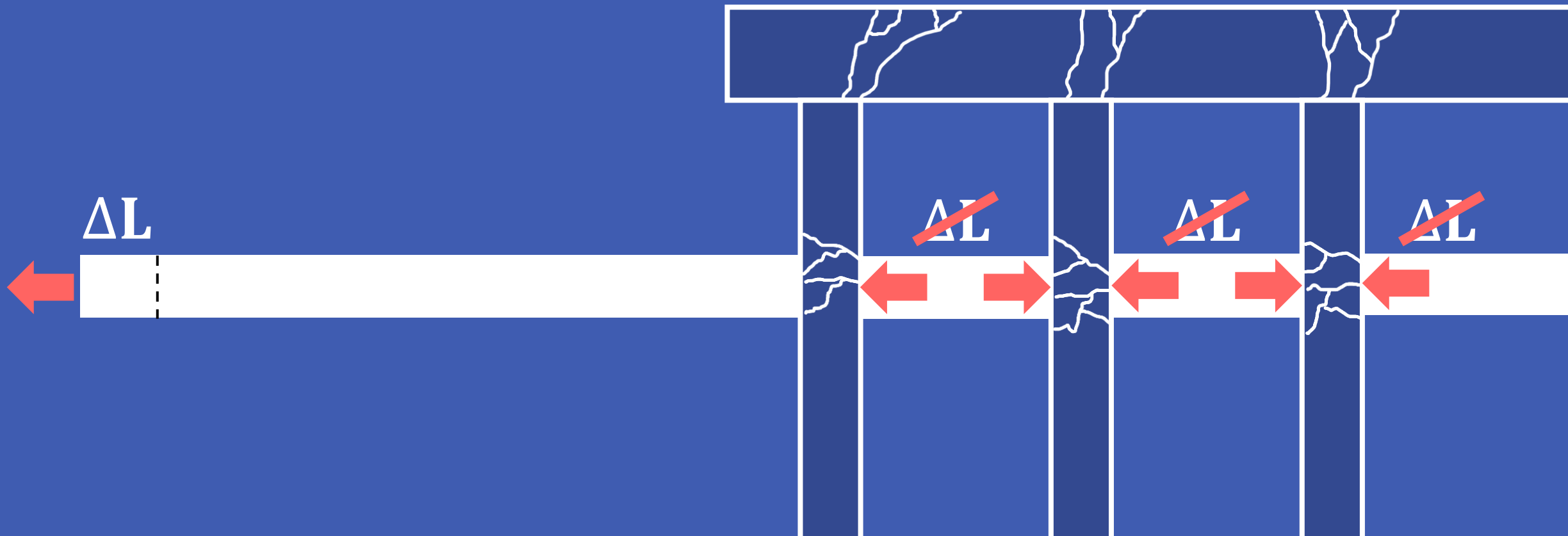
ΔL




ΔT
ΔL
ΔL
ΔL
ΔL

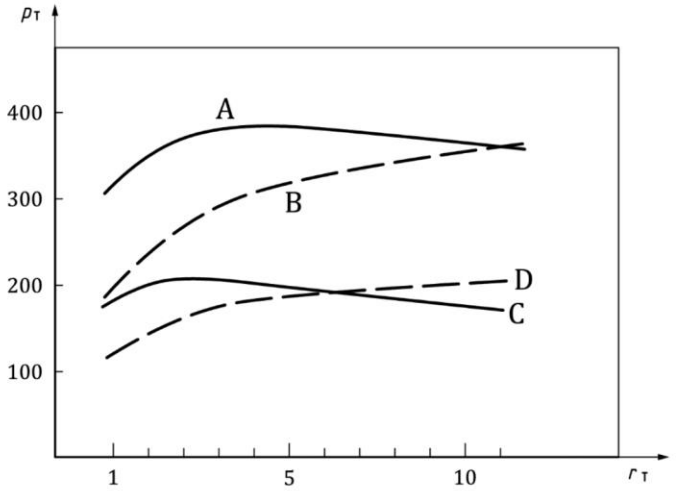


ΔT



WHAT THE STANDARDS TELL US

ISO19906:2019



Key

A	T_i = –30 °C and h = 1,0 m	p_T	thermal ice pressure, expressed in kilonewtons per metre
B	T_i = –30 °C and h = 0,5 m	r_T	rate of temperature increase, expressed in degrees Celsius per hour
C	T_i = –20 °C and h = 1,0 m	h	ice thickness
D	T_i = –20 °C and h = 0,5 m		

Figure A.8-23 — Thermal ice action versus the rate of temperature increase of the ice surface[174]

For a preliminary assessment of thermal actions, indicative values in the range of 150 kN/m to 300 kN/m can be used regardless of the ice thickness[174][175][176]. Thermal actions in freshwater ice are larger in magnitude than those in sea ice.

CSA S6 19

3.12.2.4 Slender piers

Where ice forces are significant, slender and flexible piers and their components, e.g., piles exposed to ice action, shall be used only when a specialist on the mechanics of ice and structure interaction is consulted.

3.12.3 Static ice forces

Where ice sheets are exposed to non-uniform thermal stresses and strains relative to the pier due to unbalanced freezing, the resulting forces on the piers shall be calculated using a compressive crushing strength of ice of not less than 1500 kPa when the ice temperature is significantly below the freezing point.

WHAT THE STANDARDS TELL US

SP 38.13330.2018

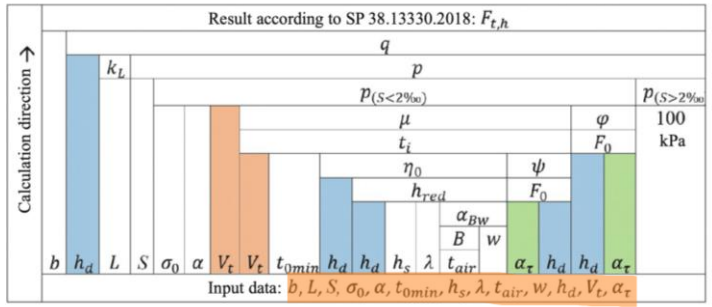


Fig. 3. Tree of analysis according to SP 38.13330.2018 (the values in the top cells are calculated from the data in the bottom cells).

N400:2023

KRAV 5.10.7—1 **SKAL** GJELDENDE FRA 01.01.2022

Ensidig last fra fast isdekke ved temperaturendringer skal beregnes ut fra jevnt fordelt last:

$q_h = 300t + 1,6|T| < 250[\mathrm{kN/m}]$ (5.10.7—1)

t	er istykkelse i meter. Skal ikke innføres med større verdi enn t = 0,5 m.
T	er minimumstemperatur med returperiode 50 år, se *NS-EN 1991-1-5:2003+NA:2008*, figur NA.A2. Muligheter for ensidig belastning fra ekspansjon skal vurderes i det enkelte tilfellet.

N400:2025

KRAV 5.10.4—1 **SKAL** GJELDENDE FRA 01.01.2024

Jevnt fordelt, énsidig horisontal last på grunn av termisk ekspansjon av kontinuerlig isdekke skal bestemmes slik:

$q_T = 200\ \mathrm{kN/m}$ (5.10.4—1)

Lastens utbredelse, plassering og retning skal velges slik at lasten blir minst gunstig for konstruksjonen.

Veiledning til kravet ›

THE PROBLEM

- **Based on Arctic conditions**
- **Fixed boundaries in standards**
  - **Suitable for: Dams, closed berth structures, large bridge pillars**

  - **Not suitable for: Open berth structures, slender bridge pillars**

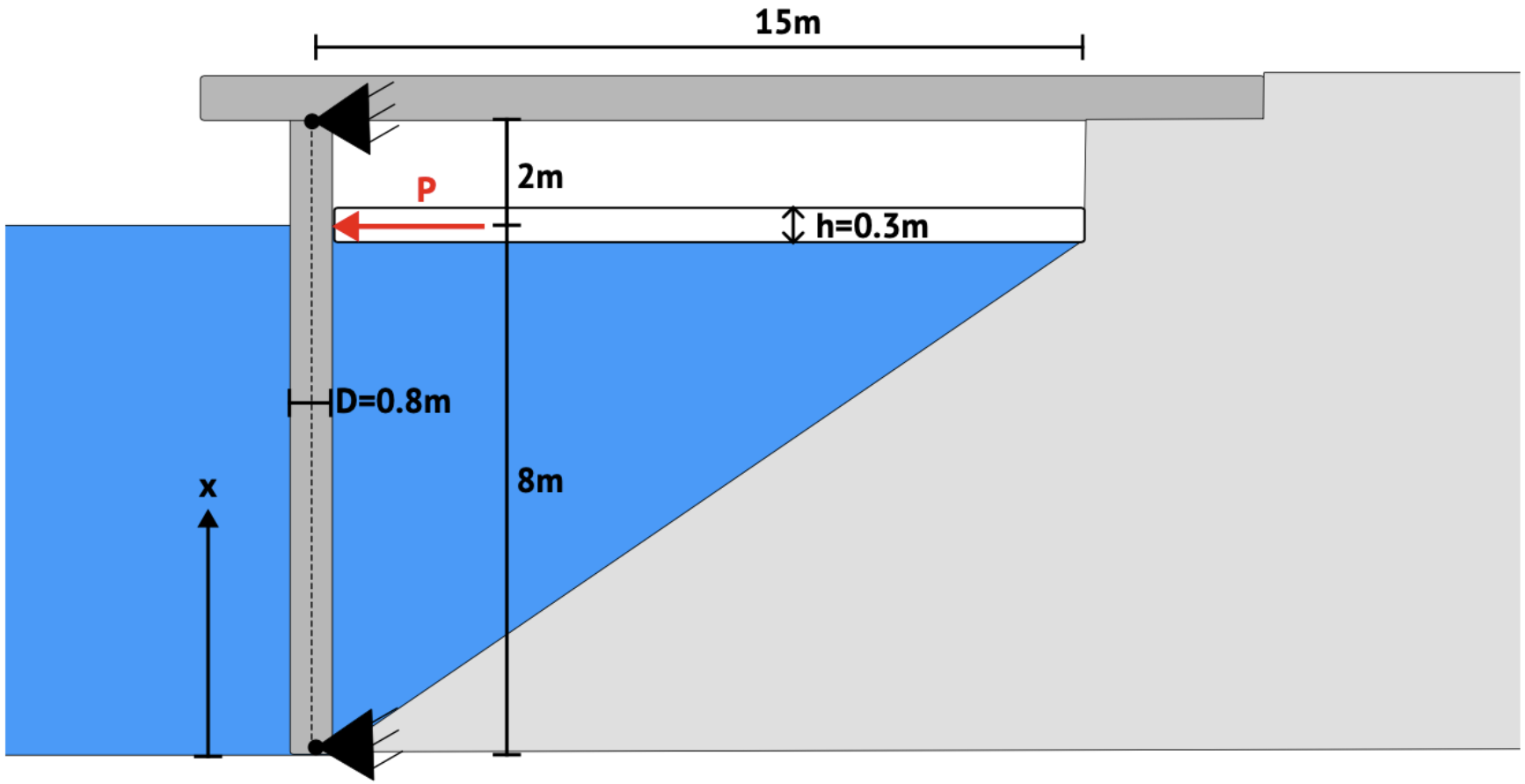
THE CONSEQUENCE

→ **High design loads**

→ **Overconservative design**

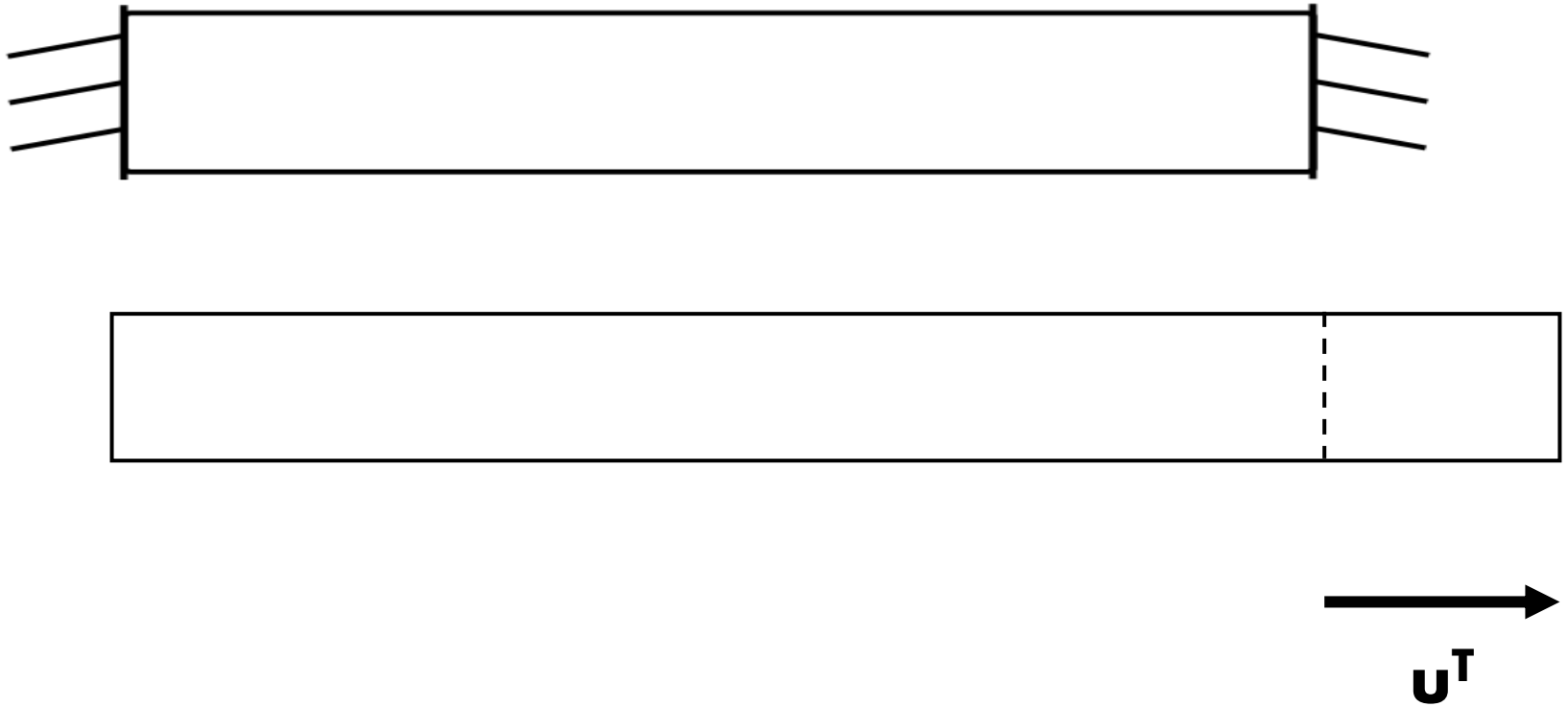
(Especially for **flexible** structures)

THE BASIC IDEA

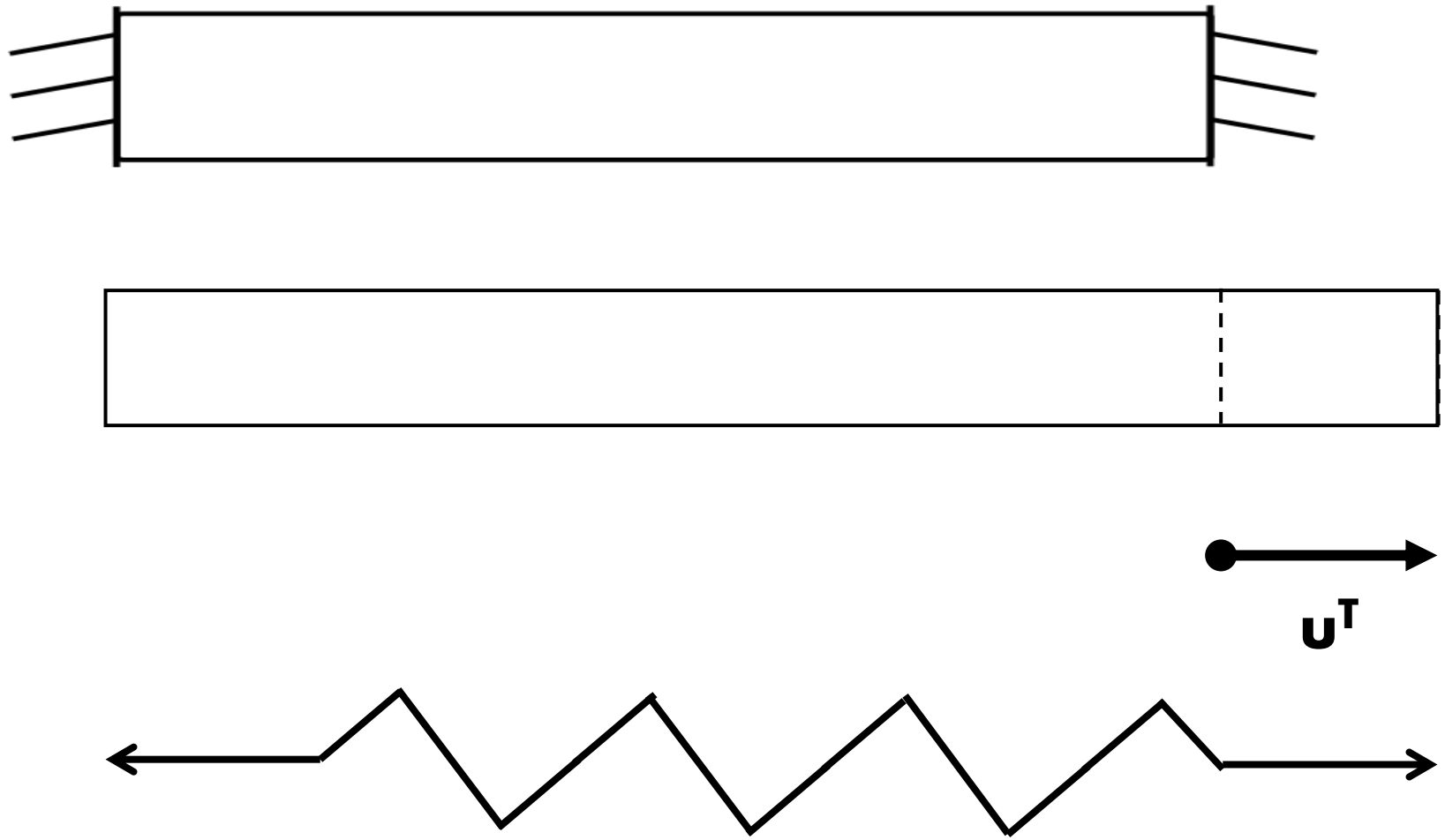


THE BASIC IDEA

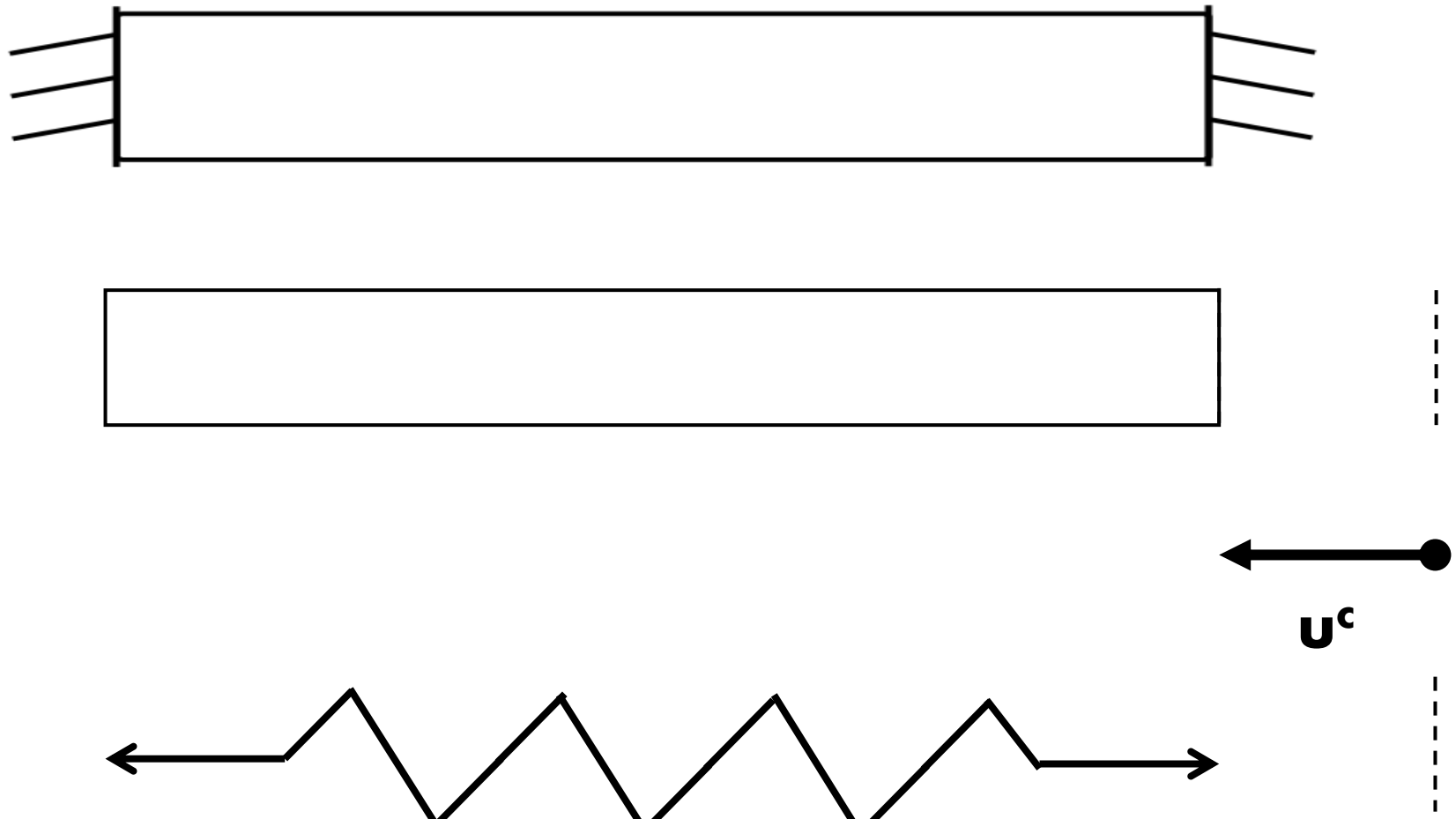
THE BASIC IDEA



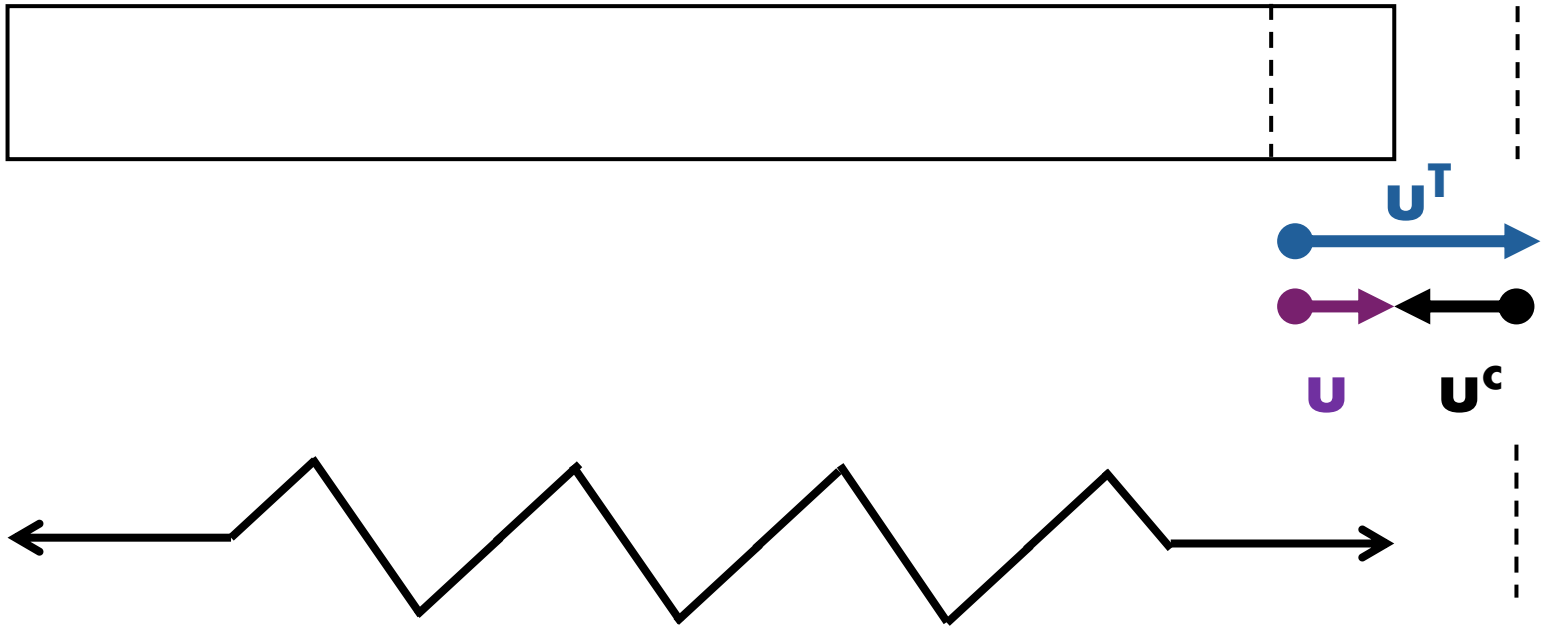
THE BASIC IDEA



THE BASIC IDEA

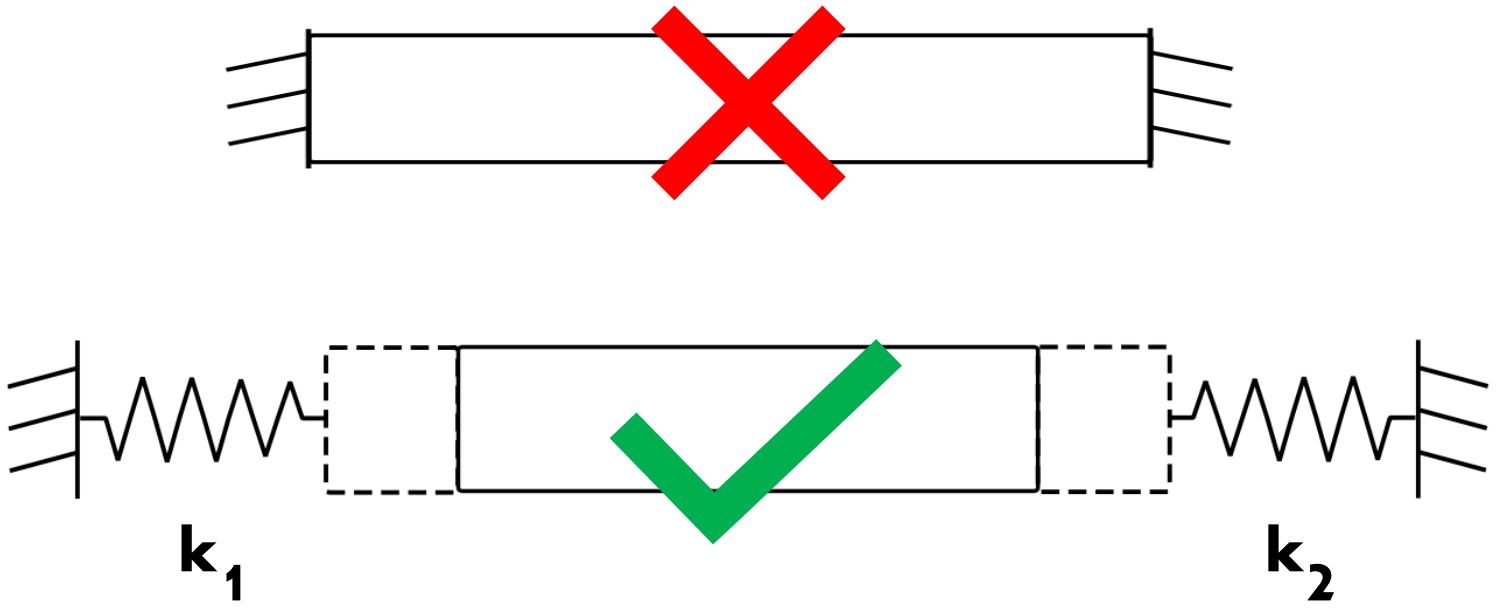


THE BASIC IDEA



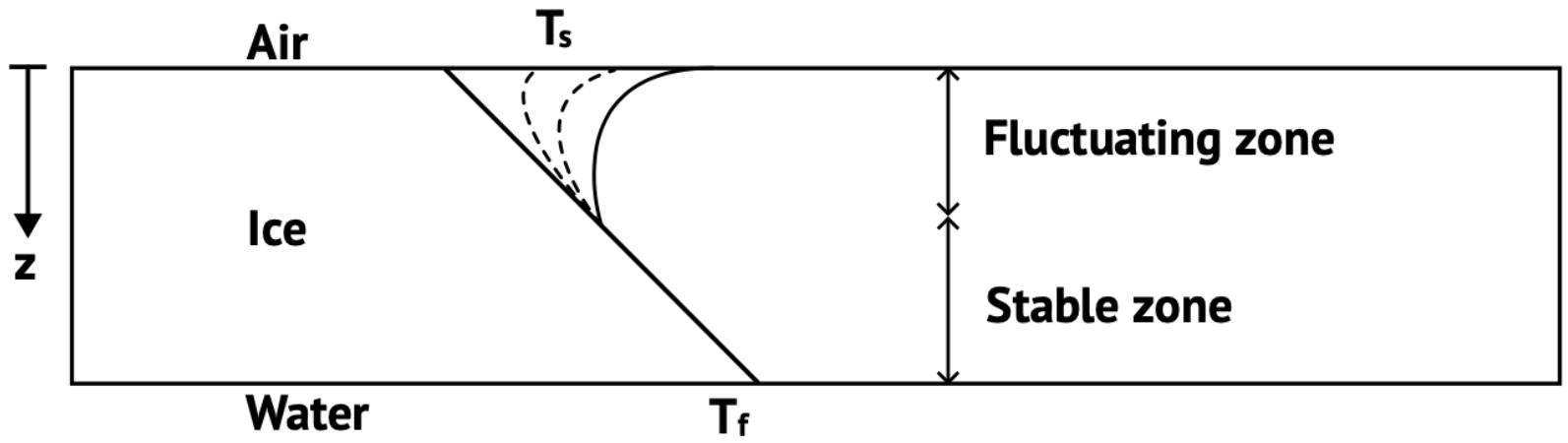
POSSIBLE SOLUTION

- **Calculation with flexible boundaries**
  - **Also suitable for: Open berth structures, slender pillars, sluice gates**



THE CHALLENGE

- **Temperature profile**
- Solve the heat equation



THE CHALLENGE

- **Temperature profile**
- **Temperature dependent material properties**
  - Young’s modulus
  - Viscosity (creep)
  - Poisson ratio

THE CHALLENGE

- **Temperature profile**
- **Temperature dependent material properties**
- **Creep**

- Influence of creep depends on
  - Temperature
  - Stress
  - Structure of ice
- Solution is particularly sensitive to the creep model
- Hard to determine a correct creep model

THE CHALLENGE

- **Temperature profile**
- **Temperature dependent material properties**
- **Creep**
- **Structure stiffness**

- Solution is sensitive to the stiffness of the structure
- Difficult to find structure stiffness

THE CHALLENGE

- **Temperature profile**
- **Temperature dependent material properties**
- **Creep**
- **Structure stiffness**
- **Weather statistics**

- What is the worst case temperature change?
- How often foes such an even occur?
- Location specific

THE CHALLENGE

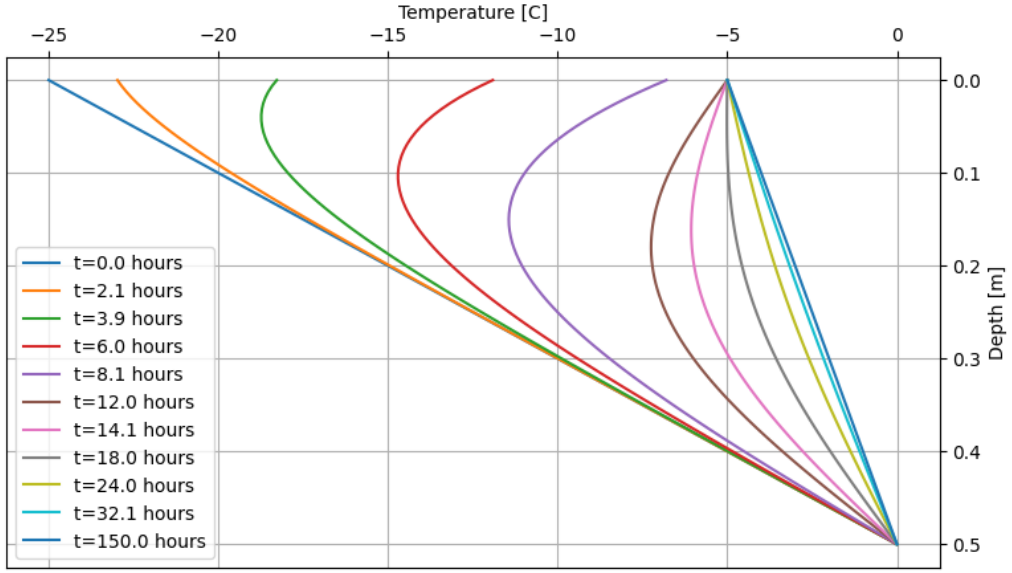
- **Temperature profile**
- **Temperature dependent material properties**
- **Creep**
- **Structure stiffness**
- **Weather statistics**
- **Advanced calculation**

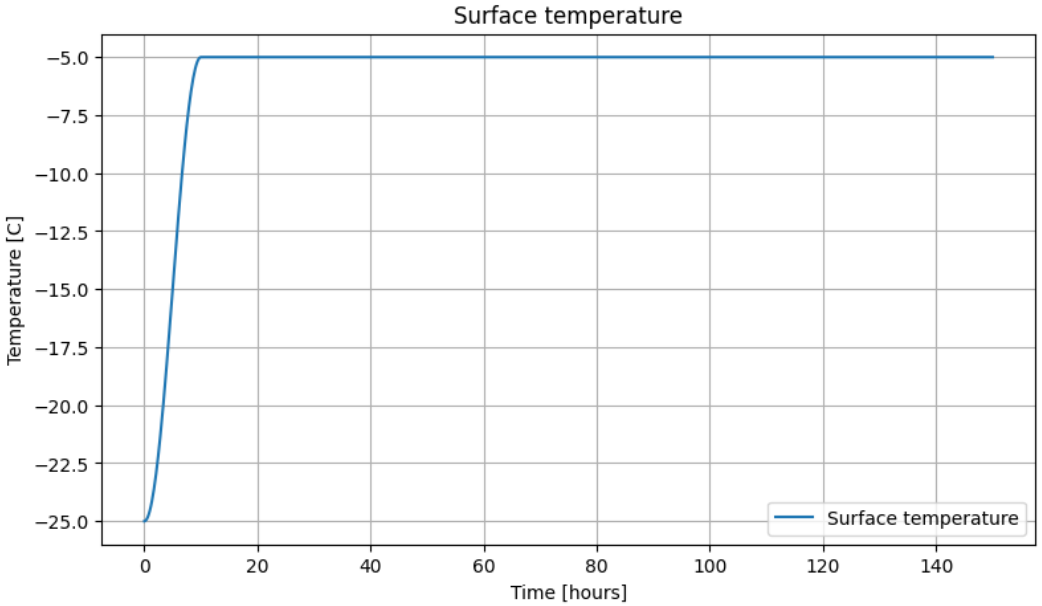
- Numerical solution of linear and non-linear differential equations
- Probably not suitable for standards for the time being

SIMULATION

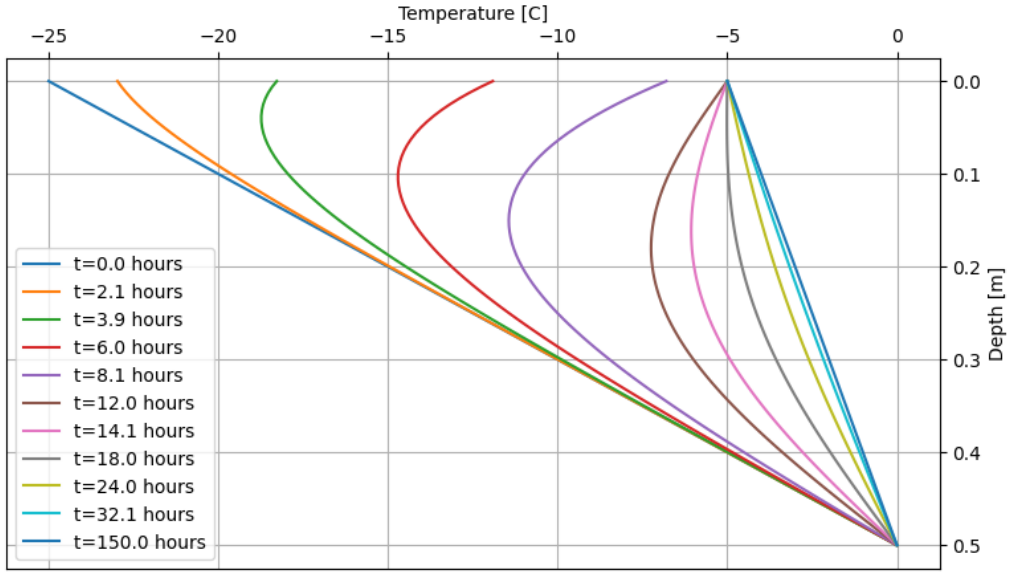
- Simulate a temperature change
- Perform numerical calculations
- Done in python (numpy, matplotlib, ice)

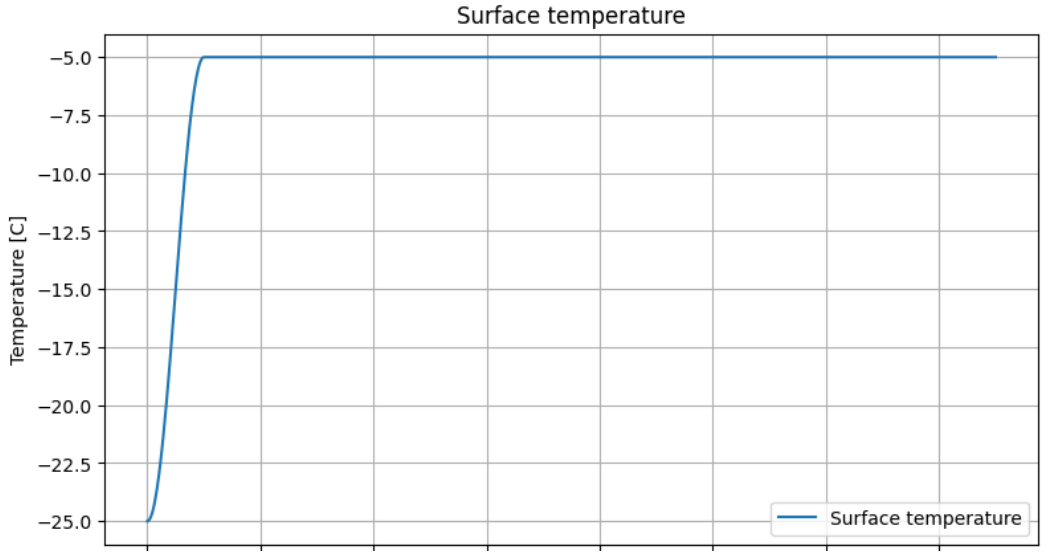
SIMULATION


Temperature [C]
−25
−20
−15
−10
−5
0
0.0
0.1
0.2
0.3
0.4
0.5
Depth [m]
t=0.0 hours
t=2.1 hours
t=3.9 hours
t=6.0 hours
t=8.1 hours
t=12.0 hours
t=14.1 hours
t=18.0 hours
t=24.0 hours
t=32.1 hours
t=150.0 hours

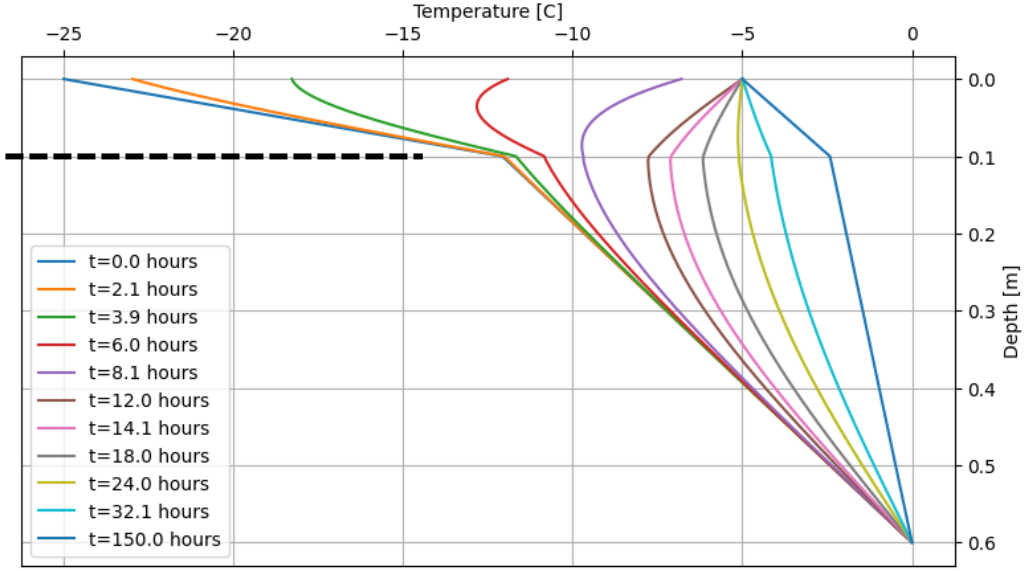

Surface temperature
−5.0
−7.5
−10.0
−12.5
−15.0
−17.5
−20.0
−22.5
−25.0
Temperature [C]
0
20
40
60
80
100
120
140
Time [hours]
Surface temperature

SIMULATION

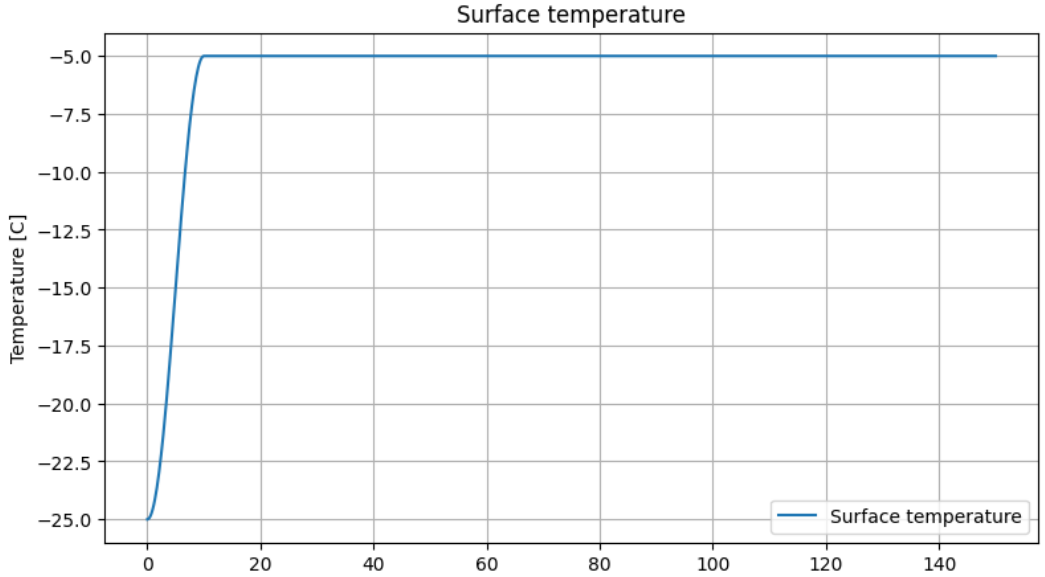




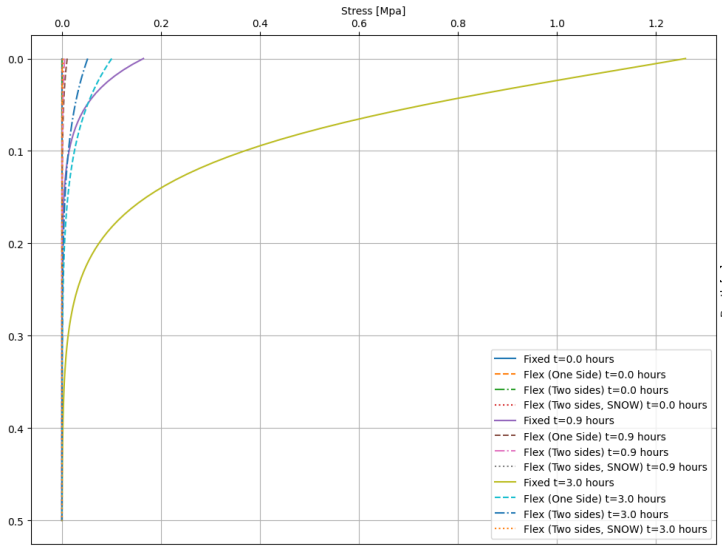
snow

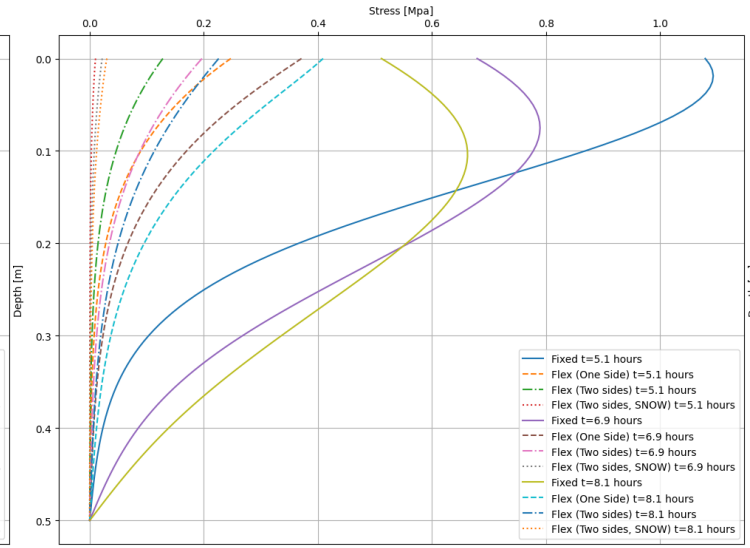


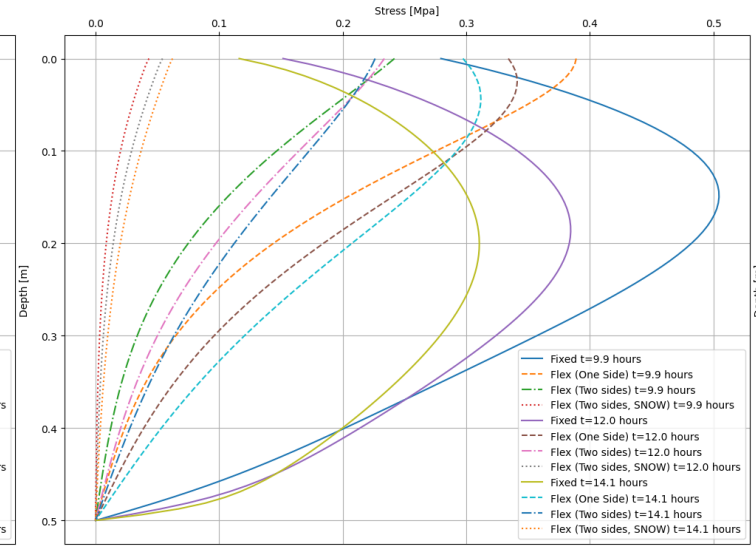
ice



SIMULATION


Stress [Mpa]
Depth [m]
Fixed t=0.0 hours
Flex (One Side) t=0.0 hours
Flex (Two sides) t=0.0 hours
Flex (Two sides, SNOW) t=0.0 hours
Fixed t=0.9 hours
Flex (One Side) t=0.9 hours
Flex (Two sides) t=0.9 hours
Flex (Two sides, SNOW) t=0.9 hours
Fixed t=3.0 hours
Flex (One Side) t=3.0 hours
Flex (Two sides) t=3.0 hours
Flex (Two sides, SNOW) t=3.0 hours


Stress [Mpa]
Depth [m]
Fixed t=5.1 hours
Flex (One Side) t=5.1 hours
Flex (Two sides) t=5.1 hours
Flex (Two sides, SNOW) t=5.1 hours
Fixed t=6.9 hours
Flex (One Side) t=6.9 hours
Flex (Two sides) t=6.9 hours
Flex (Two sides, SNOW) t=6.9 hours
Fixed t=8.1 hours
Flex (One Side) t=8.1 hours
Flex (Two sides) t=8.1 hours
Flex (Two sides, SNOW) t=8.1 hours


Stress [Mpa]
Depth [m]
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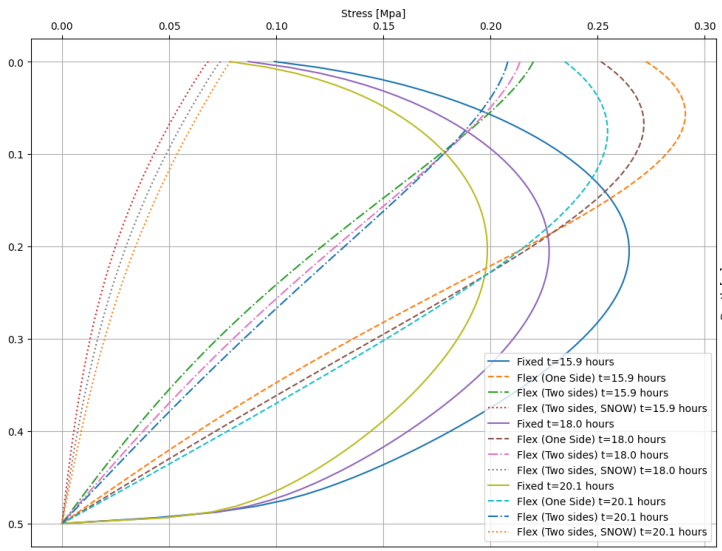
Flex (Two sides) t=9.9 hours
Flex (Two sides, SNOW) t=9.9 hours
Fixed t=12.0 hours
Flex (One Side) t=12.0 hours
Flex (Two sides) t=12.0 hours
Flex (Two sides, SNOW) t=12.0 hours
Fixed t=14.1 hours
Flex (One Side) t=14.1 hours
Flex (Two sides) t=14.1 hours
Flex (Two sides, SNOW) t=14.1 hours


Stress [Mpa]
Depth [m]
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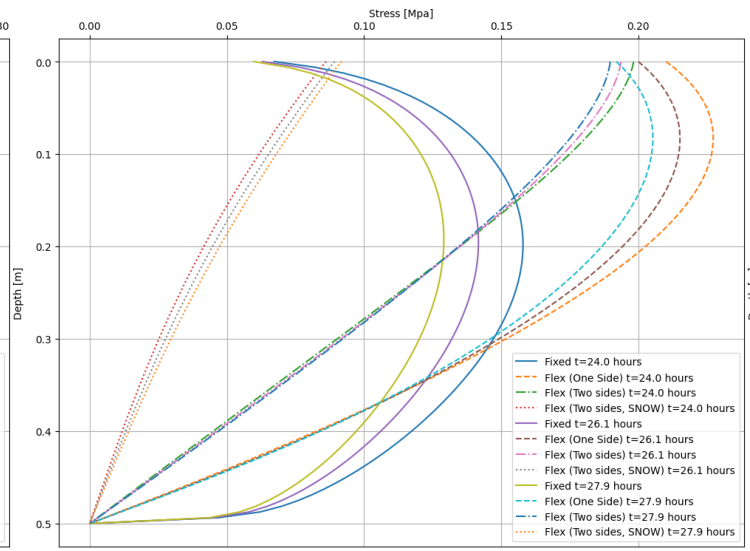
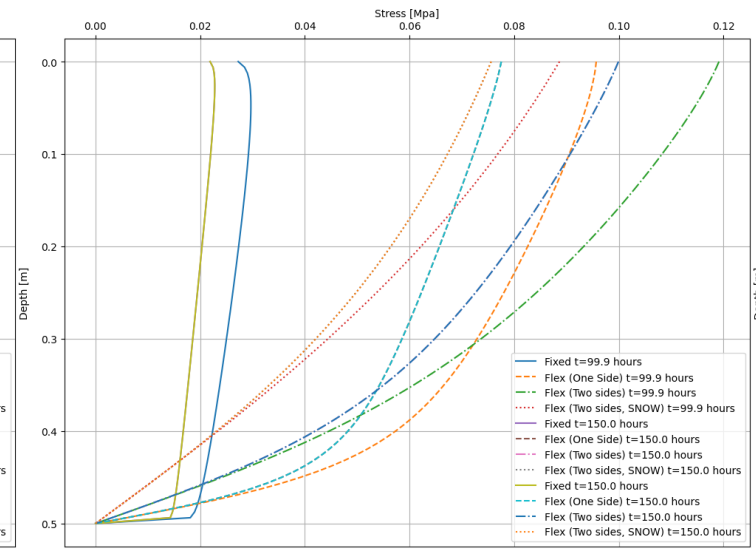
Flex (Two sides) t=15.9 hours
Flex (Two sides, SNOW) t=15.9 hours
Fixed t=18.0 hours
Flex (One Side) t=18.0 hours
Flex (Two sides) t=18.0 hours
Flex (Two sides, SNOW) t=18.0 hours
Fixed t=20.1 hours
Flex (One Side) t=20.1 hours
Flex (Two sides) t=20.1 hours
Flex (Two sides, SNOW) t=20.1 hours


Stress [Mpa]
Depth [m]
Fixed t=24.0 hours
Flex (One Side) t=24.0 hours
Flex (Two sides) t=24.0 hours
Flex (Two sides, SNOW) t=24.0 hours
Fixed t=26.1 hours
Flex (One Side) t=26.1 hours
Flex (Two sides) t=26.1 hours
Flex (Two sides, SNOW) t=26.1 hours
Fixed t=27.9 hours
Flex (One Side) t=27.9 hours
Flex (Two sides) t=27.9 hours
Flex (Two sides, SNOW) t=27.9 hours


Stress [Mpa]
Depth [m]
Fixed t=99.9 hours
Flex (One Side) t=99.9 hours
Flex (Two sides) t=99.9 hours
Flex (Two sides, SNOW) t=99.9 hours
Fixed t=150.0 hours
Flex (One Side) t=150.0 hours
Flex (Two sides) t=150.0 hours
Flex (Two sides, SNOW) t=150.0 hours
Fixed t=150.0 hours
Flex (One Side) t=150.0 hours
Flex (Two sides) t=150.0 hours
Flex (Two sides, SNOW) t=150.0 hours

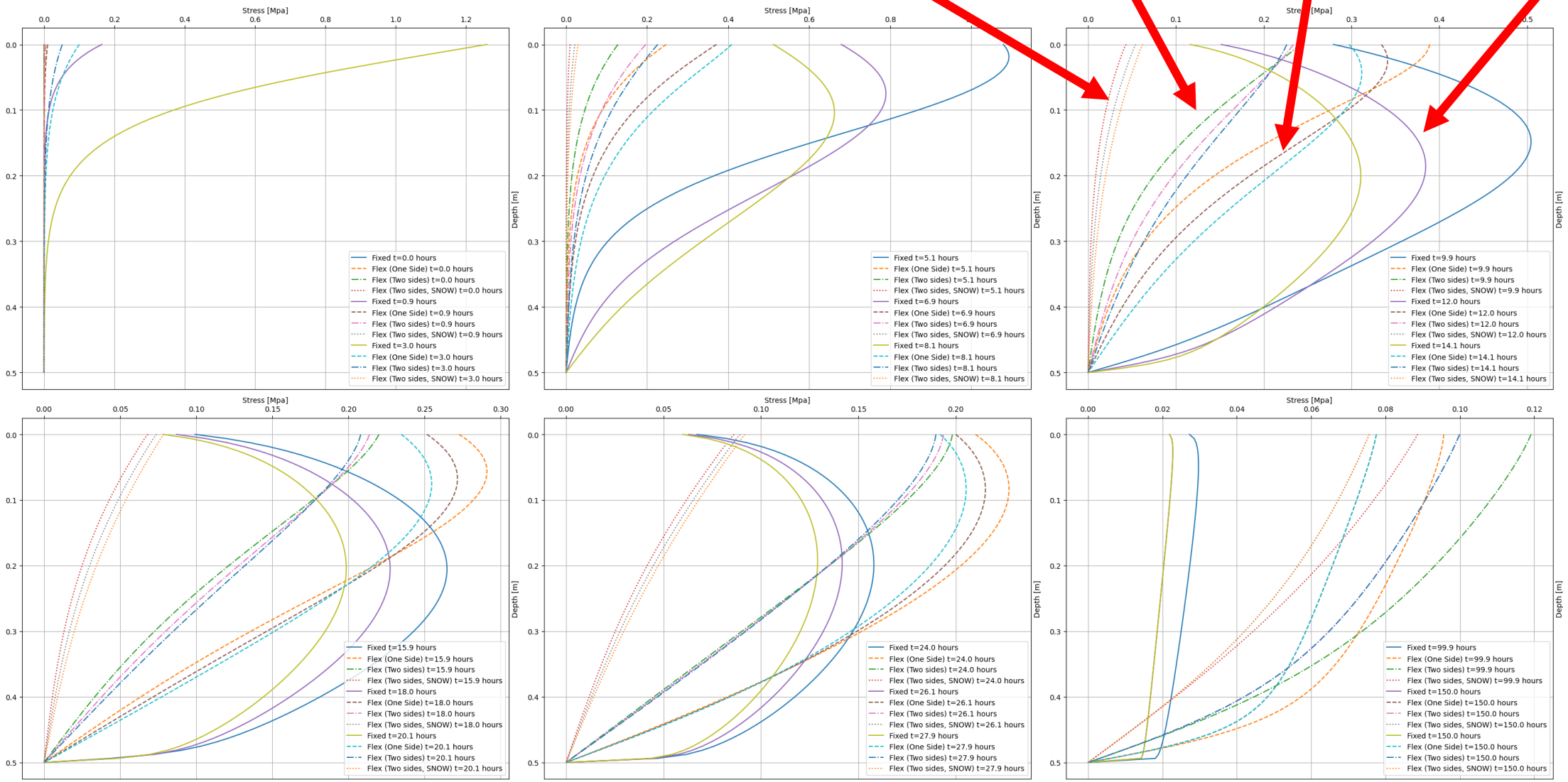
SIMULATION

Spring on two sides
+ snow

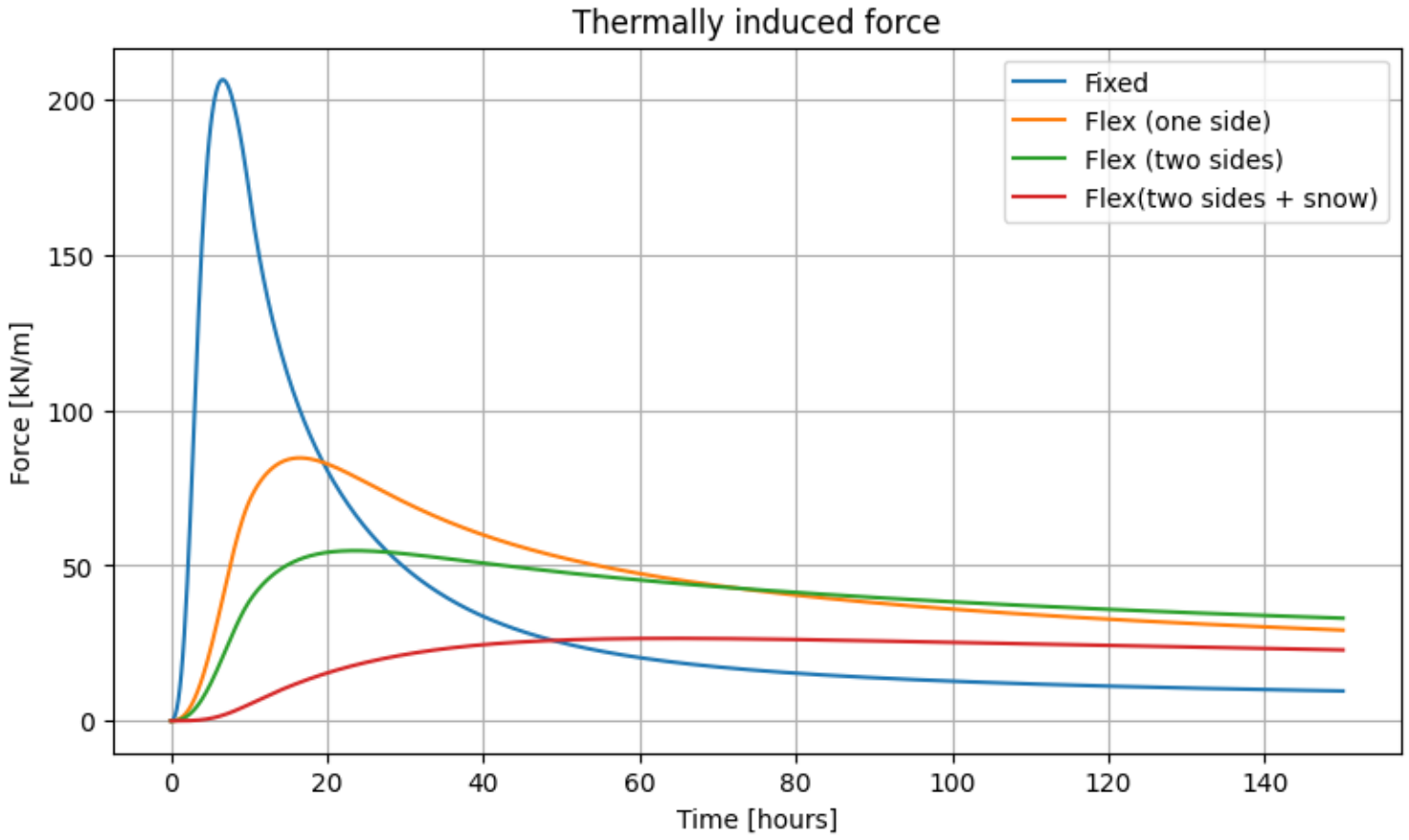
Spring on two sides

Spring on one side

Clamped



SIMULATION




```
Max force = 206.37 kN/m at time t=6.56 hours
Max force = 84.63 kN/m at time t=16.50 hours
Max force = 54.77 kN/m at time t=23.44 hours
Max force = 26.54 kN/m at time t=64.12 hours
```

RESULTS FROM SIMULATION

- **Structure flexibility is important**
- **Should provide better guidance in standards**
- **Load combinations (time delay) may also be important**