Developments in Thermal Pile Design

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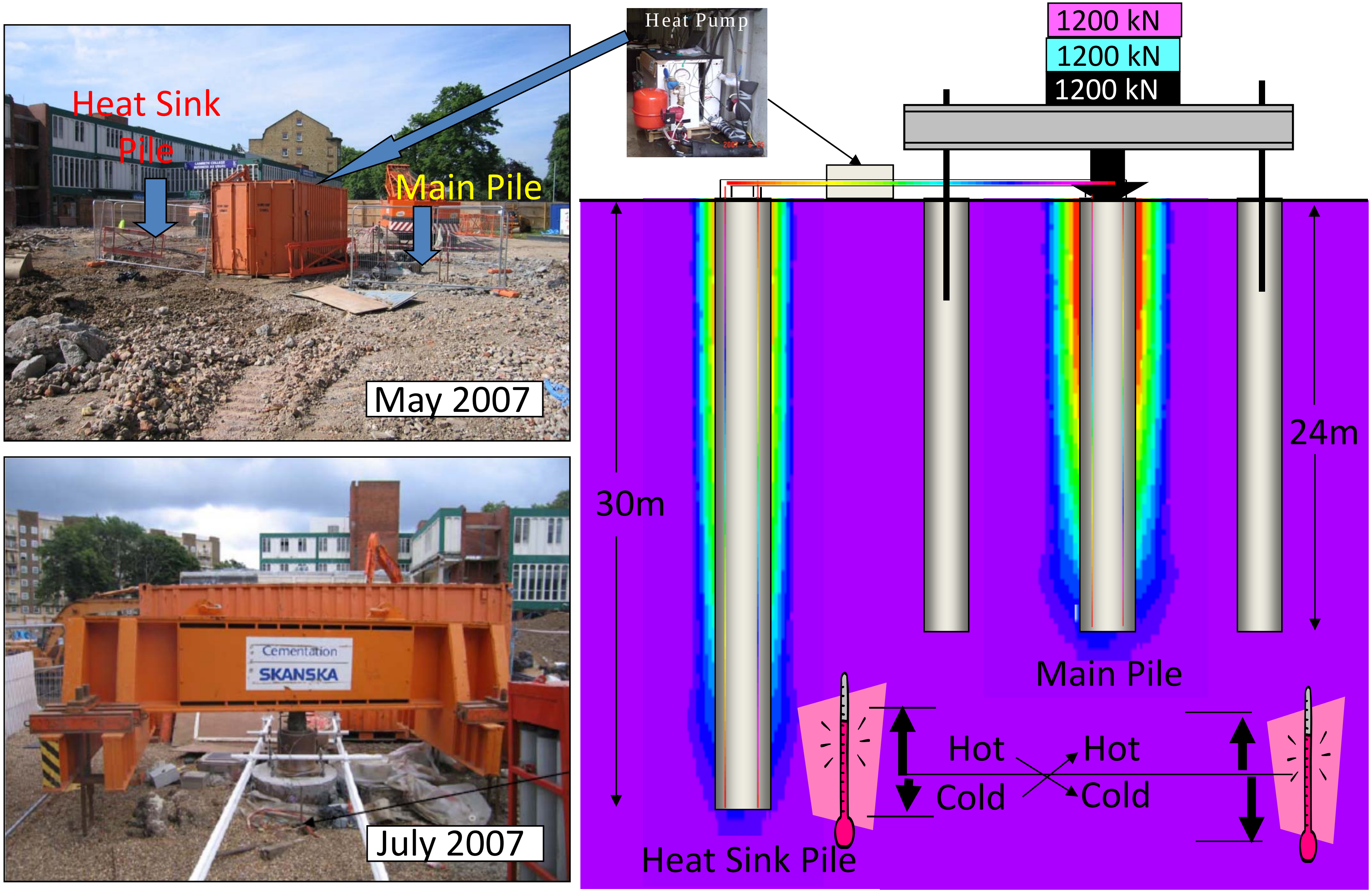
Mechanical Load Tests coupled with thermal loading

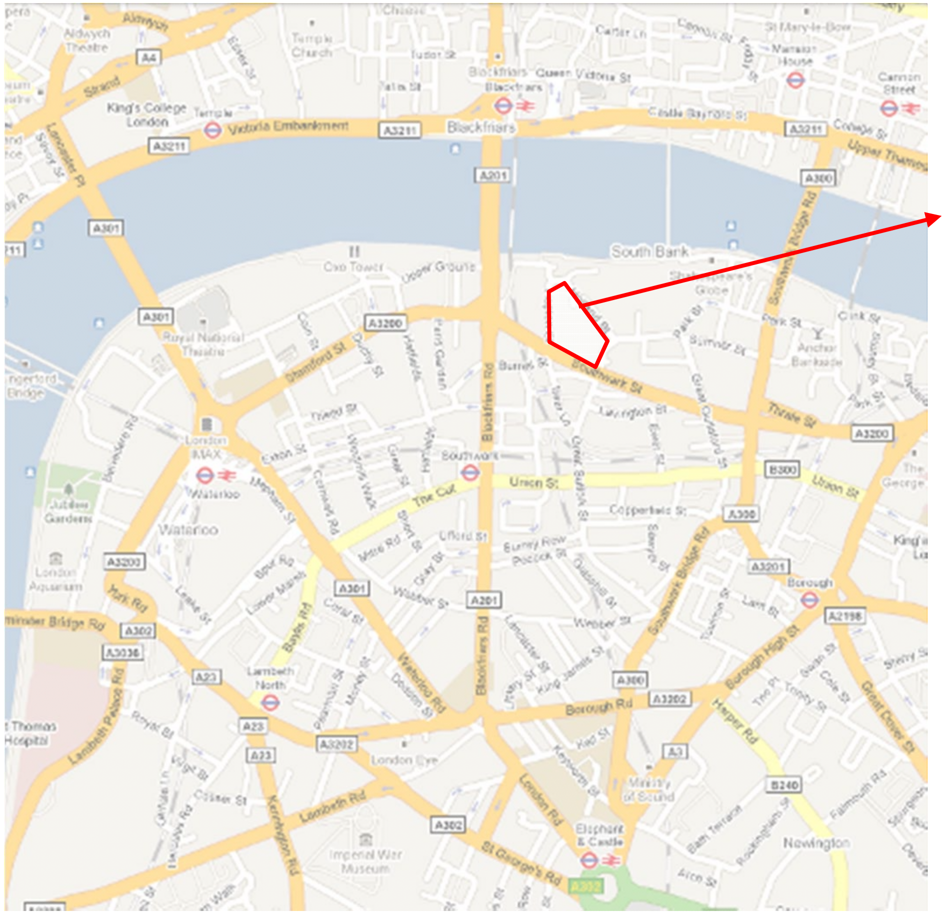


Long Term Monitoring Project - Bankside

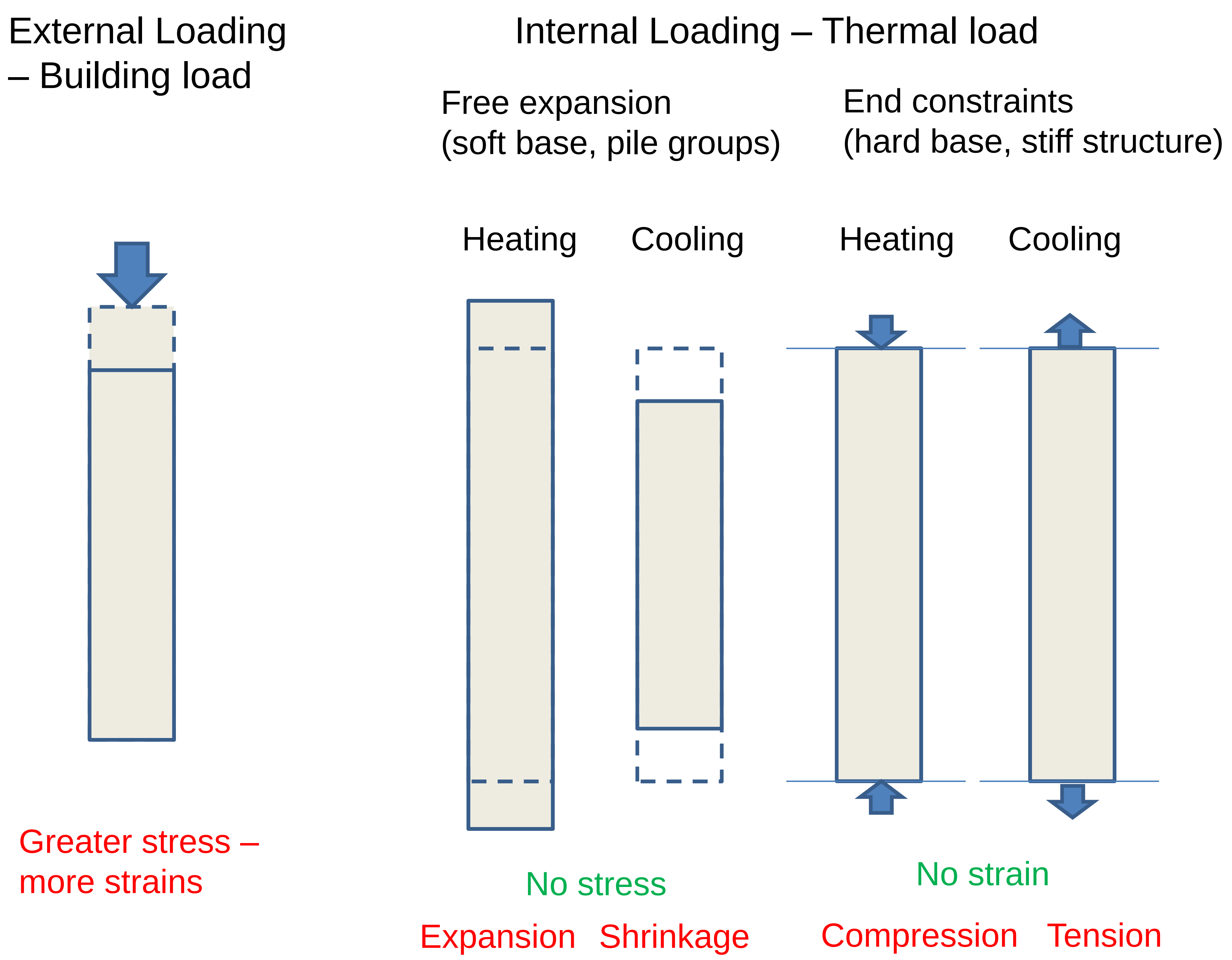
SKANSKA

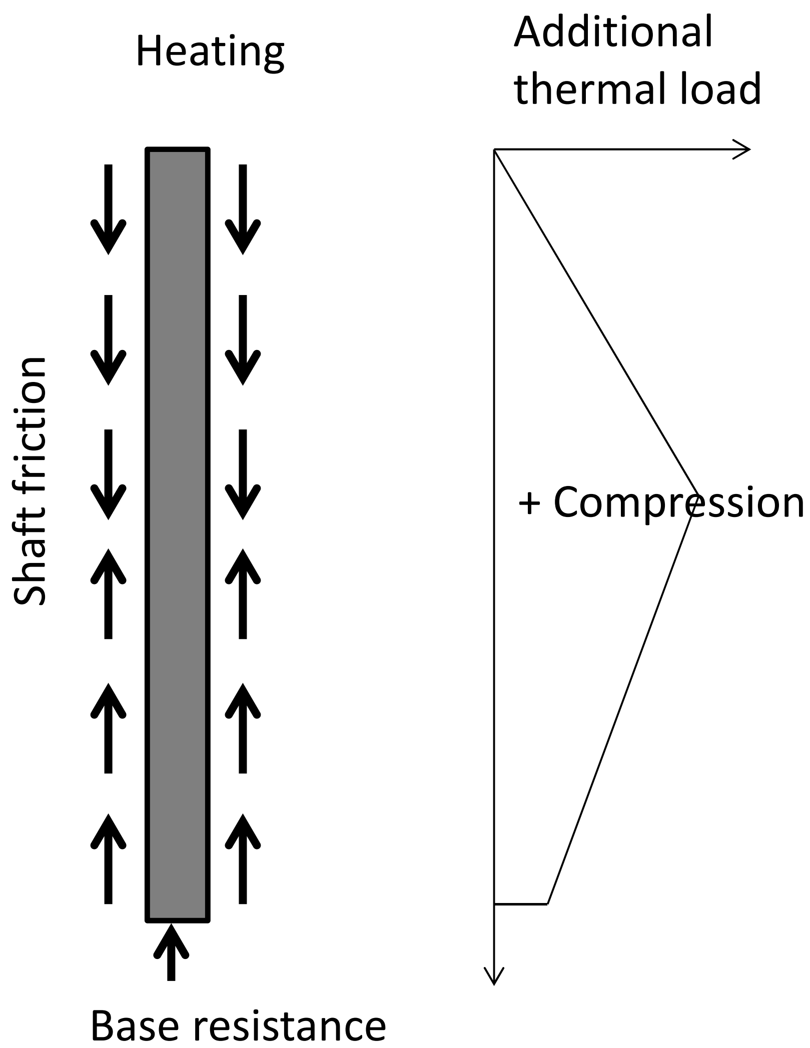
Lambeth College

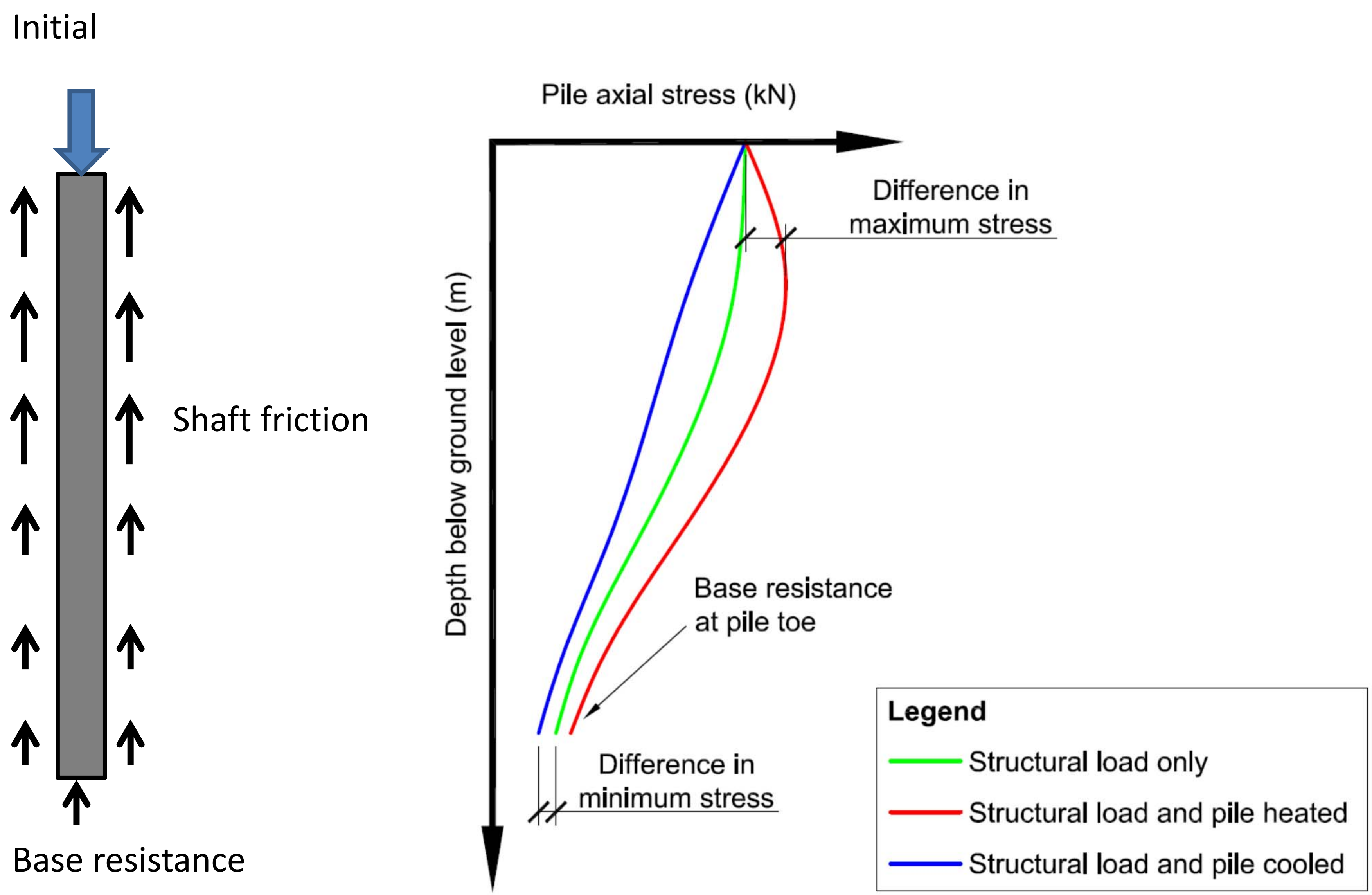
Bankside Project



Source: http://www.contractjournal.com

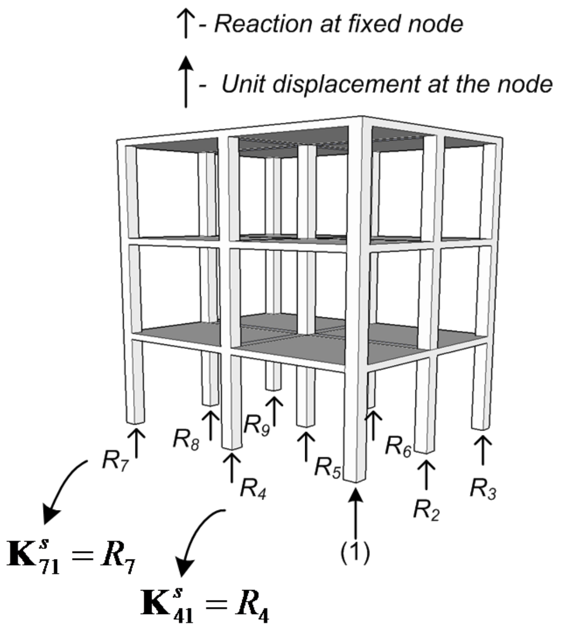

External Loading
– Building load
Internal Loading – Thermal load
Free expansion
(soft base, pile groups)
End constraints
(hard base, stiff structure)
Heating
Cooling
Heating
Cooling
Greater stress –
more strains
No stress
No strain
Expansion
Shrinkage
Compression
Tension

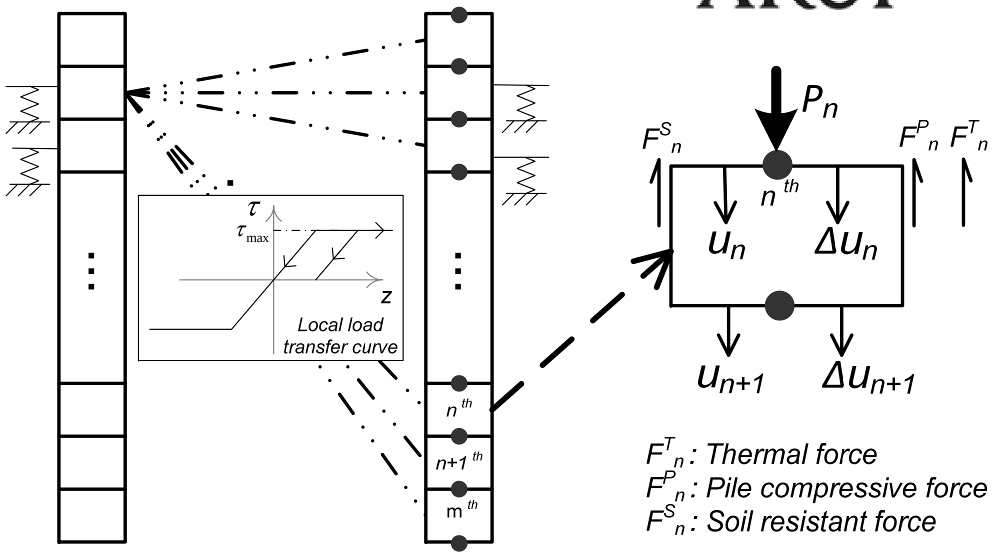

Heating
Additional thermal load
Shaft friction
+ Compression
Base resistance
Cooling
Additional thermal load
Shaft friction
- Tension
Base resistance

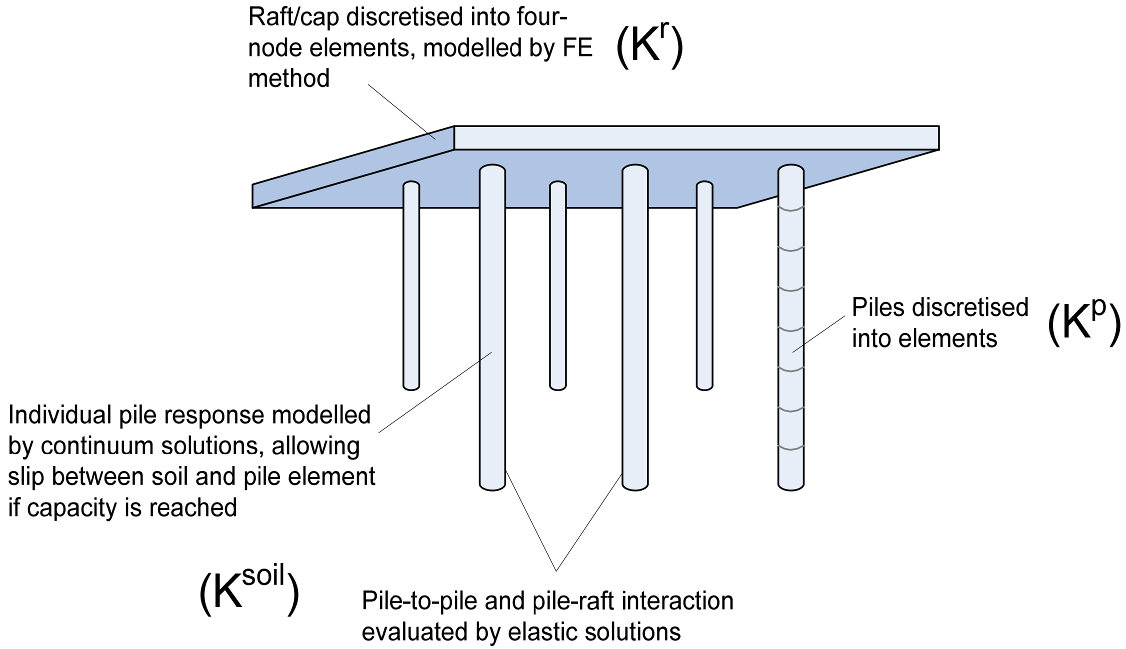


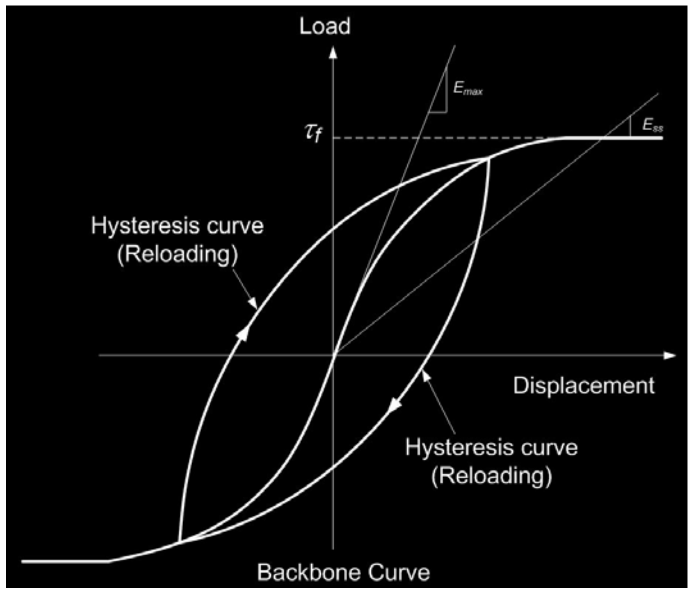
Initial
Shaft friction
Base resistance
Pile axial stress (kN)
Depth below ground level (m)
Difference in maximum stress
Base resistance at pile toe
Difference in minimum stress
Legend
Structural load only
Structural load and pile heated
Structural load and pile cooled

Thermal pile design software

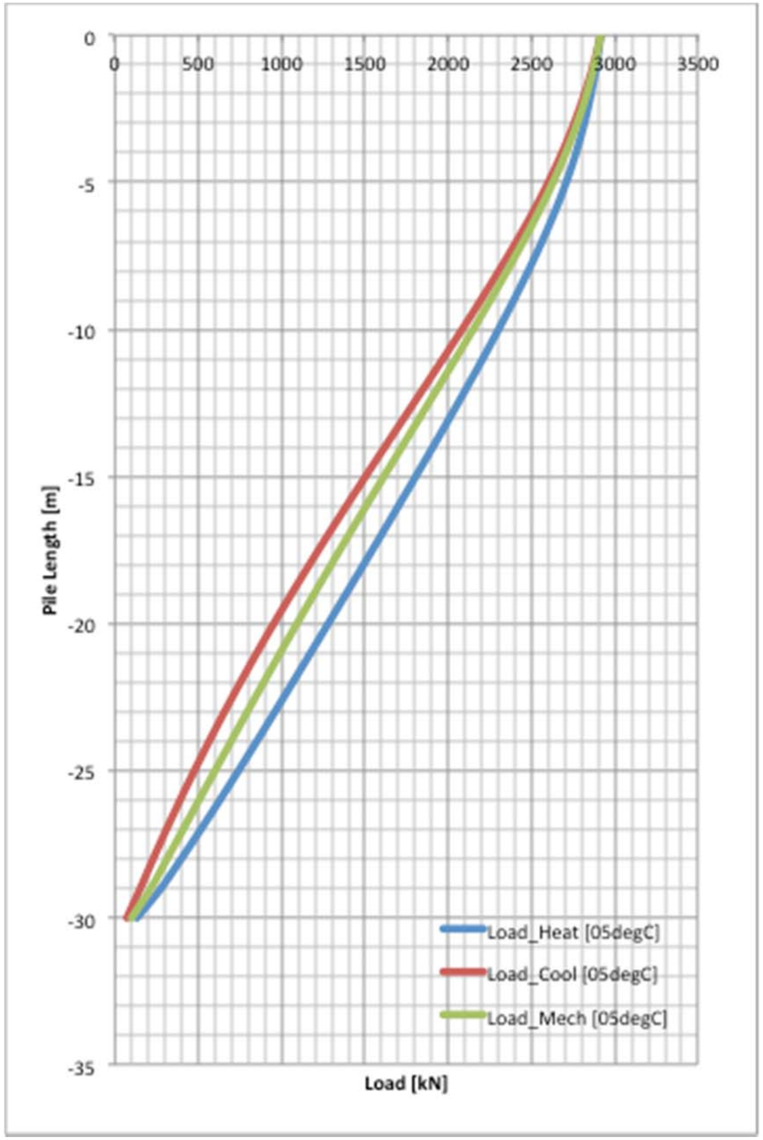




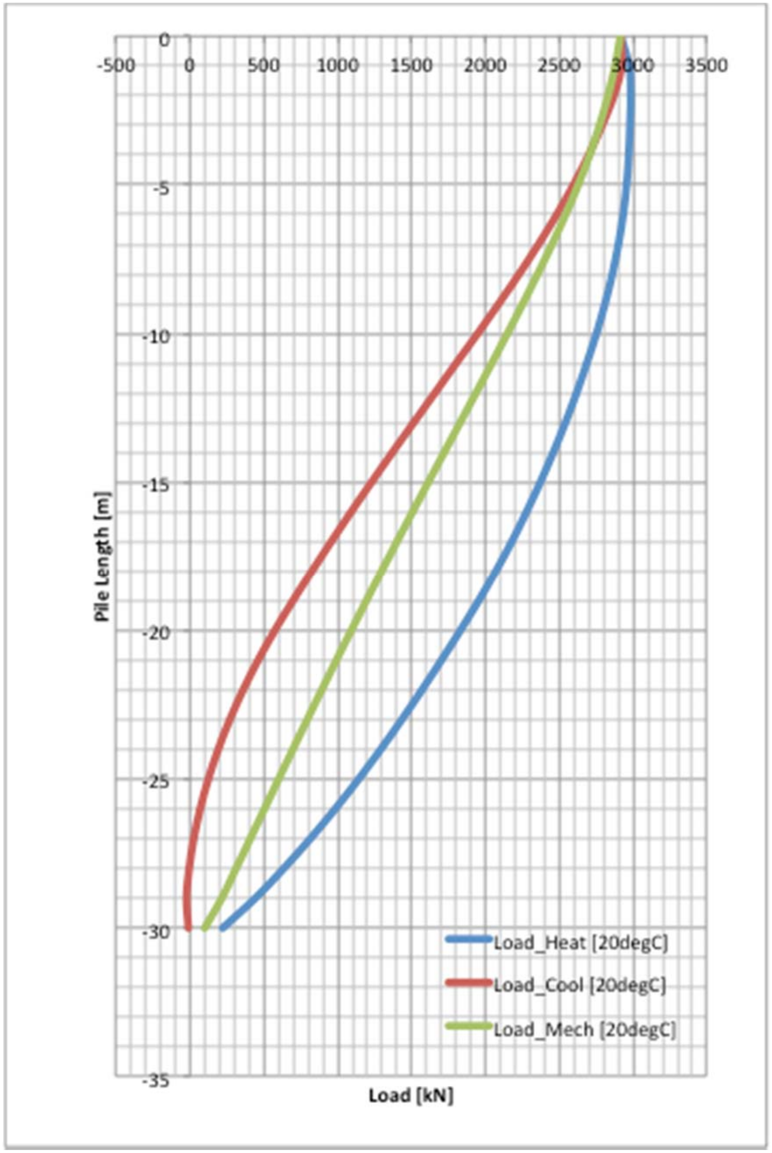




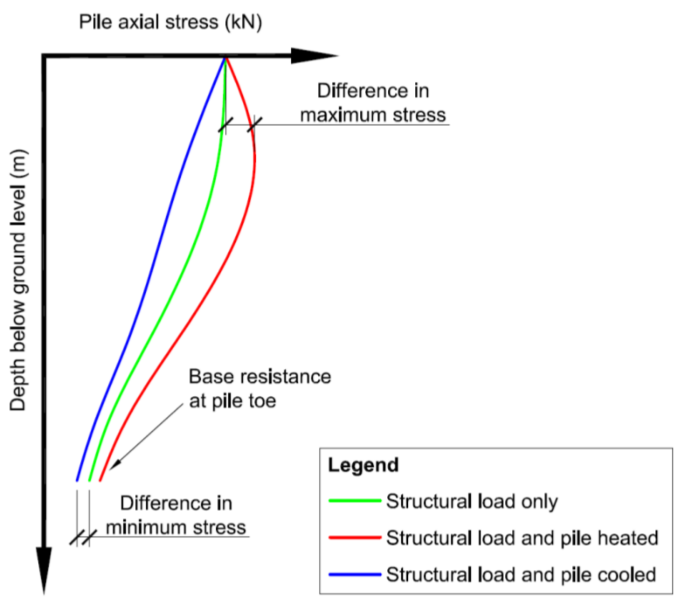
Check 1: Is the stress in the concrete smaller than the strength?

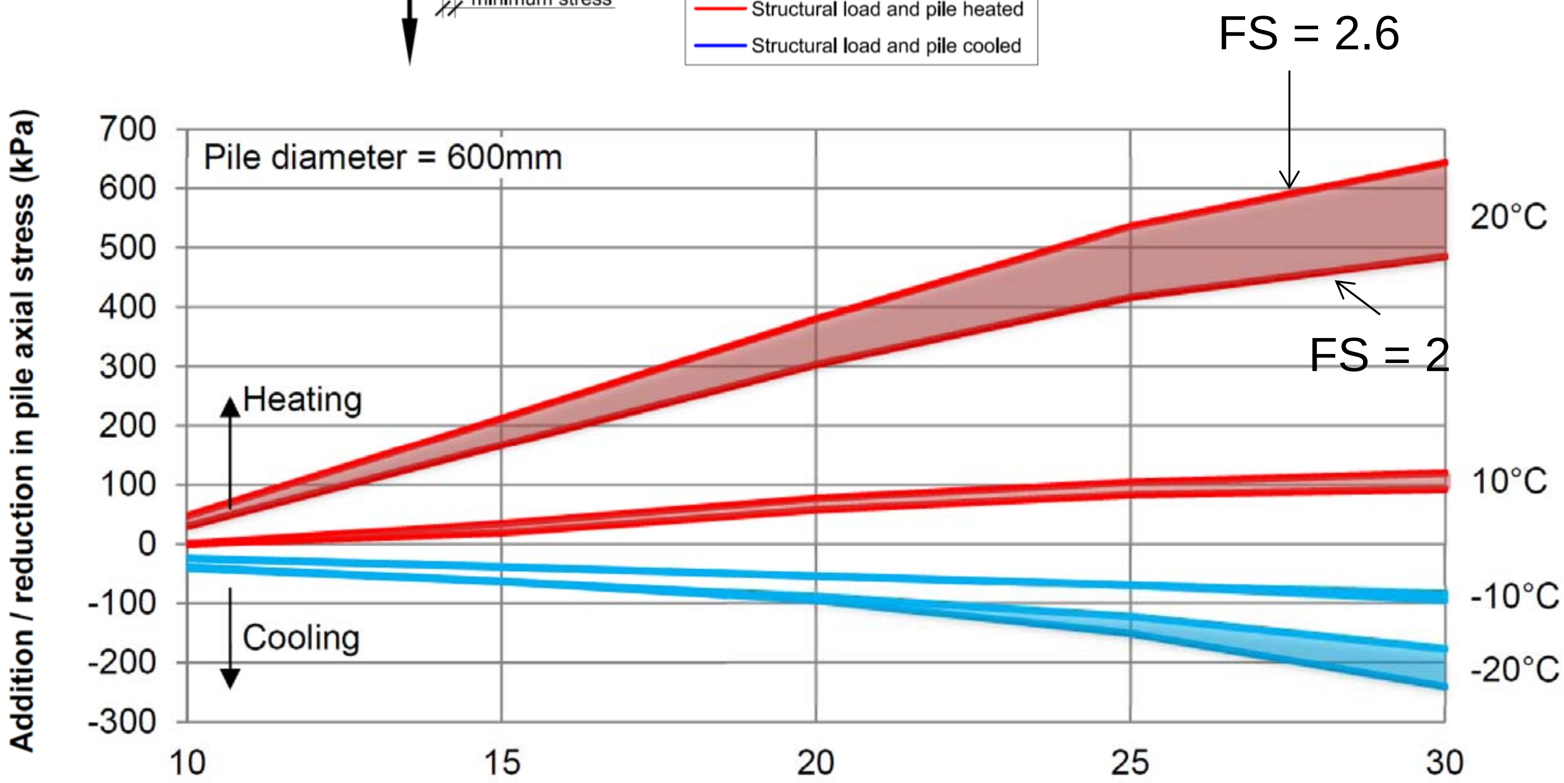


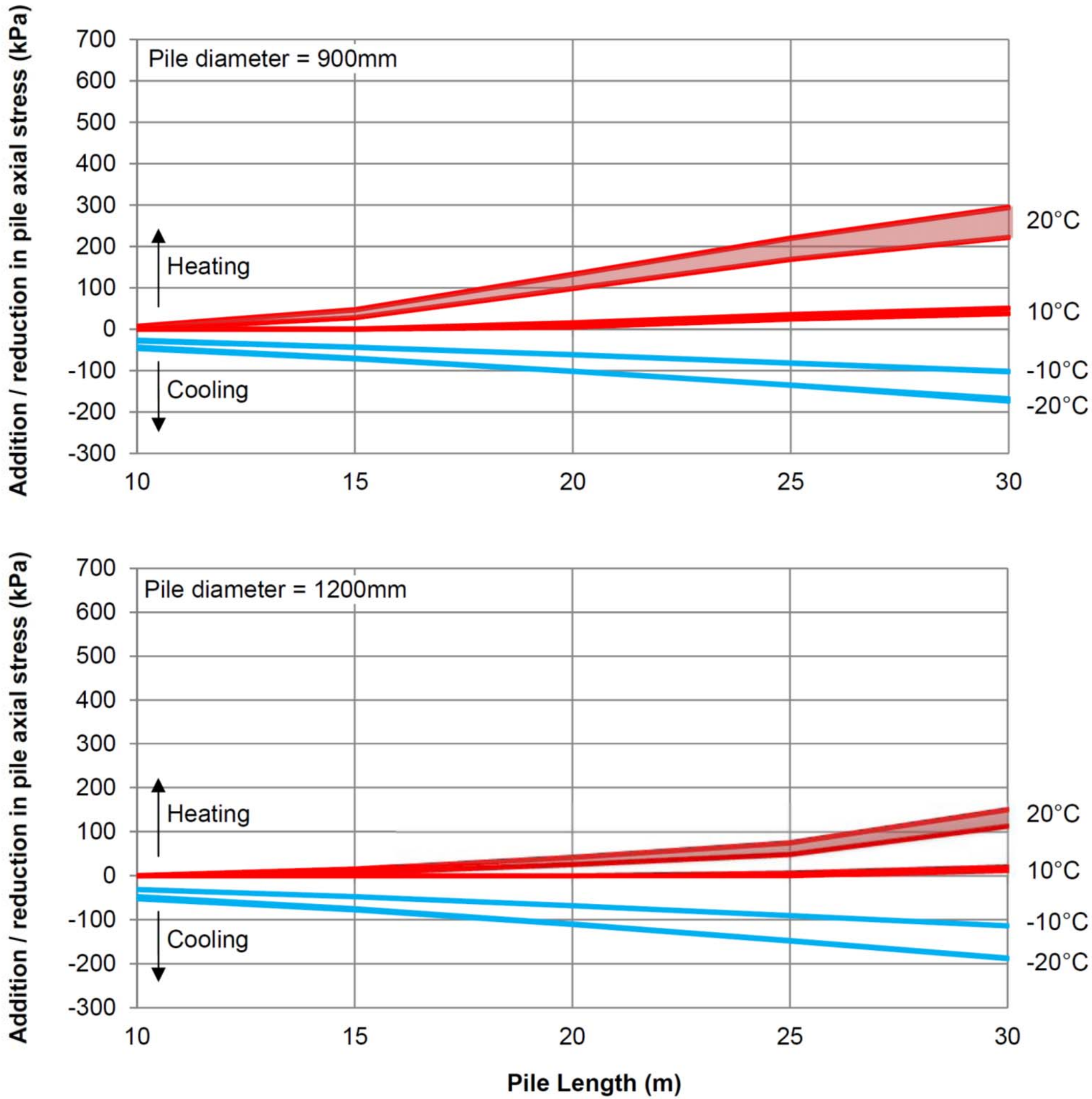
Heating and Cooling ±5 degrees



Heating and Cooling ±20 degrees


Pile axial stress (kN)
Depth below ground level (m)
Difference in maximum stress
Base resistance at pile toe
Difference in minimum stress
Legend
Structural load only
Structural load and pile heated
Structural load and pile cooled


FS = 2.6
Pile diameter = 600mm
Addition / reduction in pile axial stress (kPa)
700
600
500
400
300
200
100
0
-100
-200
-300
Heating
Cooling
20°C
FS = 2
10°C
-10°C
-20°C
10
15
20
25
30


Addition / reduction in pile axial stress (kPa)
Pile diameter = 900mm
700
600
500
400
300
200
100
0
-100
-200
-300
10
15
20
25
30
Heating
Cooling
20°C
10°C
-10°C
-20°C
Pile diameter = 1200mm
Heating
Cooling
20°C
10°C
-10°C
-20°C
Pile Length (m)

Check 2: Is the pile movement acceptable?

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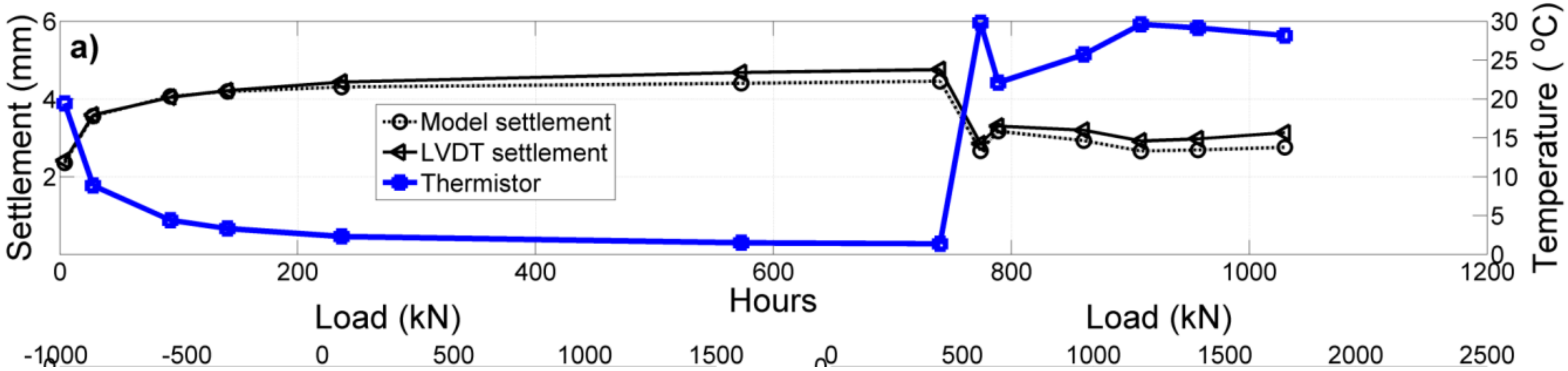
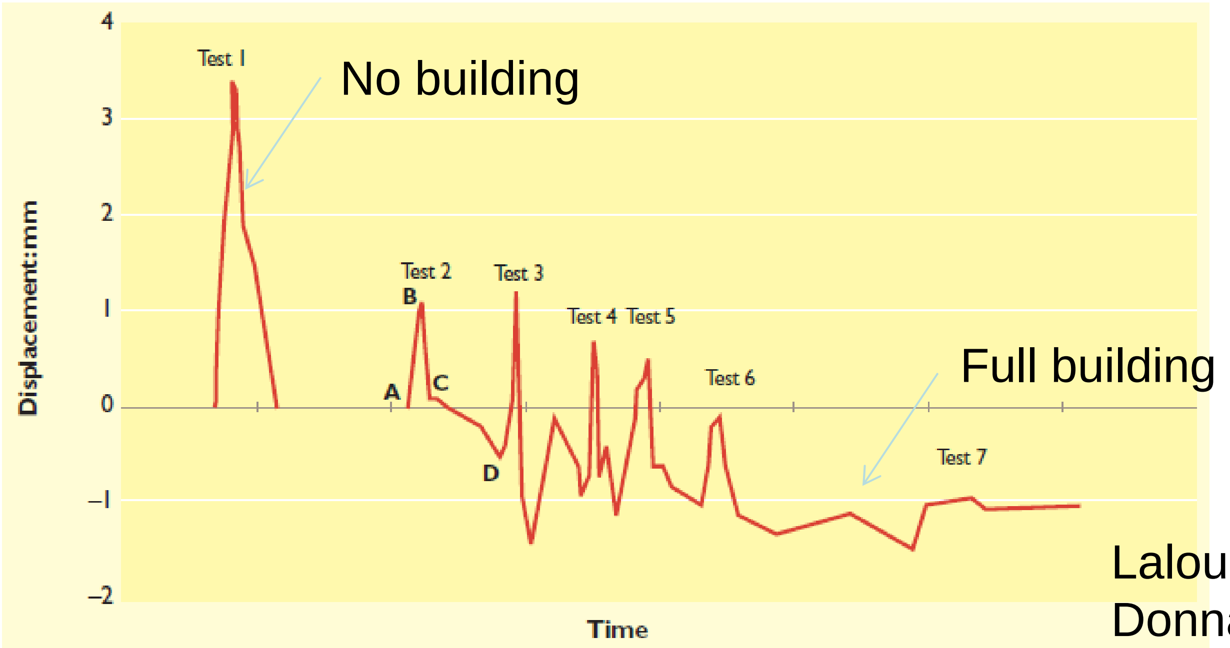
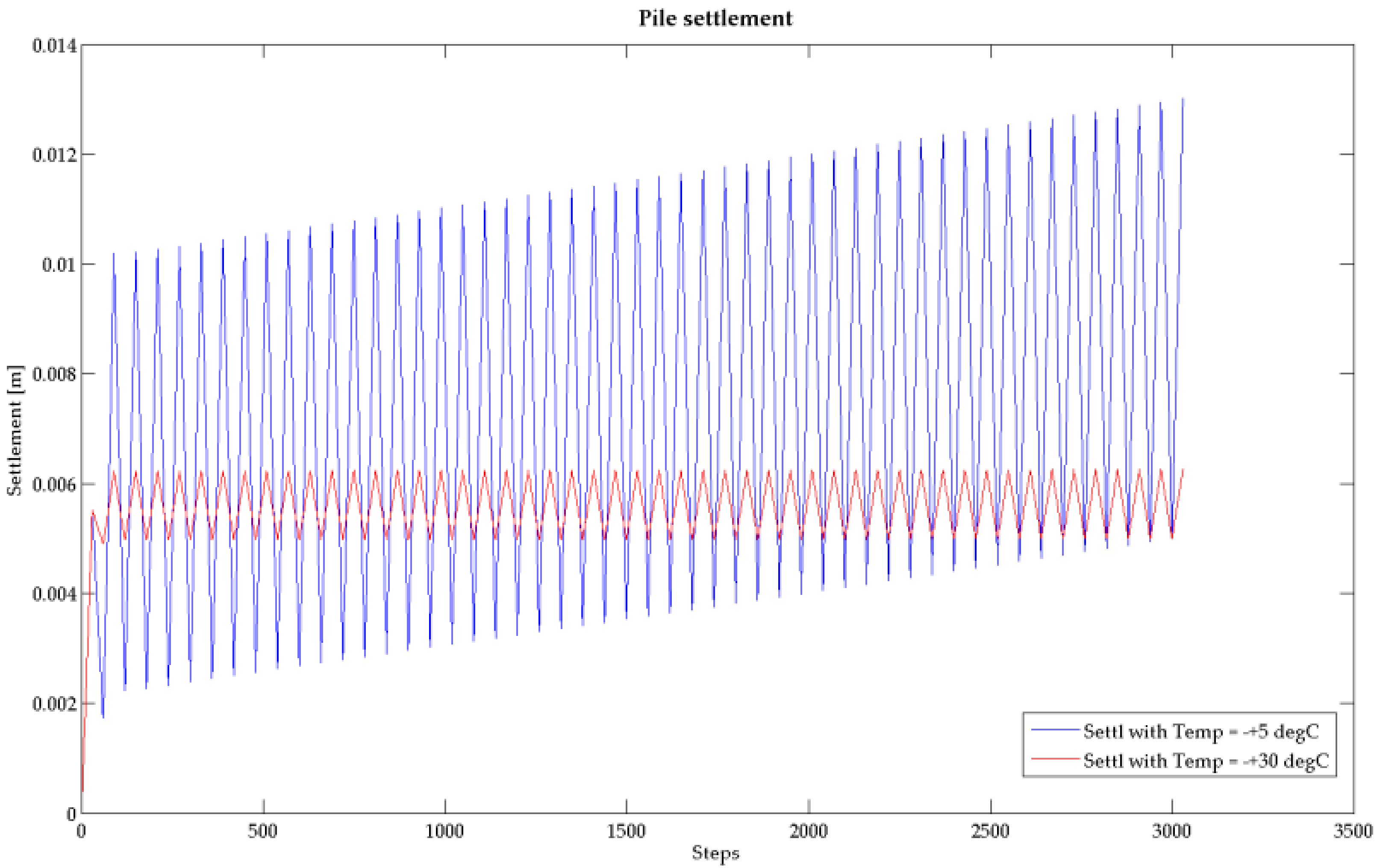


EPFL Lausanne

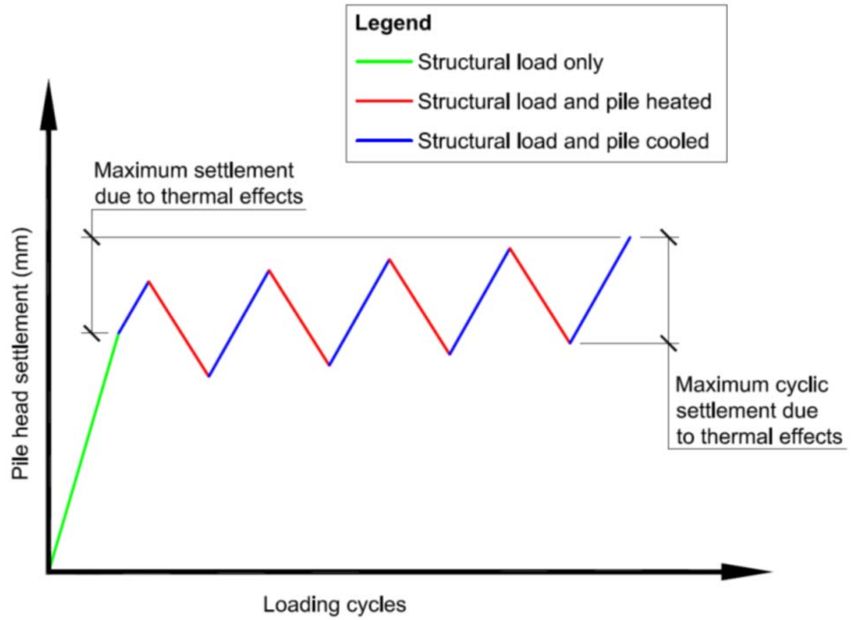


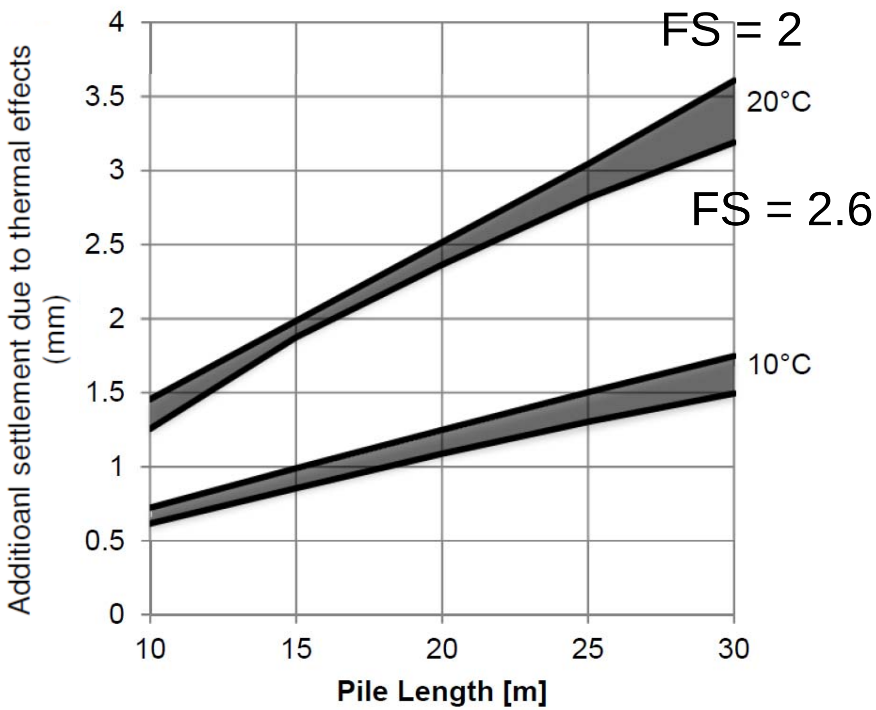
Laloui and Donna (2011)

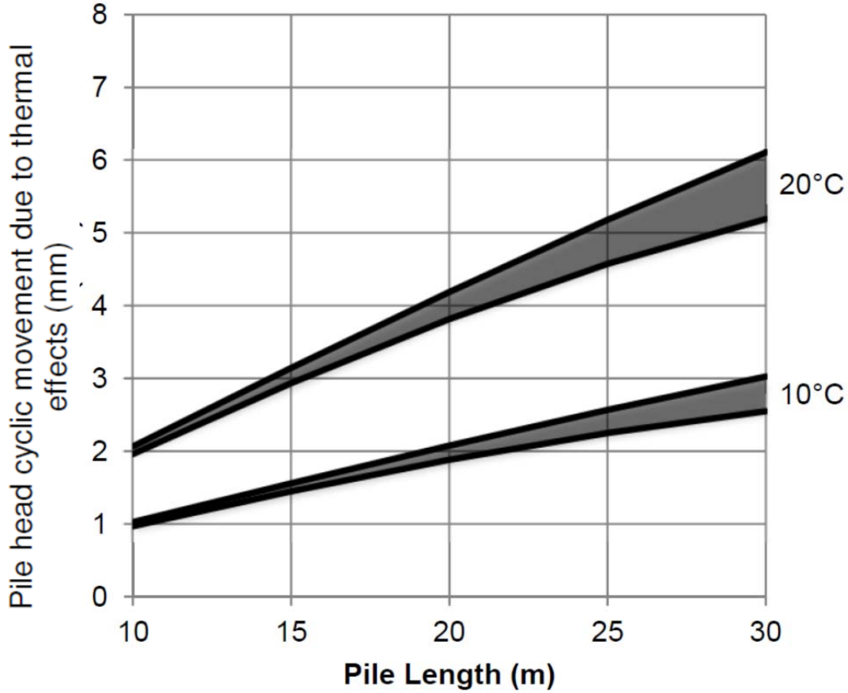
Example; Pile length = 30 m; Pile diameter = 0.6; FoS = 2;



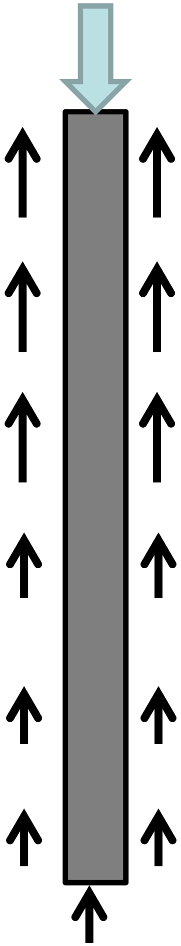
Settlement at pile top


Legend
Structural load only
Structural load and pile heated
Structural load and pile cooled
Maximum settlement due to thermal effects
Maximum cyclic settlement due to thermal effects
Pile head settlement (mm)
Loading cycles


FS = 2
FS = 2.6
20°C
10°C
Additioanl settlement due to thermal effects (mm)
4
3.5
3
2.5
2
1.5
1
0.5
0
10
15
20
25
30
Pile Length [m]


20°C
10°C
Pile head cyclic movement due to thermal effects (mm)
8
7
6
5
4
3
2
1
0
10
15
20
25
30
Pile Length (m)

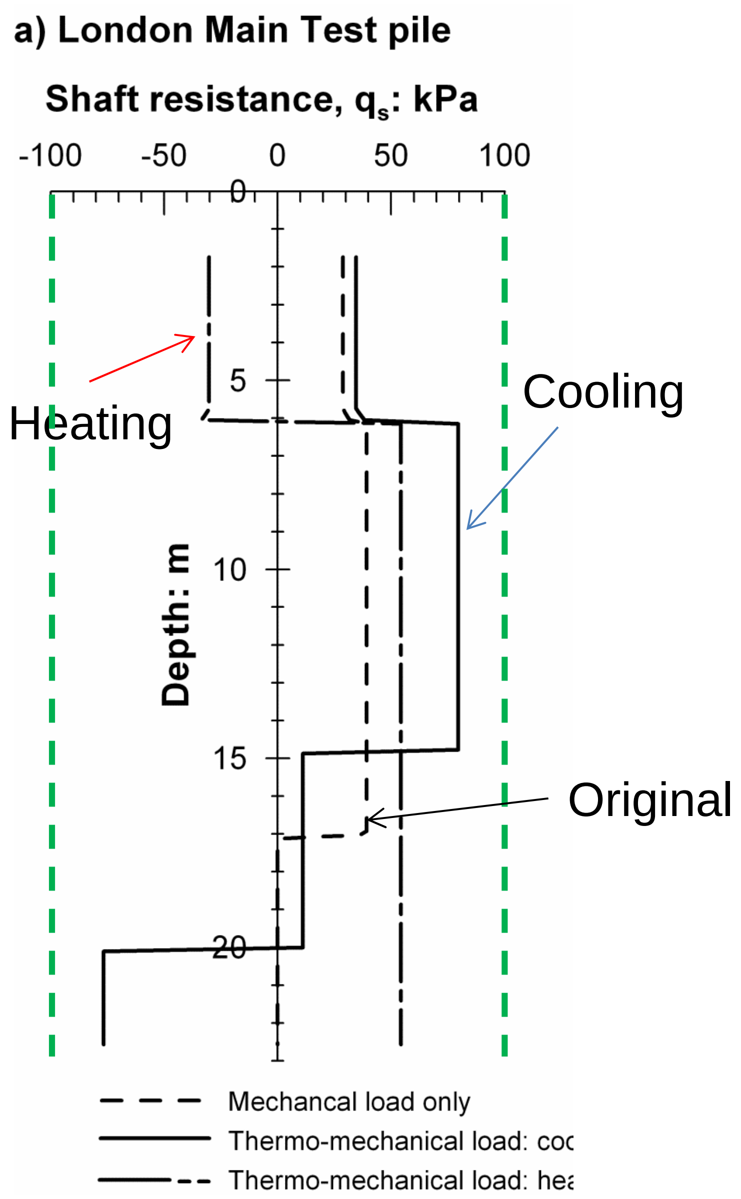
Check 3&4: Are the mobilised shaft friction and the end bearing pressure smaller than the design limits?



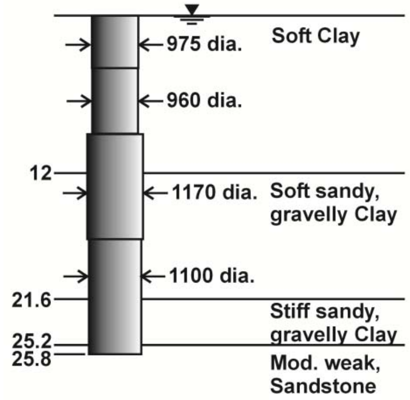
Shaft friction < shaft shear resistance

Make sure that the soil does not fail

Base resistance < base shear resistance

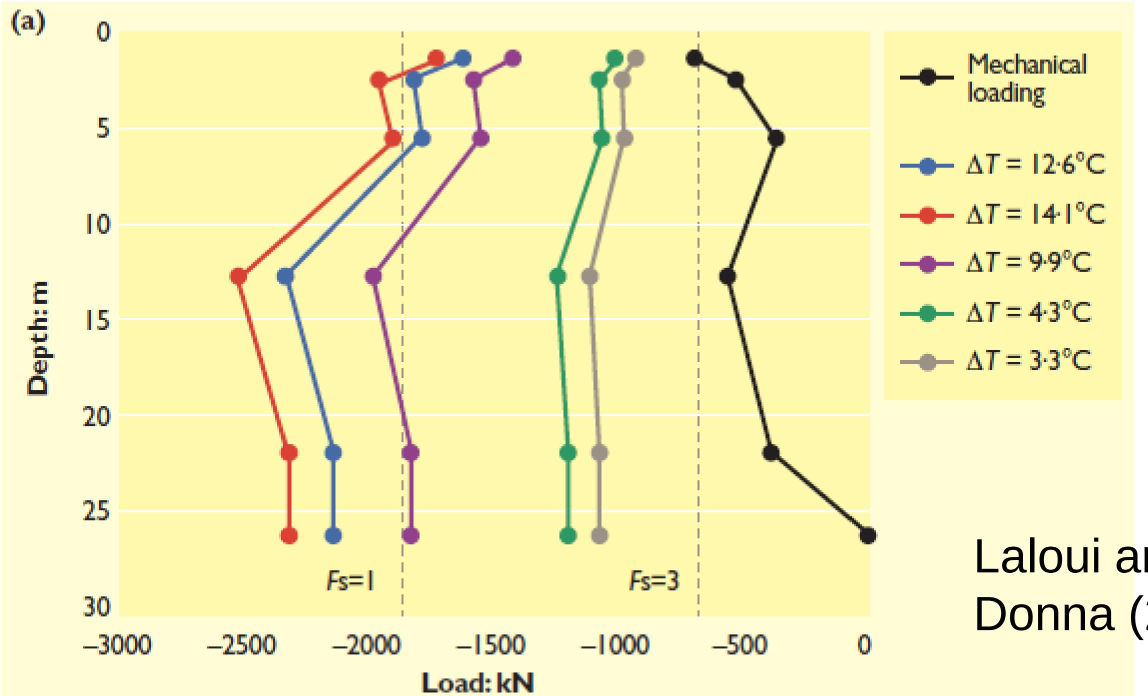

a) London Main Test pile
Shaft resistance, q_s: kPa
-100
-50
0
50
100
0
5
10
15
20
Depth: m
Heating
Cooling
Original
Mechancal load only
Thermo-mechanical load: coo
Thermo-mechanical load: hea

b) Lausanne



Typical soil properties

Soft Clay	γ = 19.6 kN/m^3 c_u = 15 - 20 kPa
Soft sandy, gravelly Clay	γ = 19.1 kN/m^3 c_u = 20 - 30 kPa
Stiff, sandy gravelly Clay	γ = 21.6 kN/m^3 c_u = 70 - 150 kPa
Mod. weak Sandstone	γ = 25 kN/m^3 UCS = 12 MPa



Laloui and Donna (2011)

2400 kN load at the base is about 3 MPa

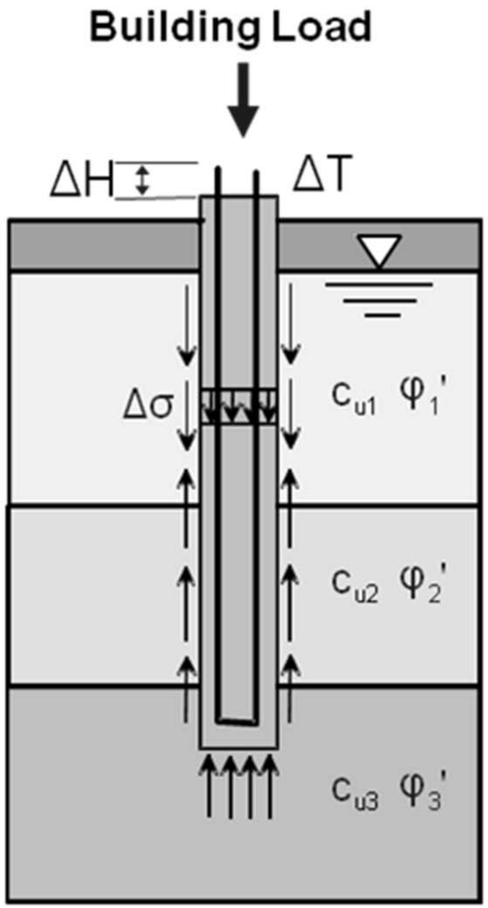
Normal pile design considerations

ULS

- Stratigraphy and soil properties
- Shear / radial stresses
- End bearing

SLS

- Pile settlement
- Differential settlement
- Concrete stress
- Negative skin friction



Additional thermal pile design considerations

ULS (Appendix D)

- Soil strength properties considering heating and cooling effects

SLS (Appendix E)

- Axial and radial pile expansion / contraction / fixity
- Thermally induced axial stresses
- Cyclic effects of thermal loading
- Temperature at soil-pile interface including daily / seasonal variations

Summary for Thermal Piles

- **Check 1: Stress in the concrete is less than the allowable limit.**
  - Extreme – assume that the pile is fully restrained
- **Check 2: Pile movement is less than what the superstructure can tolerate.**
  - Need to do pile-soil interaction analysis
- **Check 34: Mobilised shaft friction is less than the design limit.**
  - Assume that the pile can fully expand at both ends but no movement at somewhere in the middle?
- **Check 4: End bearing pressure is less than the design limit.**
  - Extreme – assume that the pile is fully restrained. But end movement will reduce the thermally applied load.