Experience on Thermal (Energy) Piles

by

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Exploiting the Energy Below Us

Torino, Italy

16.00 – 16.30hrs on 5/12/16

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Contents - Thermal Pile Experience Includes:-

1. **Specifications and Contracts**
   - GSHPA Thermal Piles Standard
2. **Design Tools**
   - Tools and Back Analysis
3. **Design Stages**
   - Preliminary and Detailed
4. **Thermal Pile Construction**
   - Bored piles, CFA , Others
5. **Thermal Walls**
   - Induced moments in walls.
6. **Operational Experience**
   - Instrumentation on ground side of GSHP

1)Specification and Contract Experience

Ground Source Heat Pump Association Thermal Pile Standard (2012)

The GSHPA Standard combines UK experience for Thermal Piles.

(In UK Cementation has Trademark on “Energy Piles”)

To be updated, – any feedback?

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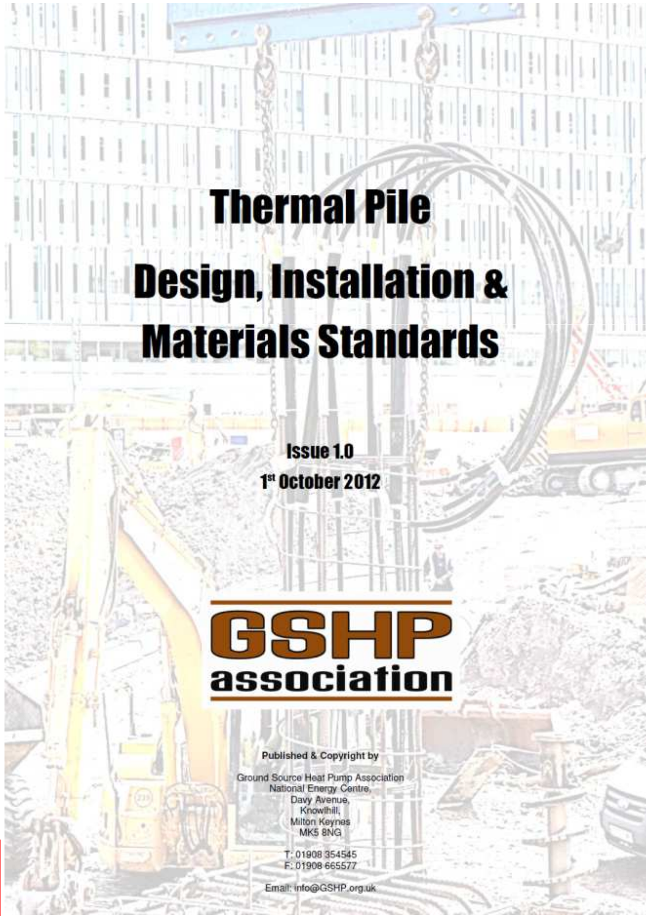
GSHPA -Thermal Pile Standard (2012)

Contents List

- **Sec 1** **Preamble (as BHS) - 1.2 Definitions**
- **Sec 2** **Regulatory & Government Agency Requirements (as BHS)**
- **Sec 3** **Contractual Responsibilities**
- **Sec 4** **Training Requirements**
- **Sec 5** **Design**
- **Sec 6** **Thermal Response Testing**
- **Sec 7** **Pipe Materials and Jointing Methods**
- **Sec 8** **Thermal Pile Concrete**
- **Sec 9** **Loops Installation**
- **Sec 10** **Pressure Testing**
- **Sec 11** **Indoor Piping / Values (as BHS)**
- **Sec 12** **Thermal Transfer Fluids (as BHS)**
- **Sec 13** **Design Drawings**
- **Sec 14** **Monitoring and Checking**
- **Sec 15** **Alterations**



Free Download www.gshp.org.uk

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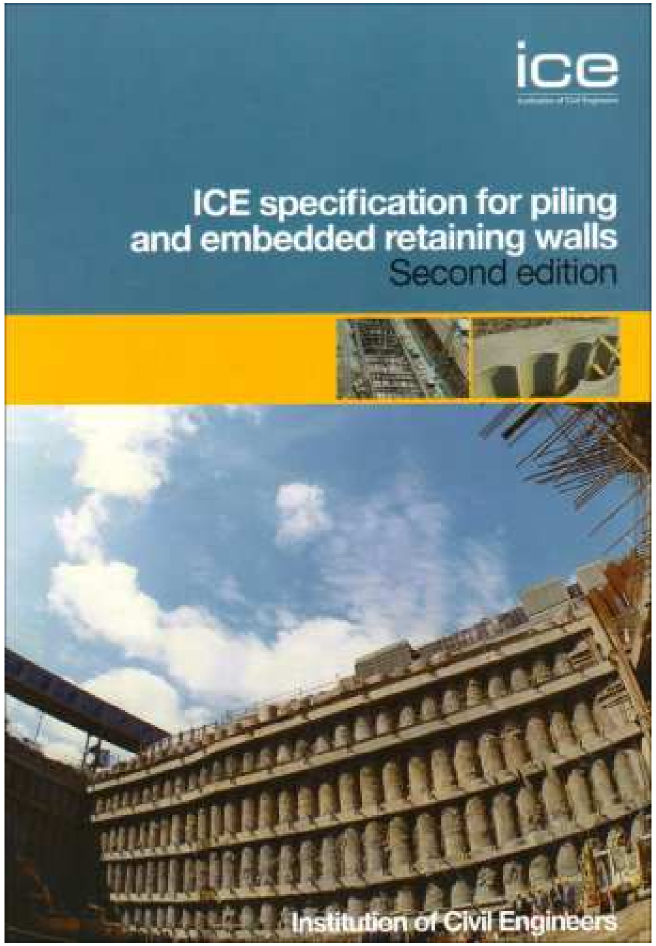
Section 3 - Contractual Responsibilities -Piling

- **Many contractual parties – clear division of responsibilities**

- **ICE Specification for Piling and Embedded Retaining Walls (SPERW) is the starting point:**
  - Engineer design
  - Contractor design



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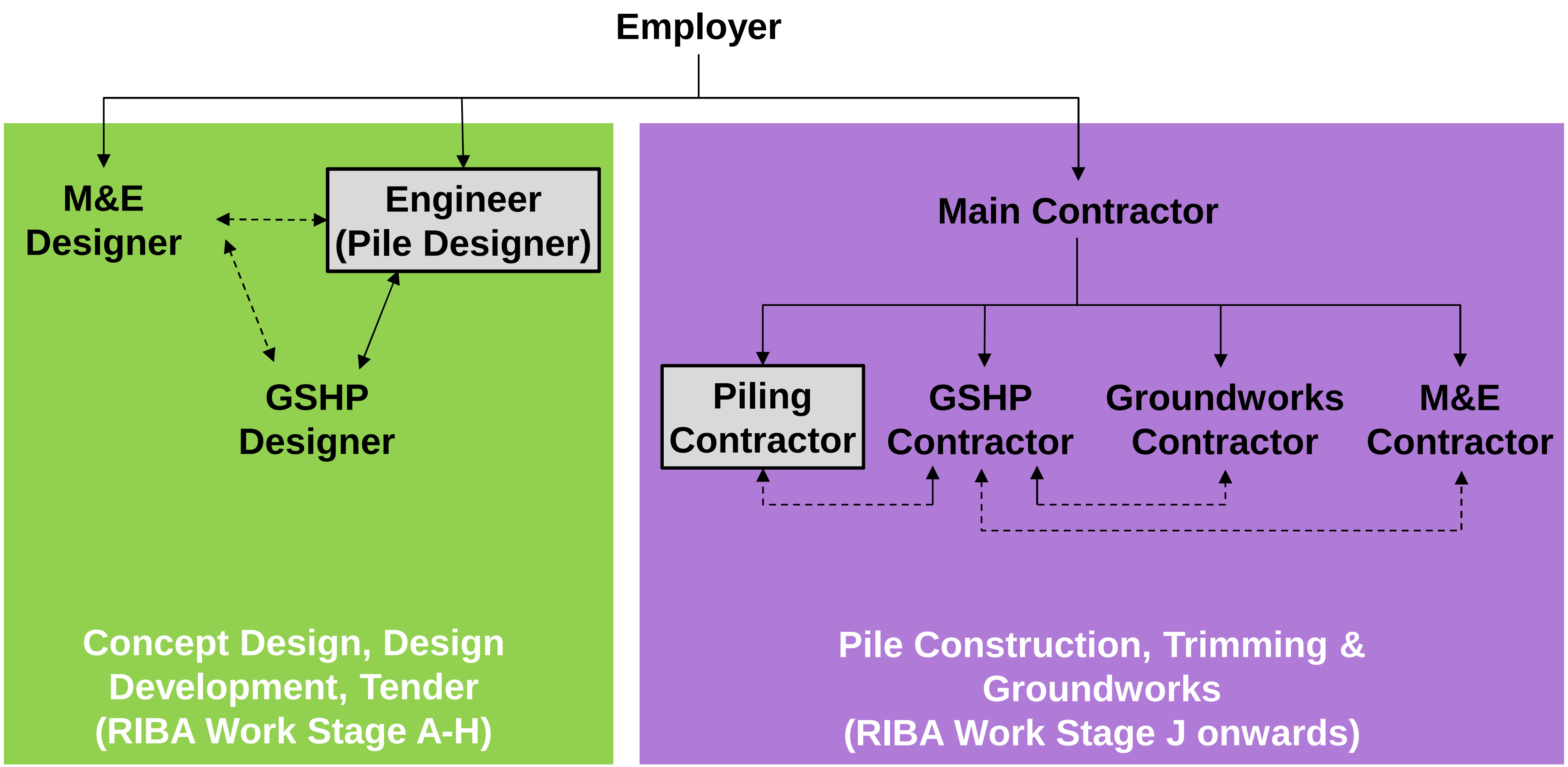
Contractual Responsibilities – Engineer Design



Denotes parties with responsibilities set out in SPERW (2007)

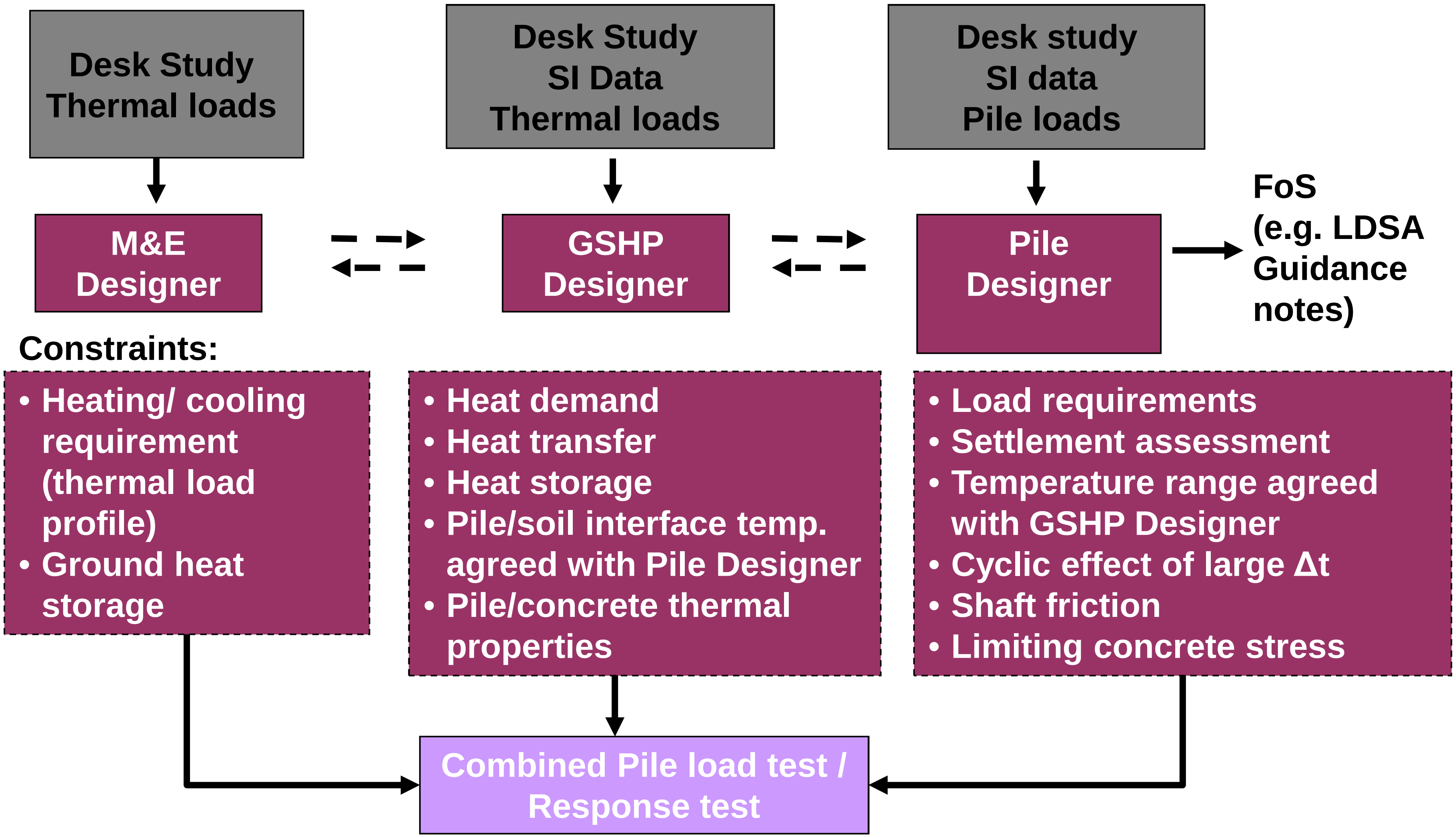
Contractual links

Possible non-contractual links

How to educate the design team???

Section 5 – Building Design Interactions

Thermal effects complicate traditional pile design

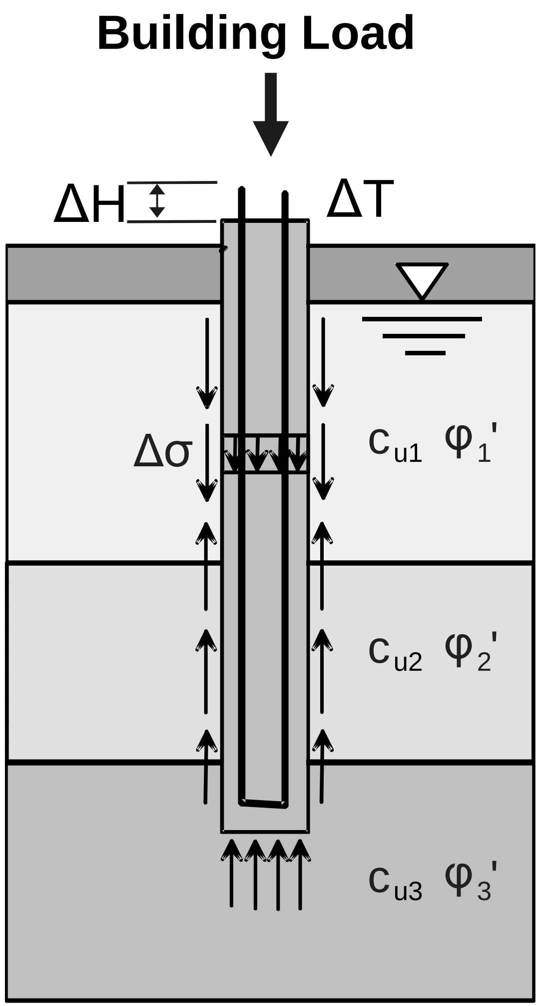


Geotechnical Pile Design Issues

Normal pile design considerations

ULS
- Stratigraphy and soil properties
- Shear / radial stresses
- End bearing
- Ult. pile load – settlement 10% pile dia.
- Factor of Safety

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



Additional thermal pile design considerations

ULS
- Thermal effect on soil strength.
  - OC soils - small
  - NC soils - large (–ve skin friction).

SLS
- Axial and radial pile expansion.
- Pile head fixity.
- Thermally induced axial stresses.
- Cyclic effects of thermal loading.
  - Daily / seasonal cycles

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2) Design Experience –
Design Tools and Back Analysis

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Design Tools - Experience

1. **Thermal Design - Preliminary stage**
   - GDA
   - EED
   - Case histories – 35W/m

2. **Pile Design – Detailed stage**
   - Additional stress in pile   OASYS “PILE”

3. **Raft / Pile / Soil interaction – Detailed stage**
   - Thermo/ Hydro/ Mechanical (THM) models - DYNA

4. **Back Analysis – Validate programs**

Back Analysis Experience
Combined load and thermal test
Lambeth College, London (2007)
Bourne-Webb et al, (2009) Geotechnique

- **Pile loading test**
- **Thermal Response Test (TRT)**
- **Cyclic thermal loads**
- **Instrumentation**
  - Fibre Optics – temp and strain.
  - Vibrating-wire strain gauges (VWSG).
  - Extensometers.
  - Thermistors.

Lambeth College - Test Layout

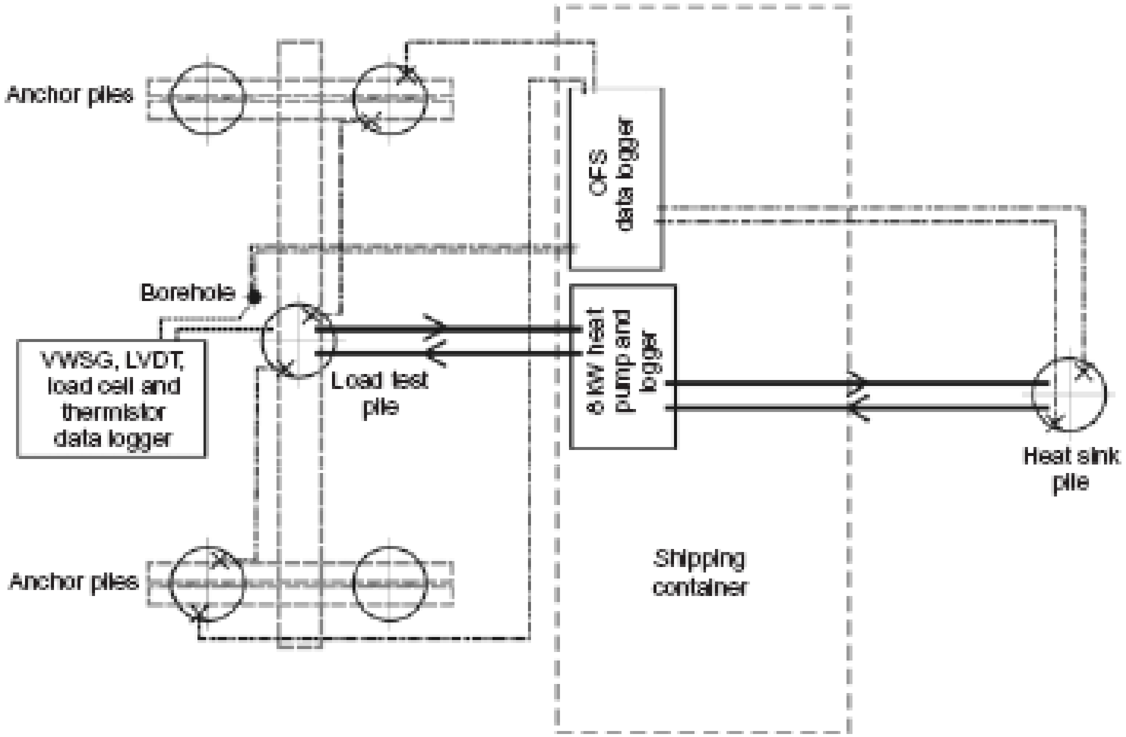
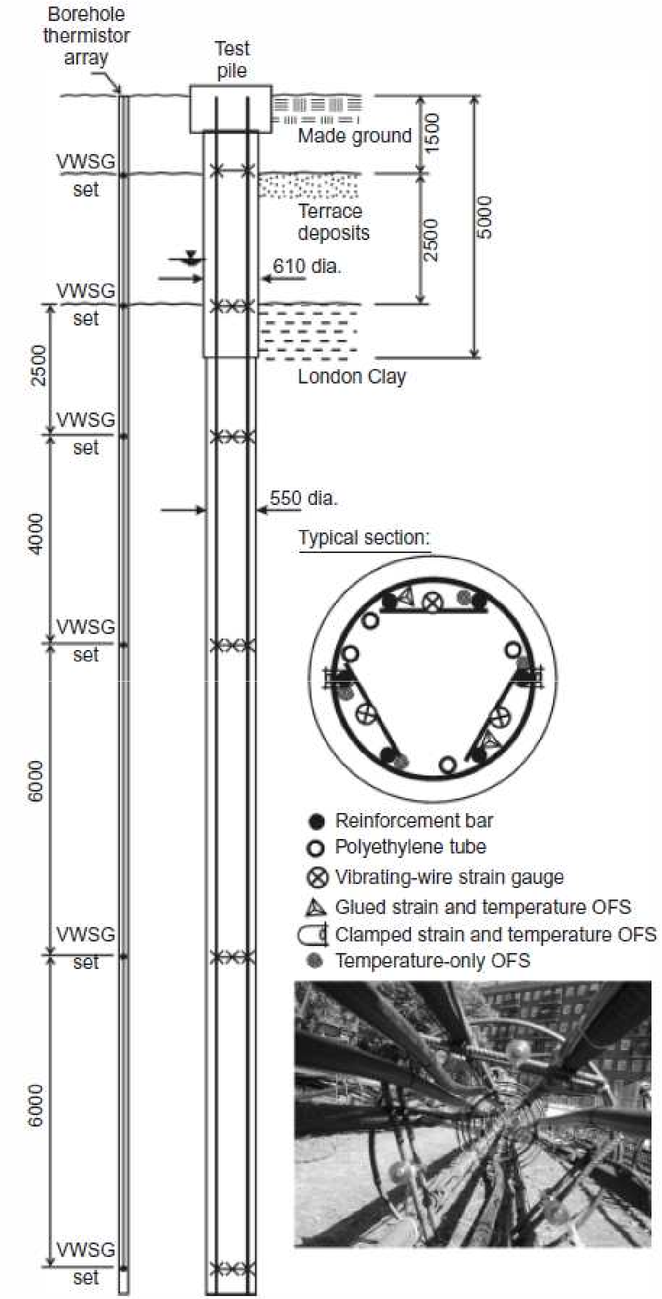


Fig. 2. Schematic layout of test components



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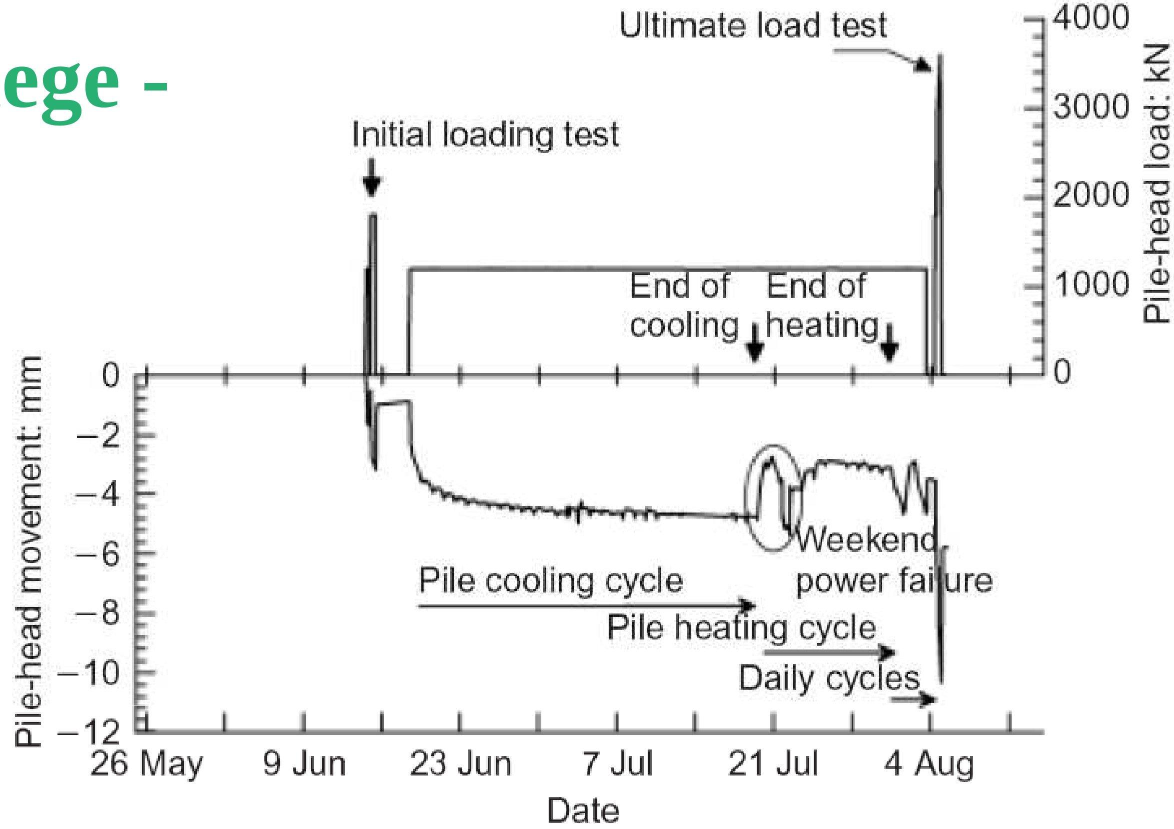
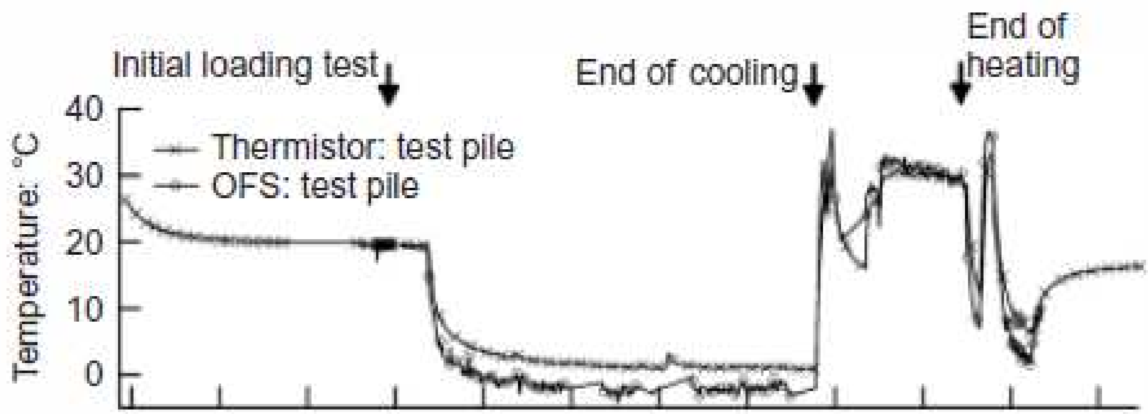
Lambeth College - Results





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Lambeth College - Back Analysis
PILE and LS DYNA - Input parameters

- **Made Ground / Terrace Gravel: Mohr Coulomb material, ϕ'= 36°, drained behaviour.**
- **London Clay: undrained behaviour, strength profile:**
  - 4m to 18m bgl: cu,top = 60 kPa; cu,bot = 184 kPa;
  - 18m to 30m bgl, cu,top = 184 kPa; cu,bot = 194 kPa

  α = 0.5, E/c_u = 600, ν=0.5, N_c = 9

  Pile Design:
  - $q_s = \alpha\, c_u$
  - $q_b = N_c\, c_u$
- **Pile : Elastic, E=40GPa**
- **Thermal expansion coefficient of pile = 0.85×10^{-5}**

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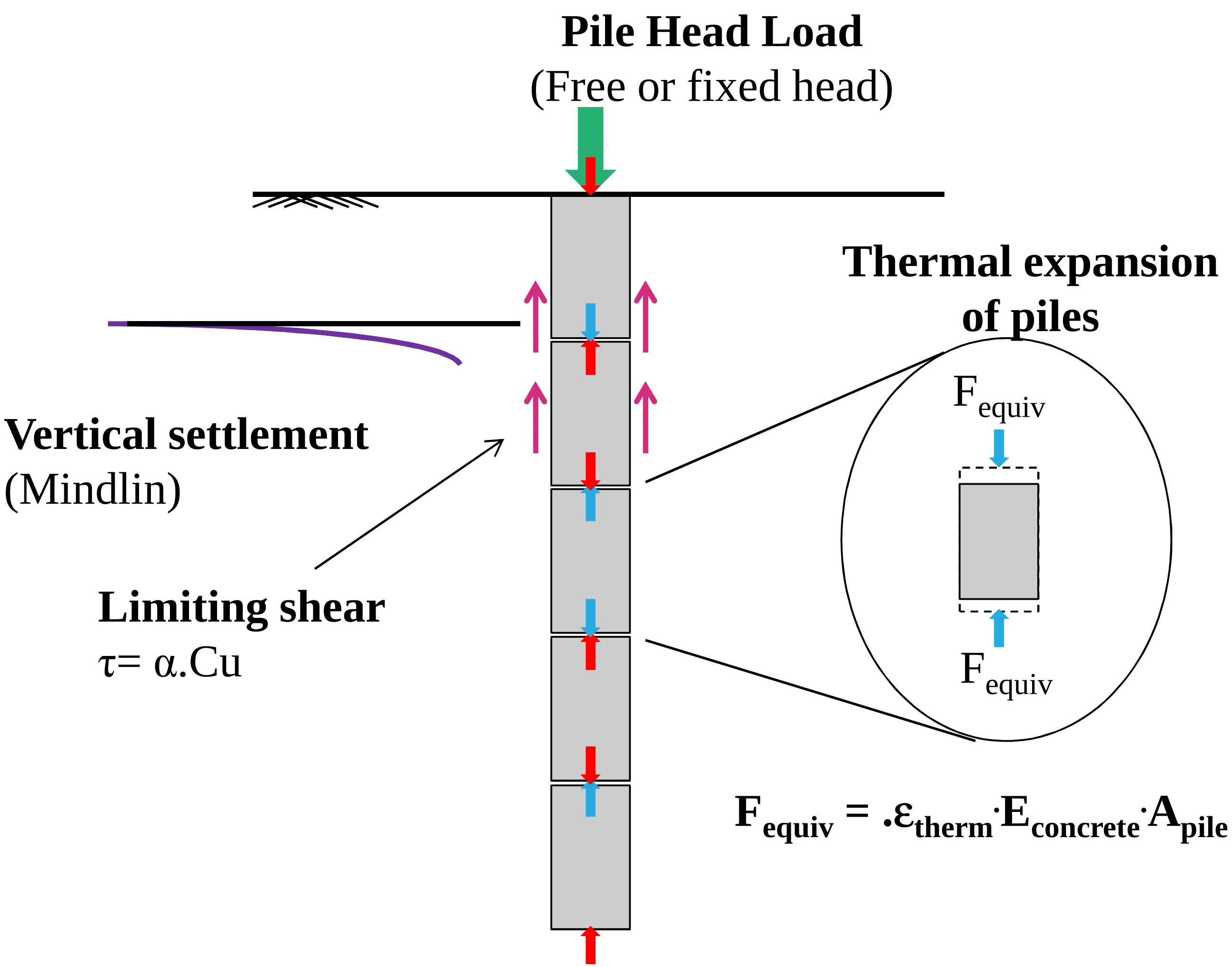
OASYS "PILE" T-S model



$$F_{equiv} = .\varepsilon_{therm} \cdot E_{concrete} \cdot A_{pile} \,.\, DT^{o}$$

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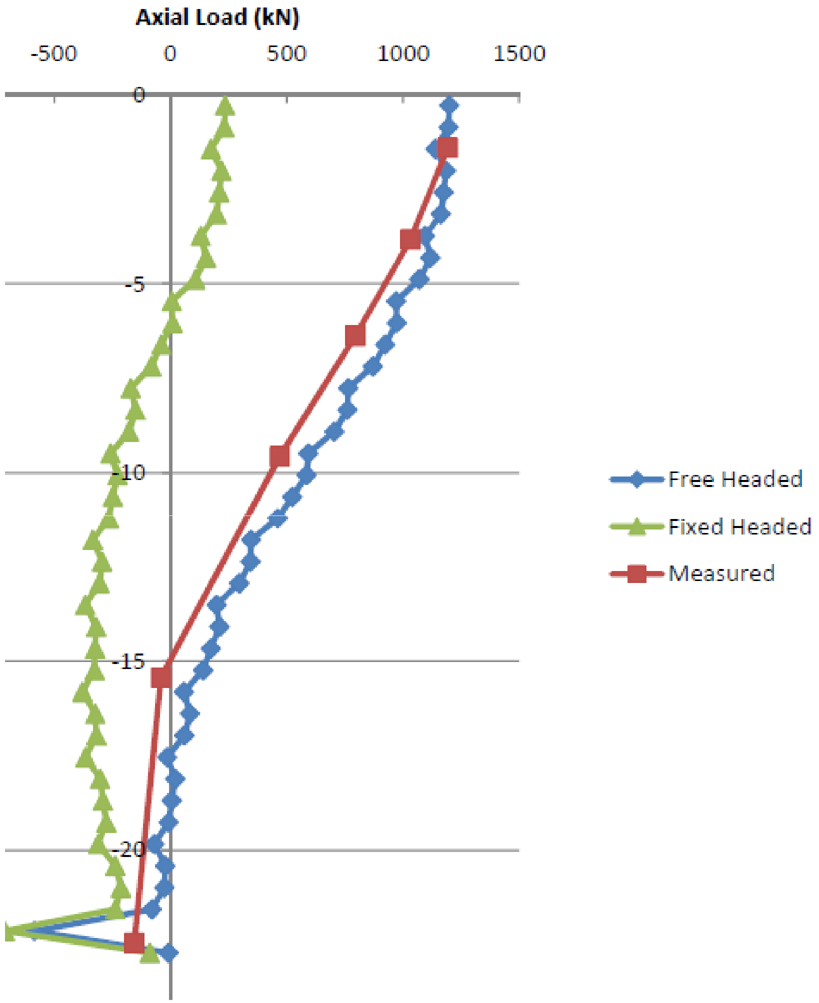
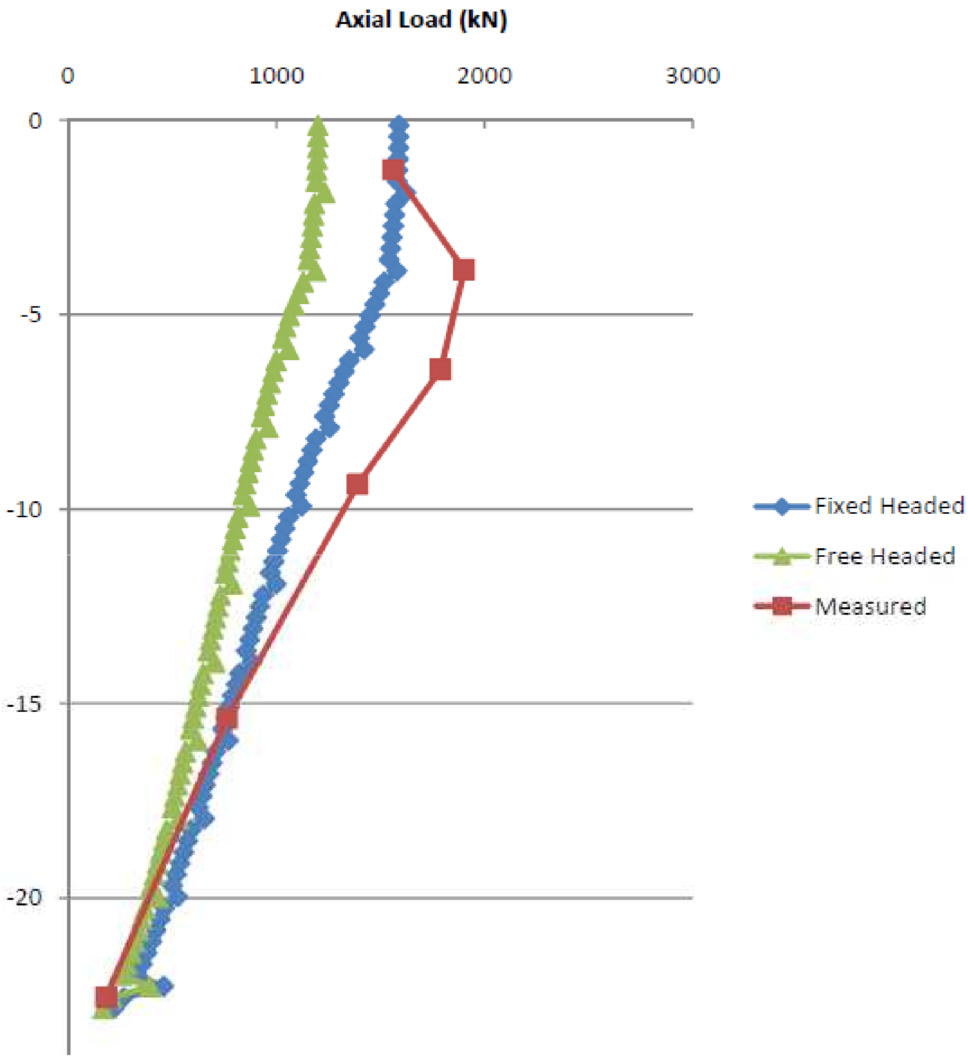
Back analysis – Oasys “PILE” Model



Cooling Phase



Heat Phase

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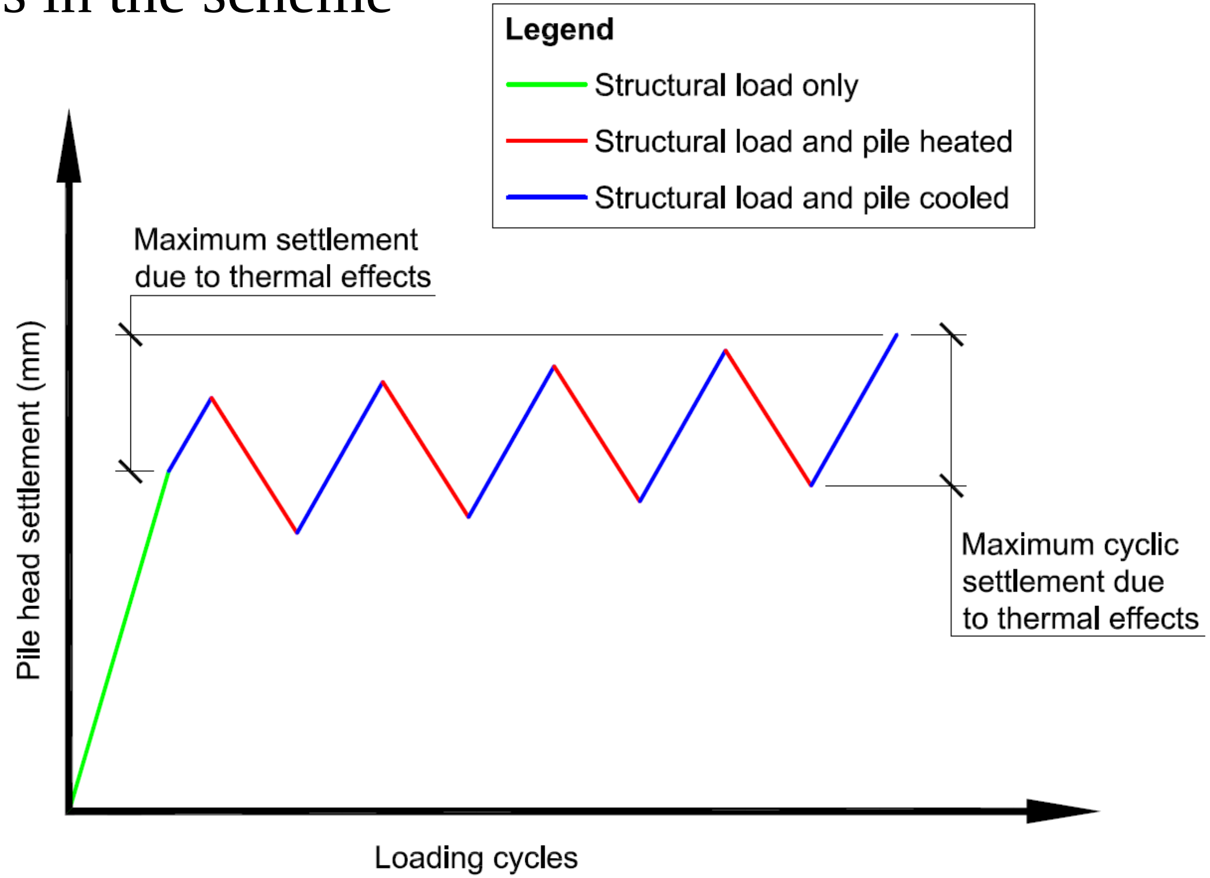
Impact on Structural Design
Settlement

- **Pile head fixity**
  - % of thermal piles in the scheme
- **Additional settlement due to thermal effects**
- **Cyclic movement due to heating & cooling**



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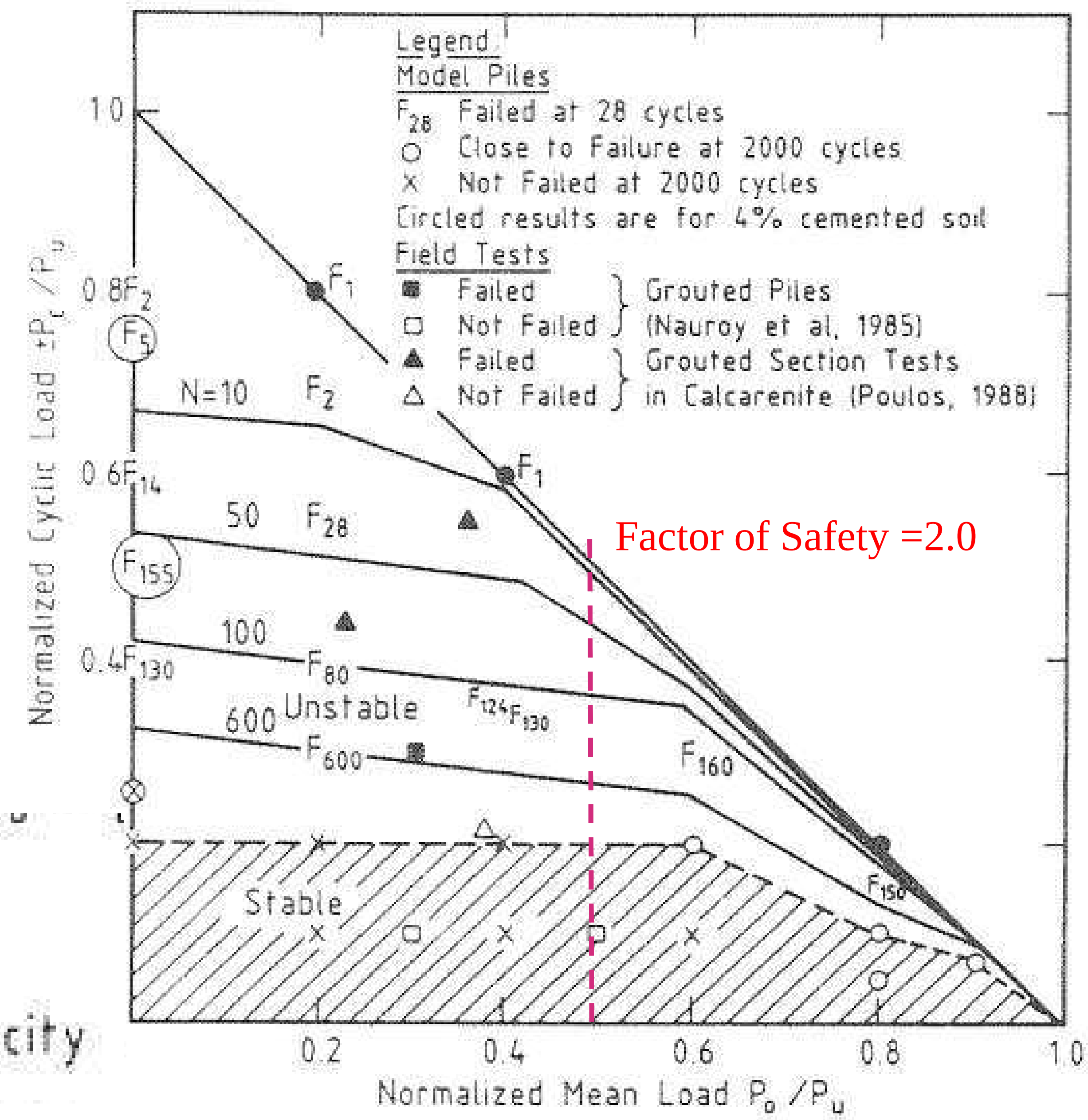
Thermal Cyclic Loading

- **Comparison with cyclic stability diagram (Poulos)**

- **Annual Cycle**
- **Daily Cycle**



P_c = Cyclic load
P_o = Mean load
P_u = Static load capacity

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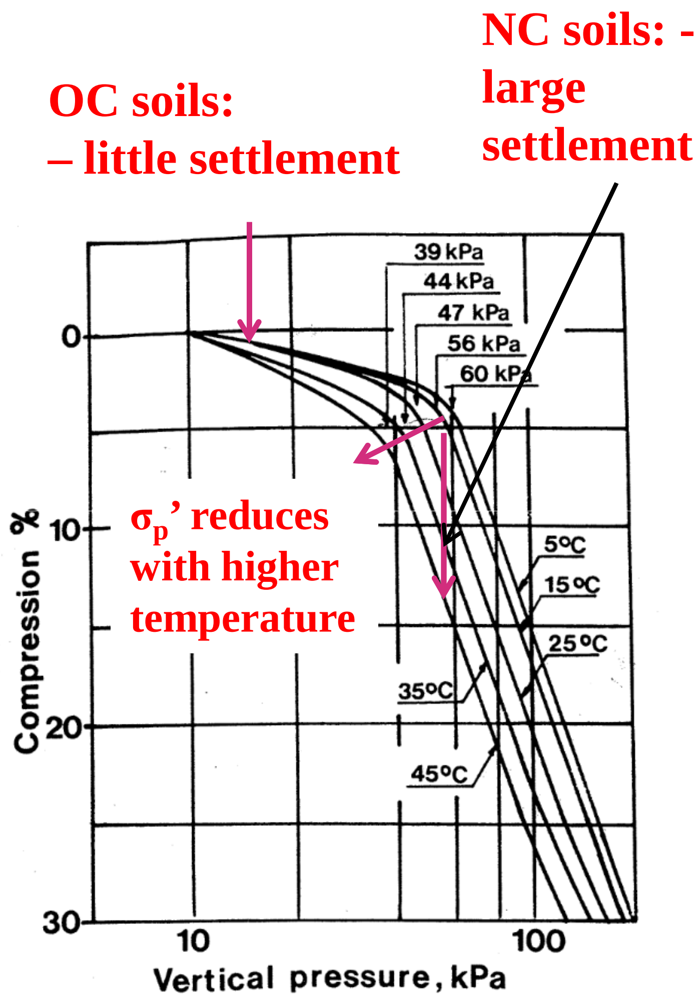
Normally / Over Consolidated Soils

- **Effects of heating soil**
  - Strength and stiffness reduces – from reduction in preconsolidation pressure (quasi-creep effect)
  - Consolidation regains the strength
  - OC soils – less effect
- **Undrained**
  - Excess pore pressures
- **Drained**
  - Consolidation – regains soil strength (increased strength when cooled)
- **DYNA THM model**
  - Used on OC soils.



(Eriksson, 1989)

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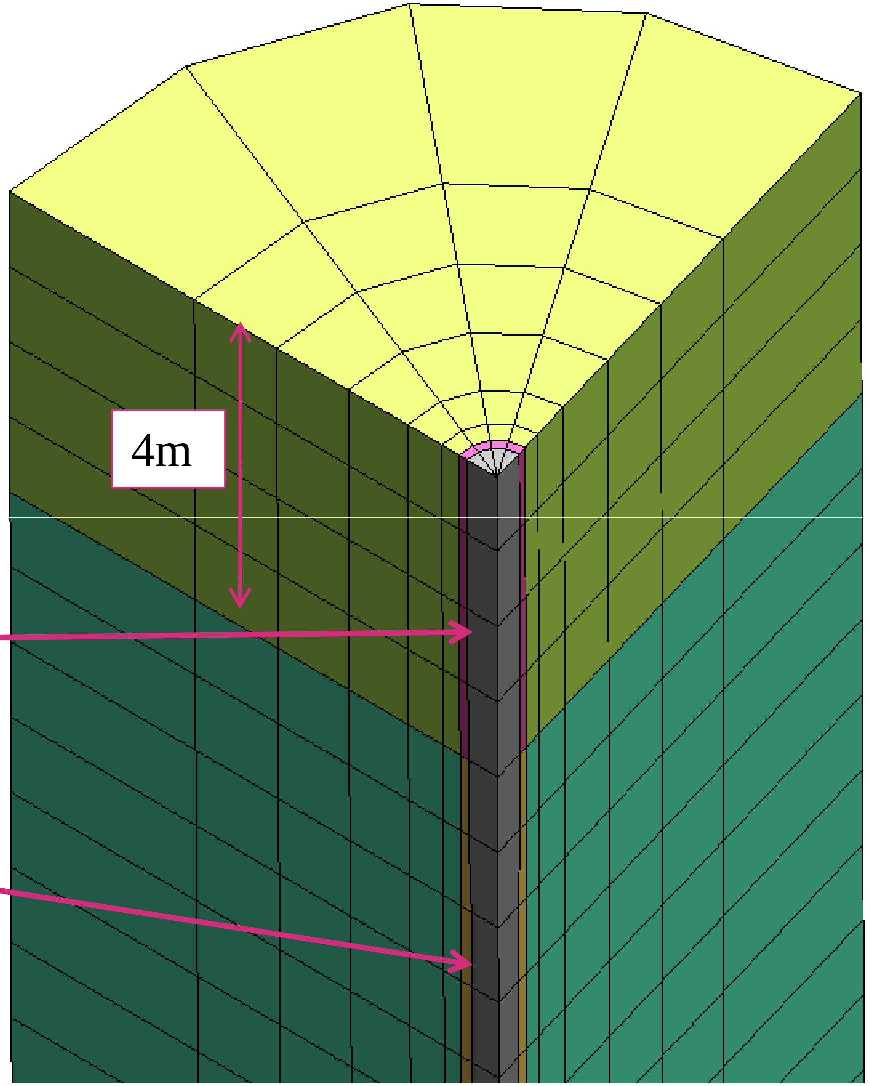
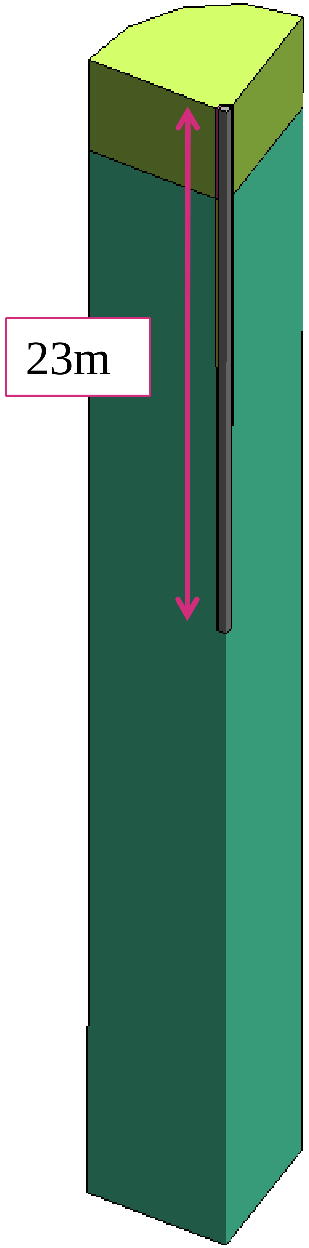
Comparison: LS DYNA – Oasys PILE



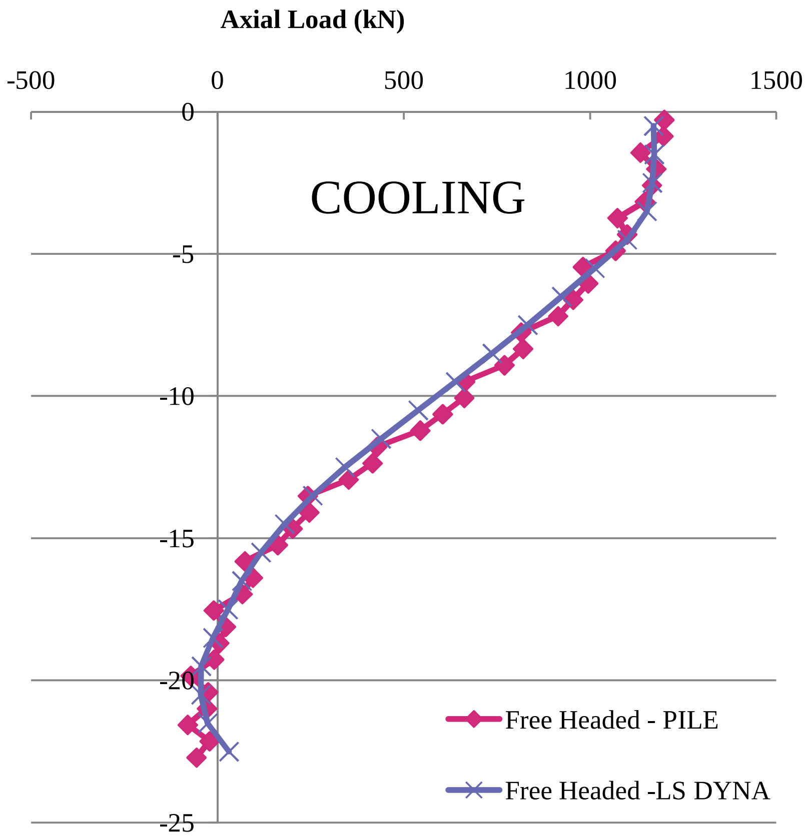
Top 5m of pile
has diameter
610mm

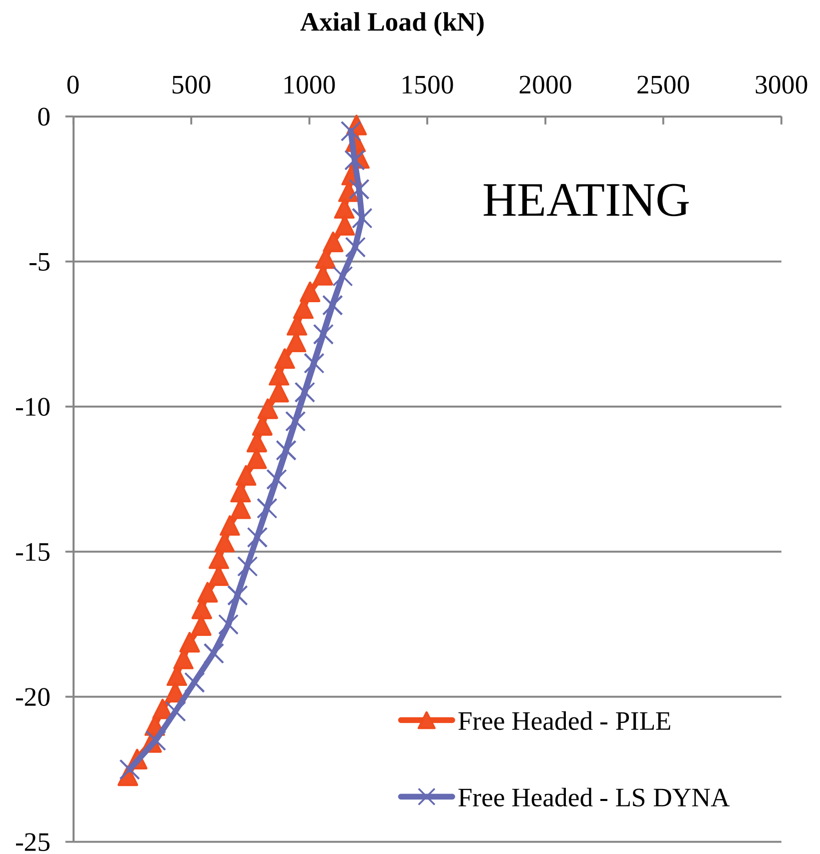
Remainder of pile
has diameter
550mm



Comparison DYNA and PILE

- **Same problem has been modelled in DYNA, results are compared below:**





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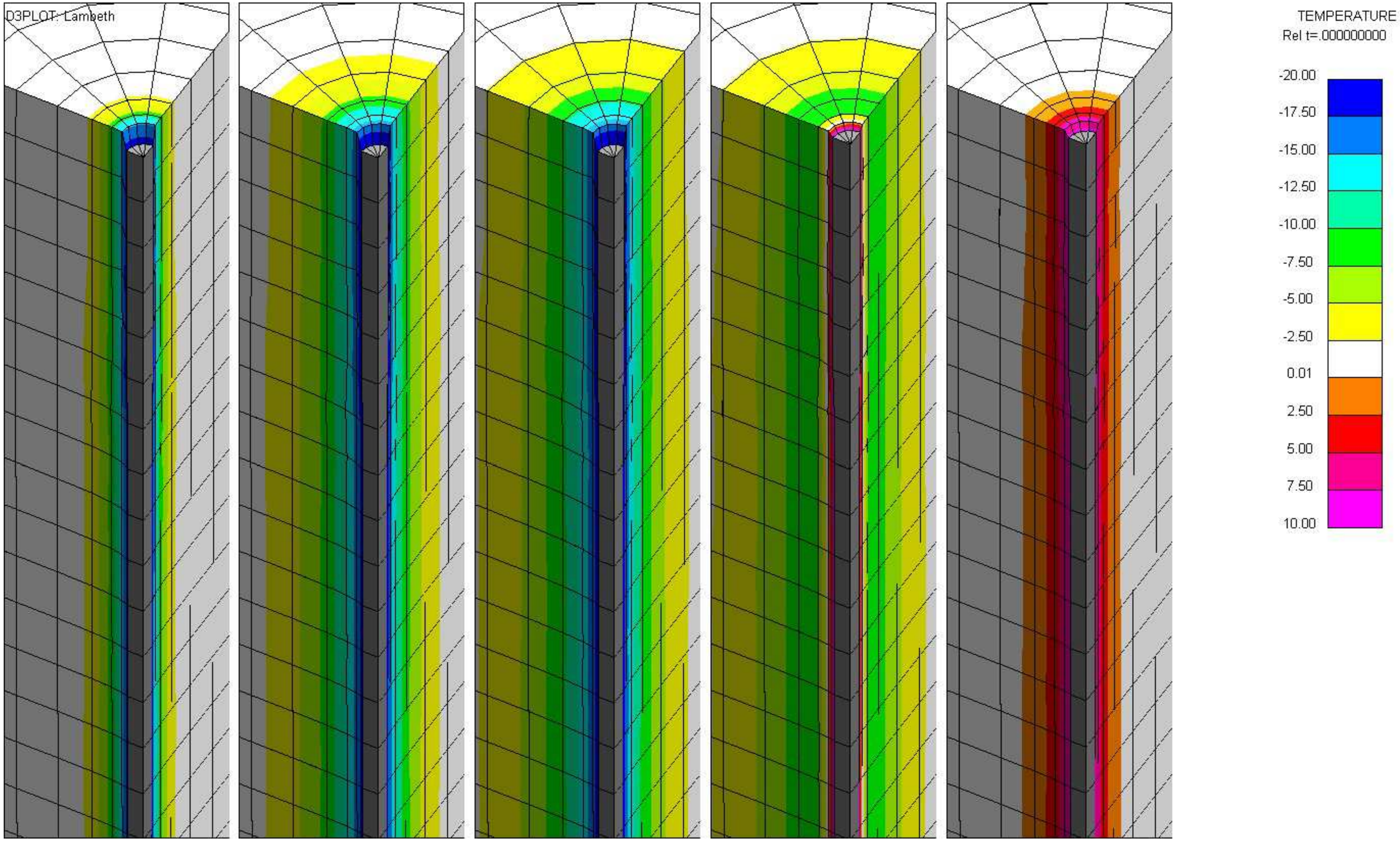
Temperature Change in Soil



Near start of cooling	Mid-way through cooling	End of cooling	Near start of heating	End of heating

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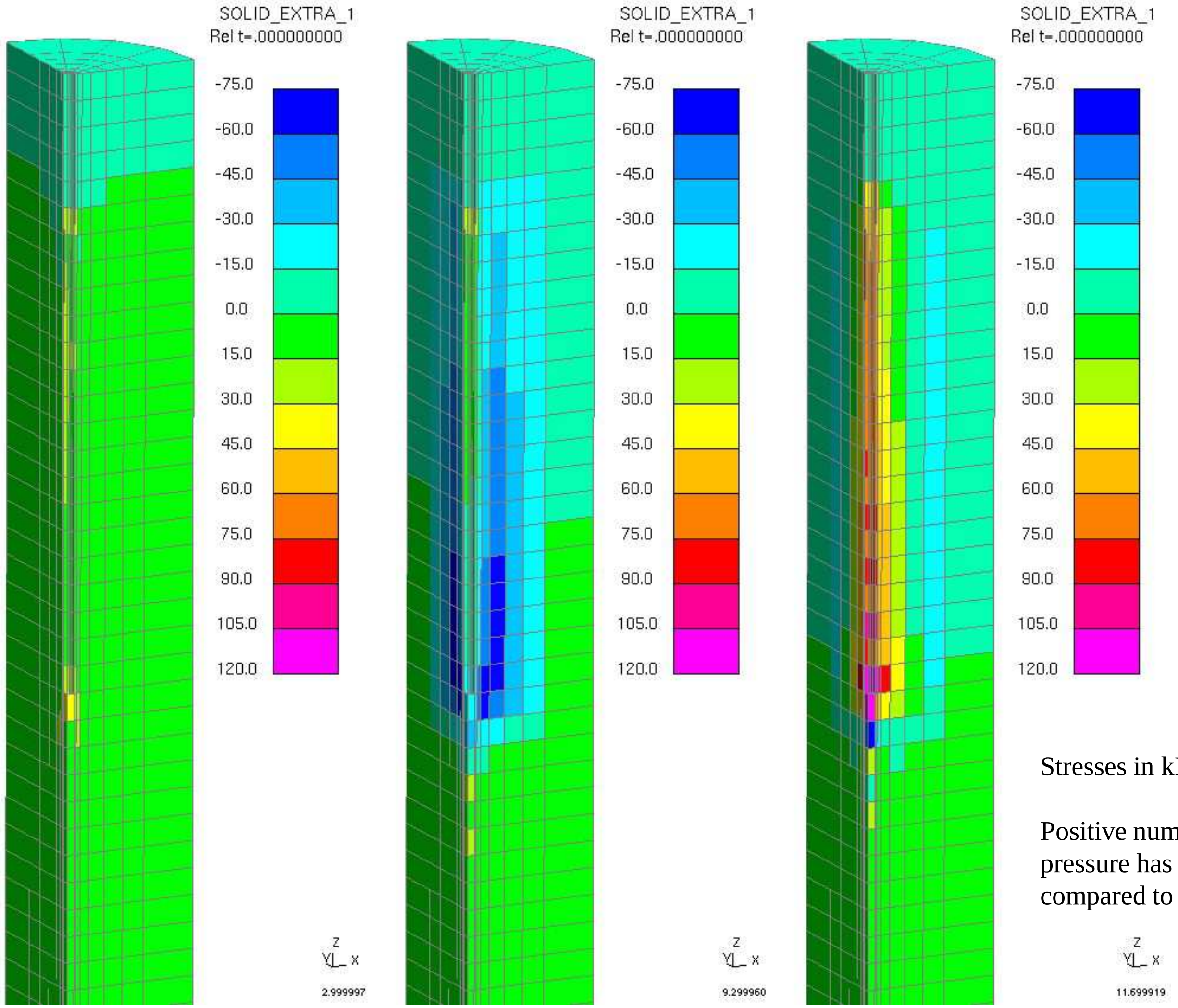
Pore Pressure Change – (Undrained)

After reload | **End of cooling** | **End of heating**



Stresses in kPa, relative to initial stress state.

Positive numbers mean that the pore pressure has increased (more compressive) compared to the initial stress state

Model: /data3/rsturt/ENERGY_PILES/LAMBETH_JAN2012/Aw_CURVE_SLIP/Lambeth_12_AwCur.key

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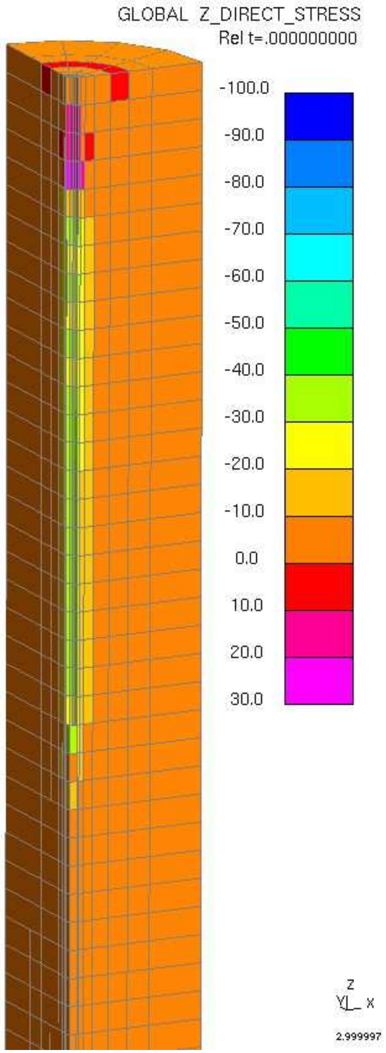
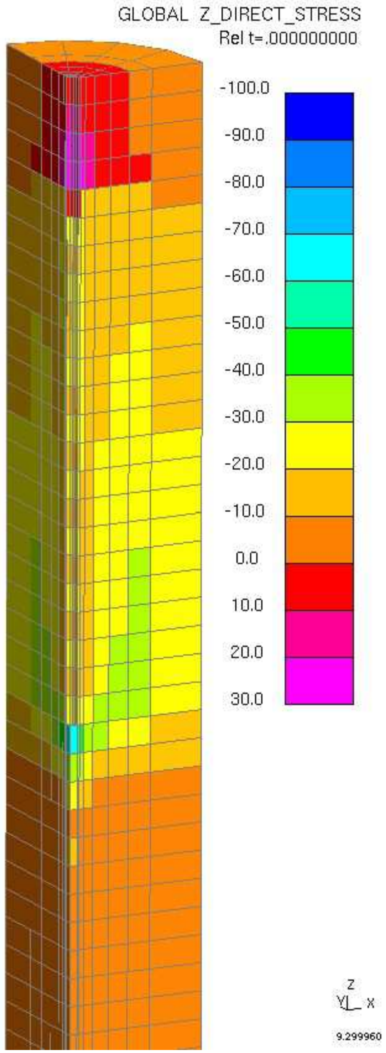
Vertical Effective Stress Change (Undrained)

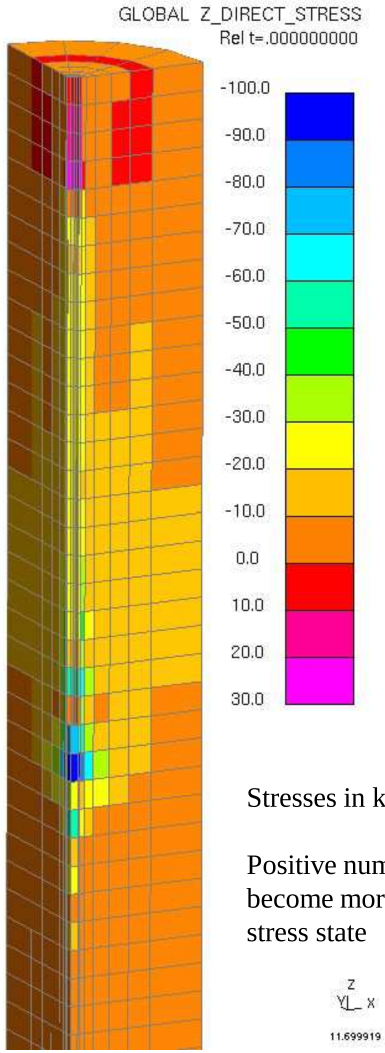
After reload



End of cooling



End of heating



Stresses in kPa, relative to initial stress state.

Positive numbers mean that the stress has become more tensile compared to the initial stress state

Model: /data3/rsturt/ENERGY_PILES/LAMBETH_JAN2012/Aw_CURVE_SLIP/Lambeth_12_AwCur.key

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3) Design Stage Experience

Preliminary Design - Feasibility

Detailed Design – for Construction

Preliminary Design

- **M&E - Thermal loading – Monthly estimate**
  - Generally very crude and an over estimate.
  - Are heating and cooling loads balanced over the year?
- **Consider geology -** Previous experience
- **Assume max heating/cooling –** 35W/m of pile (Brandl)
- **Review pile layout. –** Need pile length
- **Pile types -** thermal pile options?
- **Run thermal heat pump model - long term temp?**
  - EED – <600mm piles - <2 loops
  - GLD
- **Additional pile loads -** thermal expansion – PILE**.**

Detailed Design

- **Thermal loads –** Evolve - pile interface > 4 degree C
- **Consider hottest pile – Use OASYS PILE**
- **Large Piles or Piled raft – Use DYNA**
- **Pile thermal expansion and contraction**
- **Slab design – manifold locations**
- **Thermal cyclic loading**
- **NC clays - ?**

London Piled Raft - DYNA model

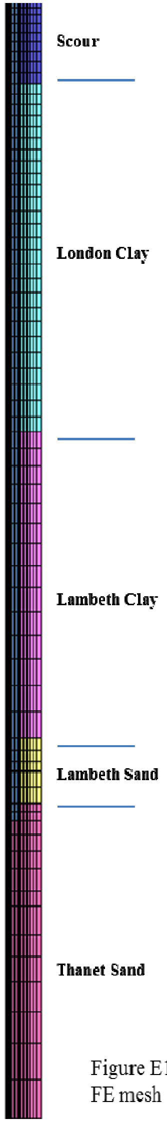
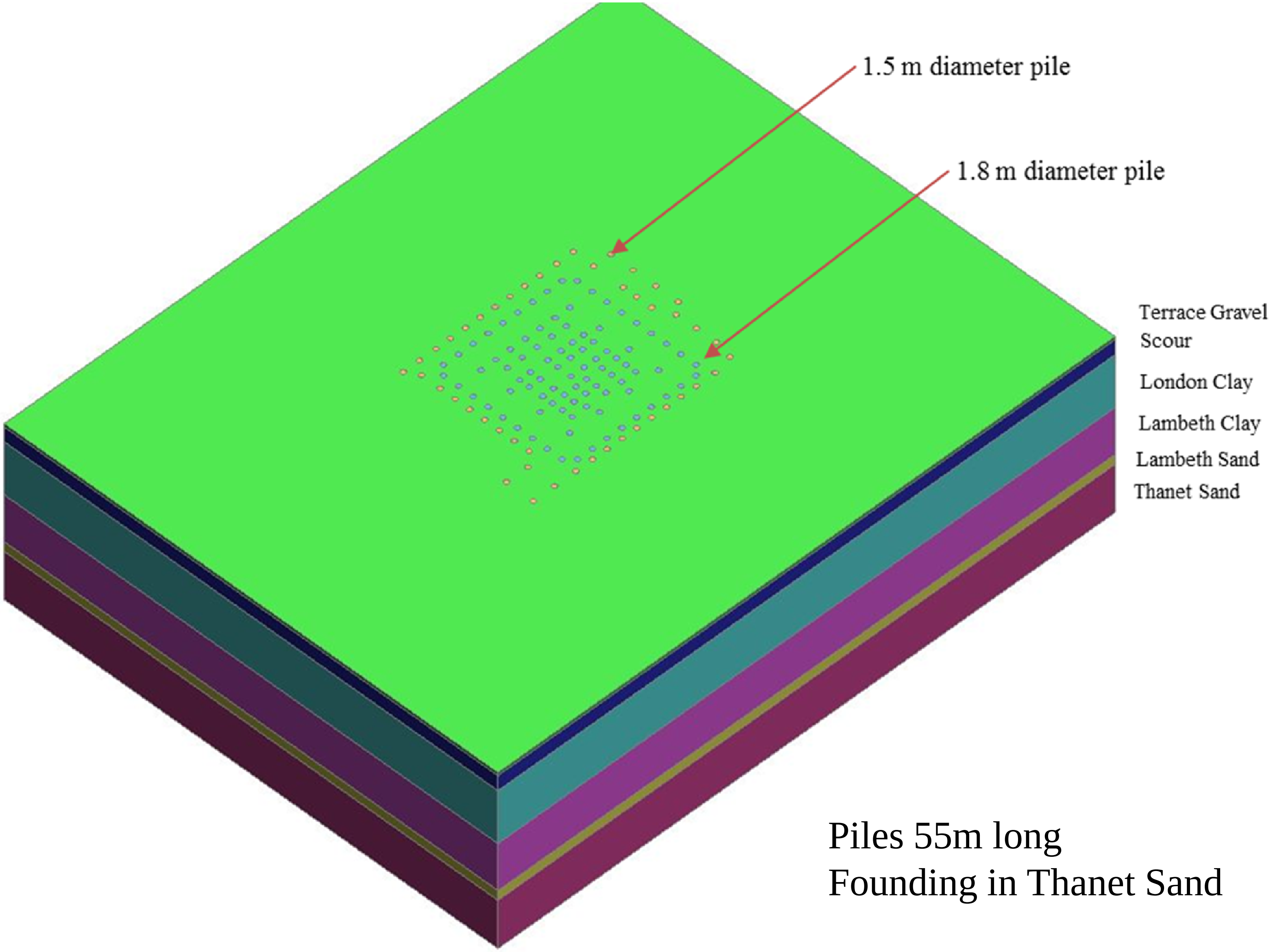


Figure E1.5.3
FE mesh – sid



Piles 55m long
Founding in Thanet Sand

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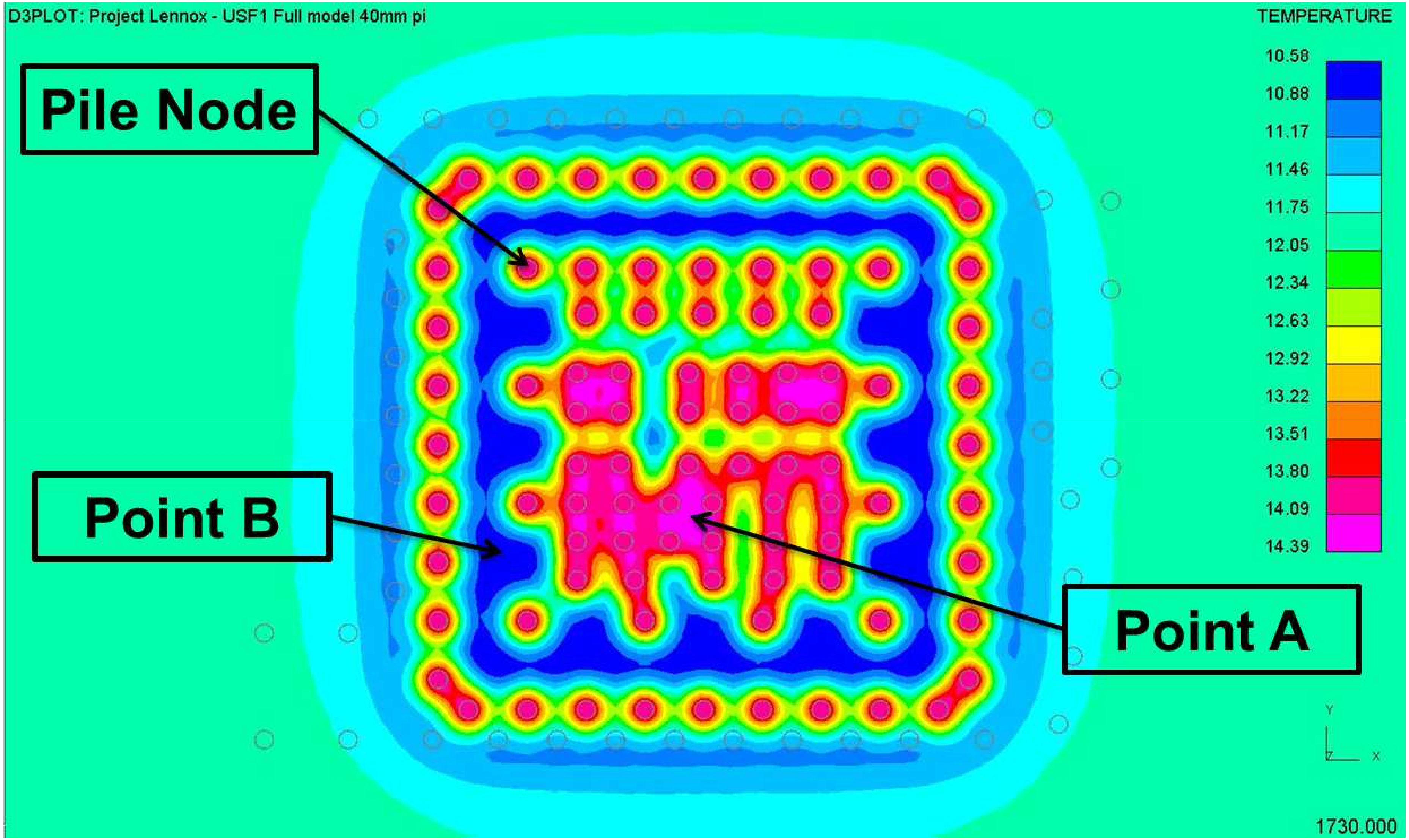
Predicted Temperature - Summer



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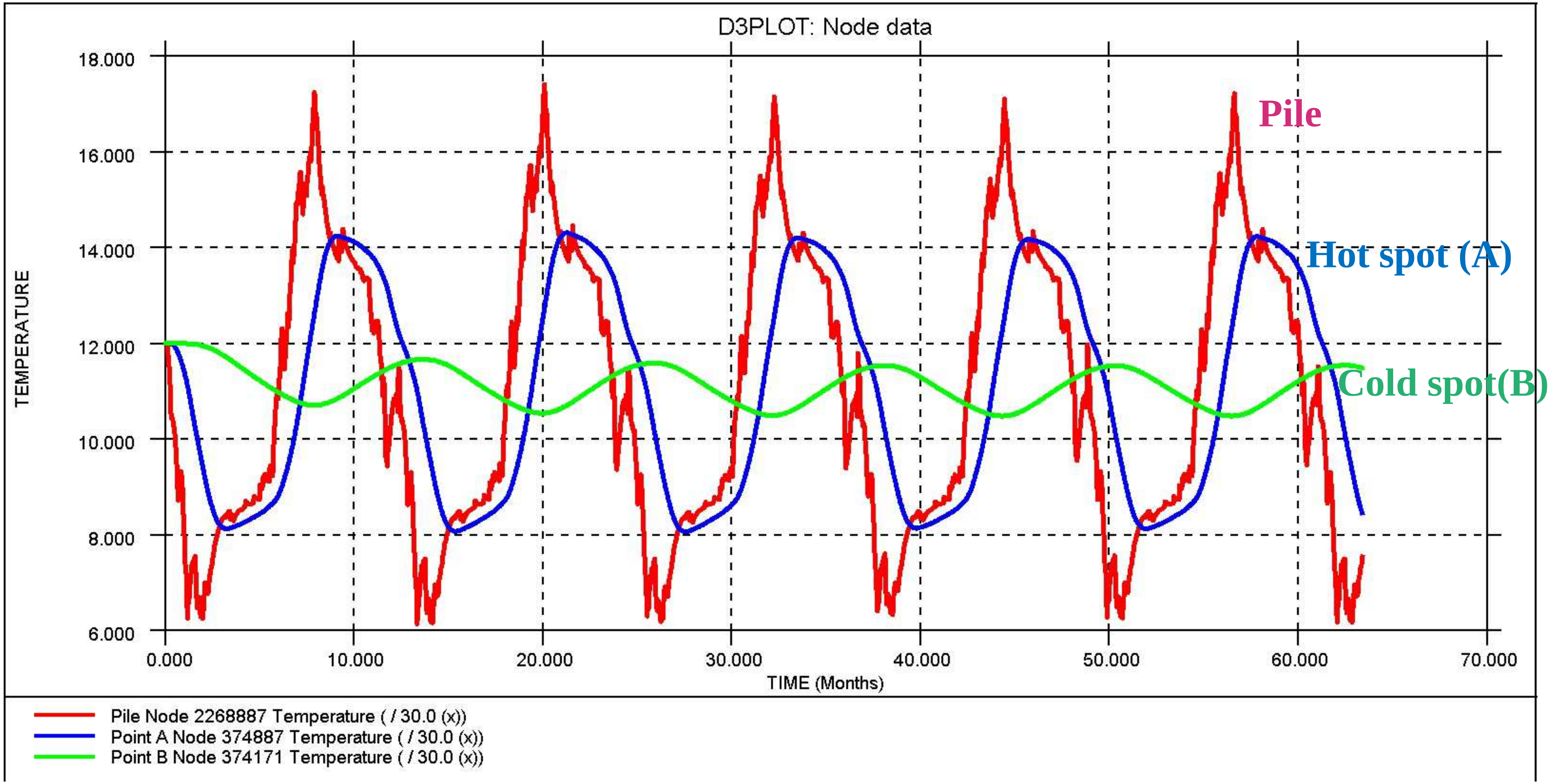
Temperatures – Actual pile grid

- **DYNA predictions**



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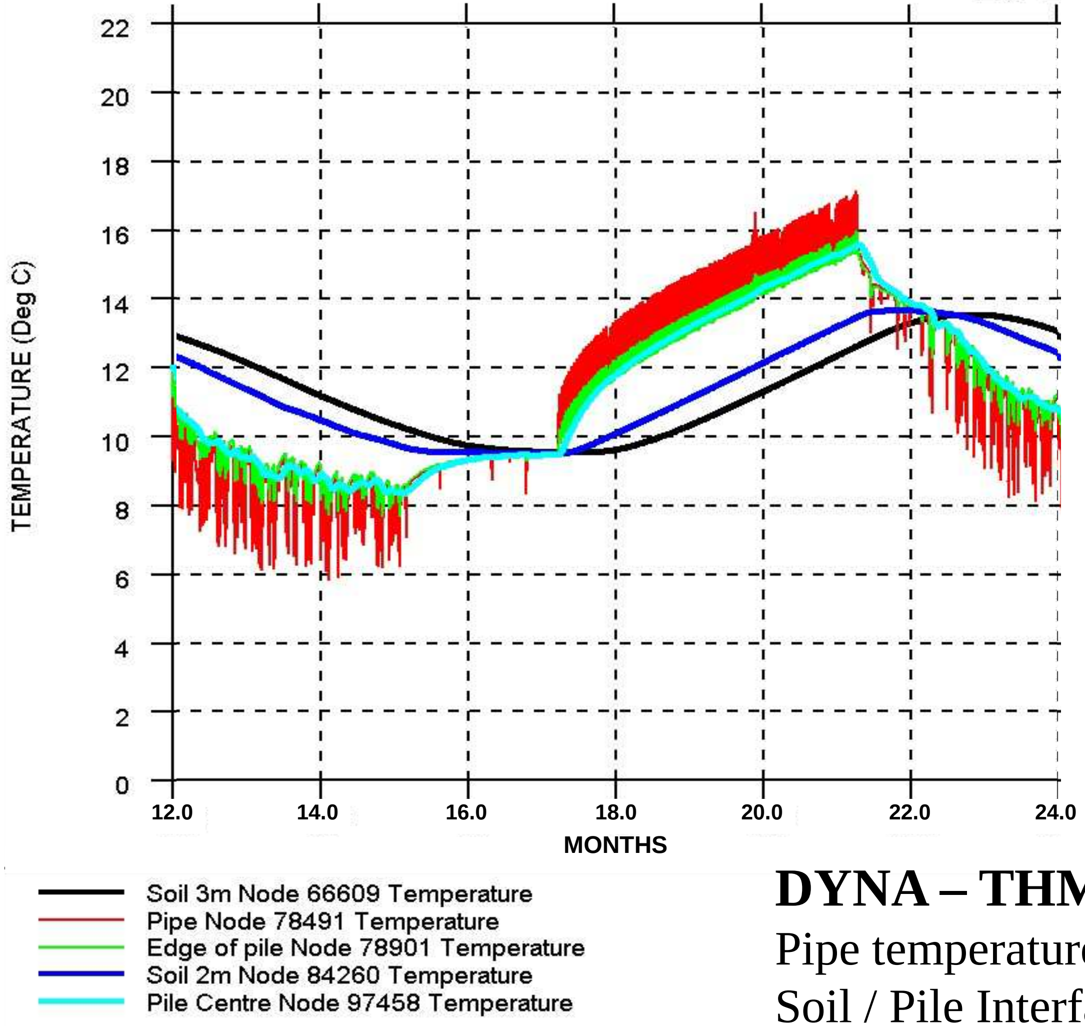
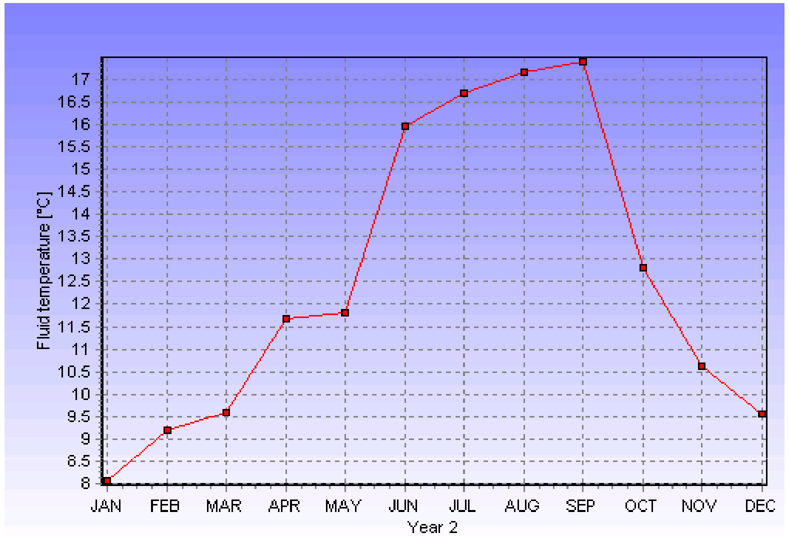
DYNA – Temperatures - Pile and soil EED comparison





Earth Energy Designer (EED)

Fluid temperature

Preliminary design

DYNA – THM

Pipe temperature

Soil / Pile Interface – 2^{o}C less then pipes

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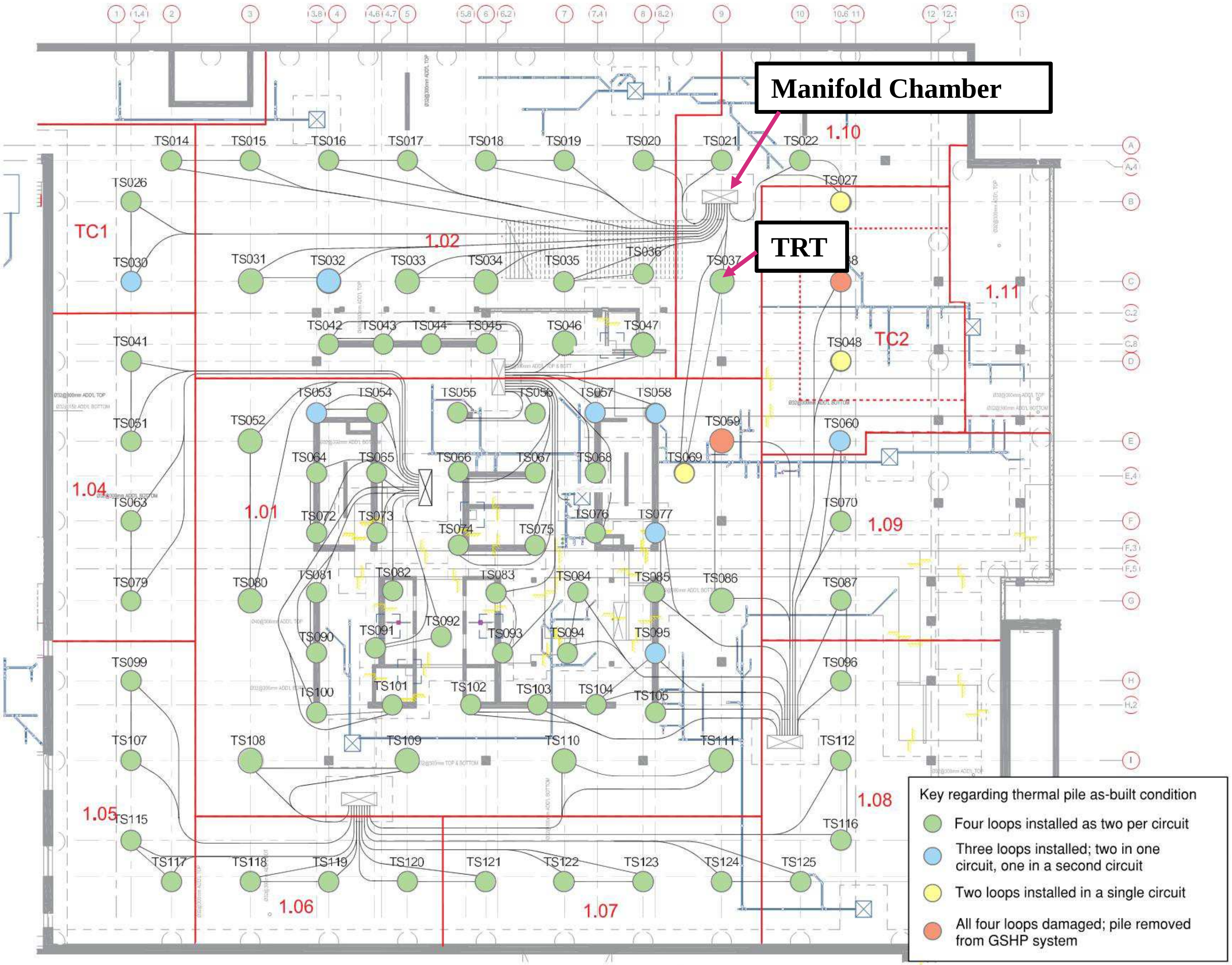
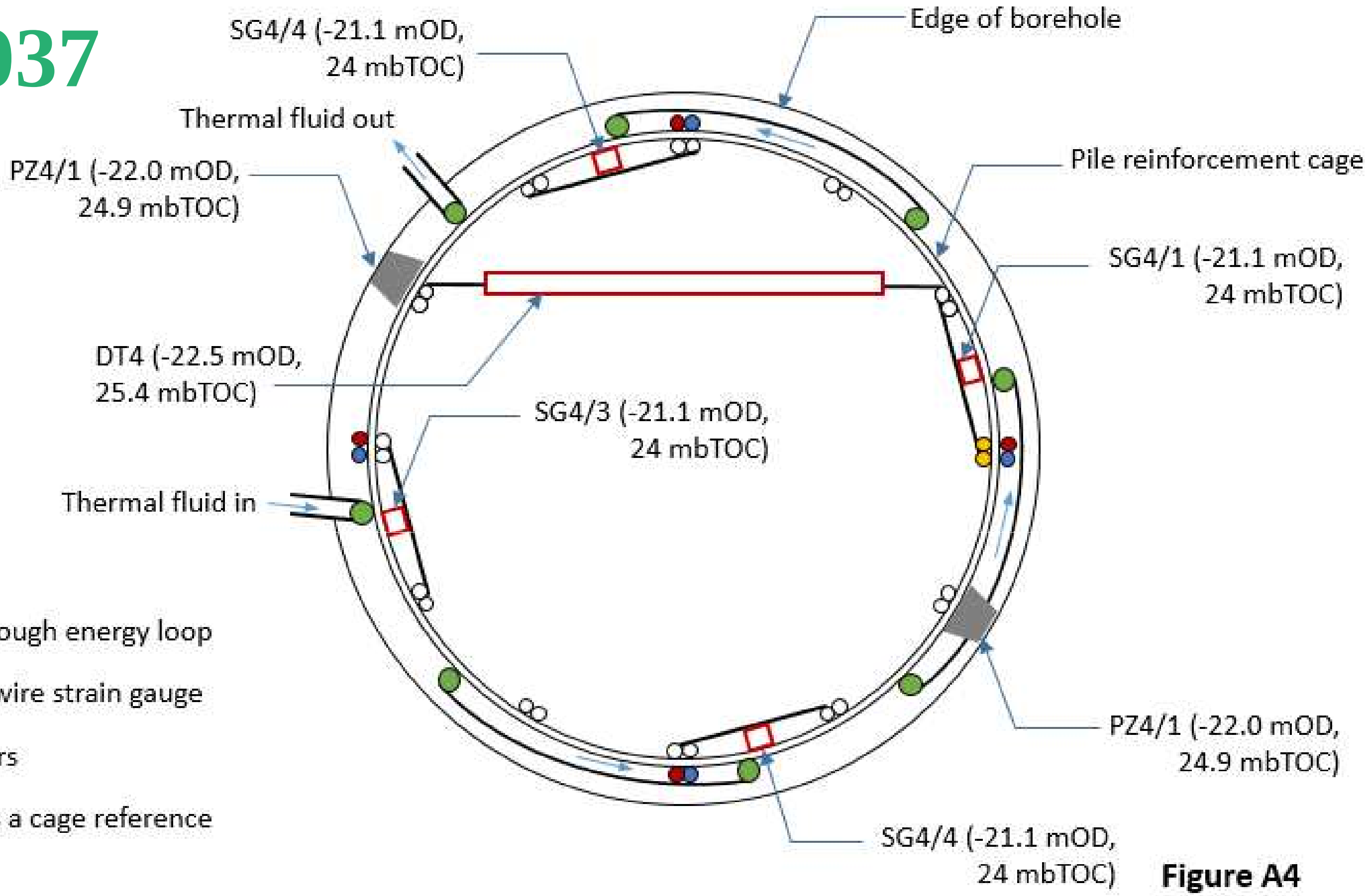
Header Pipes and Manifold Chambers



Thermal Response Test (TRT) Instrumentation
Pile TS 0037



Legend

- Flow direction through energy loop
- Vertical vibrating wire strain gauge
- Reinforcement bars
- Bar marks used as a cage reference
- Geothermal loop
- Fibre optic strain gauge
- Fibre optic thermistor
- Pore water pressure transducer (set into concrete block spacer)
- Horizontal vibrating wire strain gauge

Figure A4
As built thermal
instrument confi
Plan view of Arra
- 21.1 mOD, 24 m
top of cage [mbT

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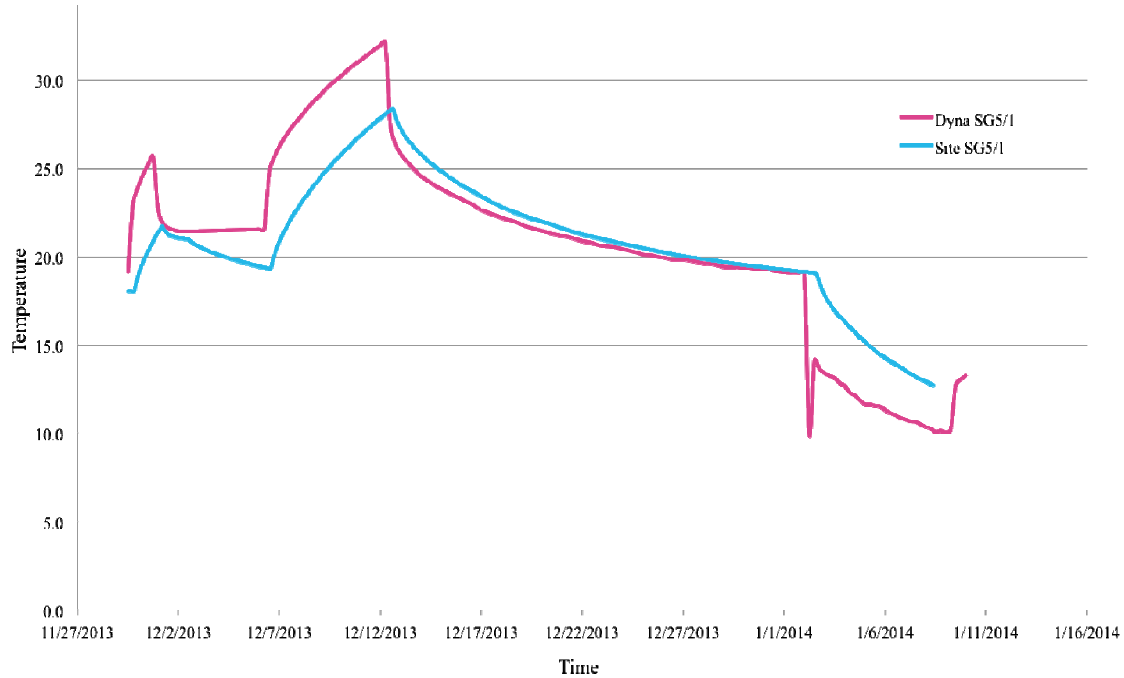
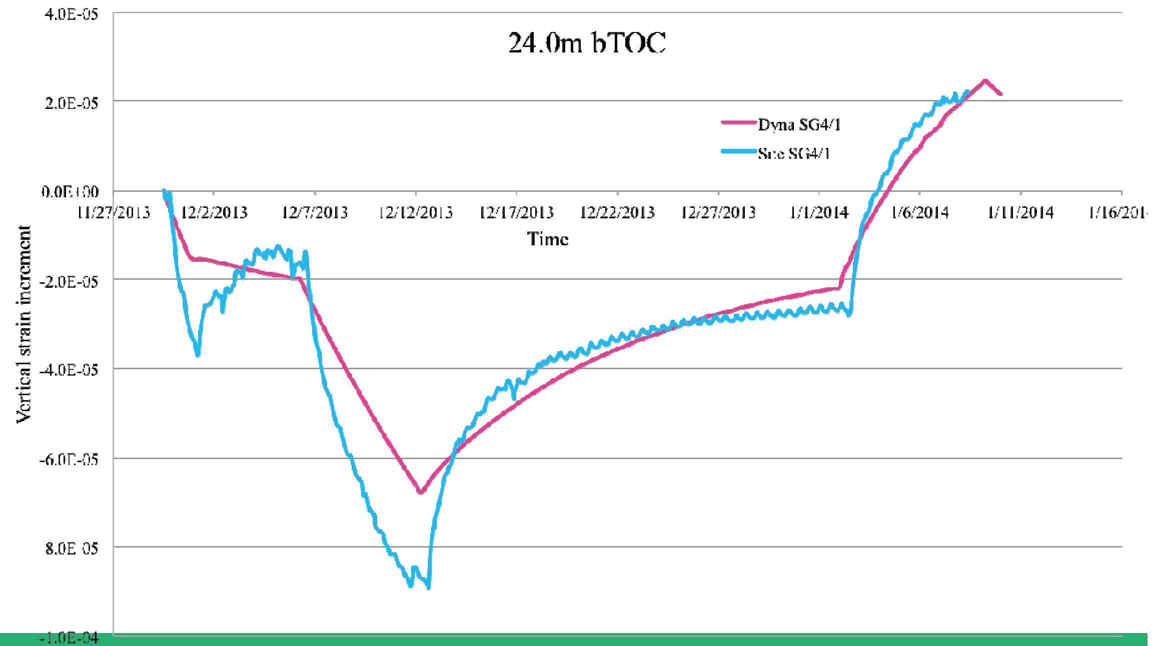
TRT – Comparison with DYNA





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4) Construction Experience

How to make construction cheaper ?

In UK the GSHP installations are reducing

Housing – ASHP / Solar PH /

Buildings – Cooling dominated – Insulation very good.

Bored piles - Short cages

CFA Piles – Max installation depth

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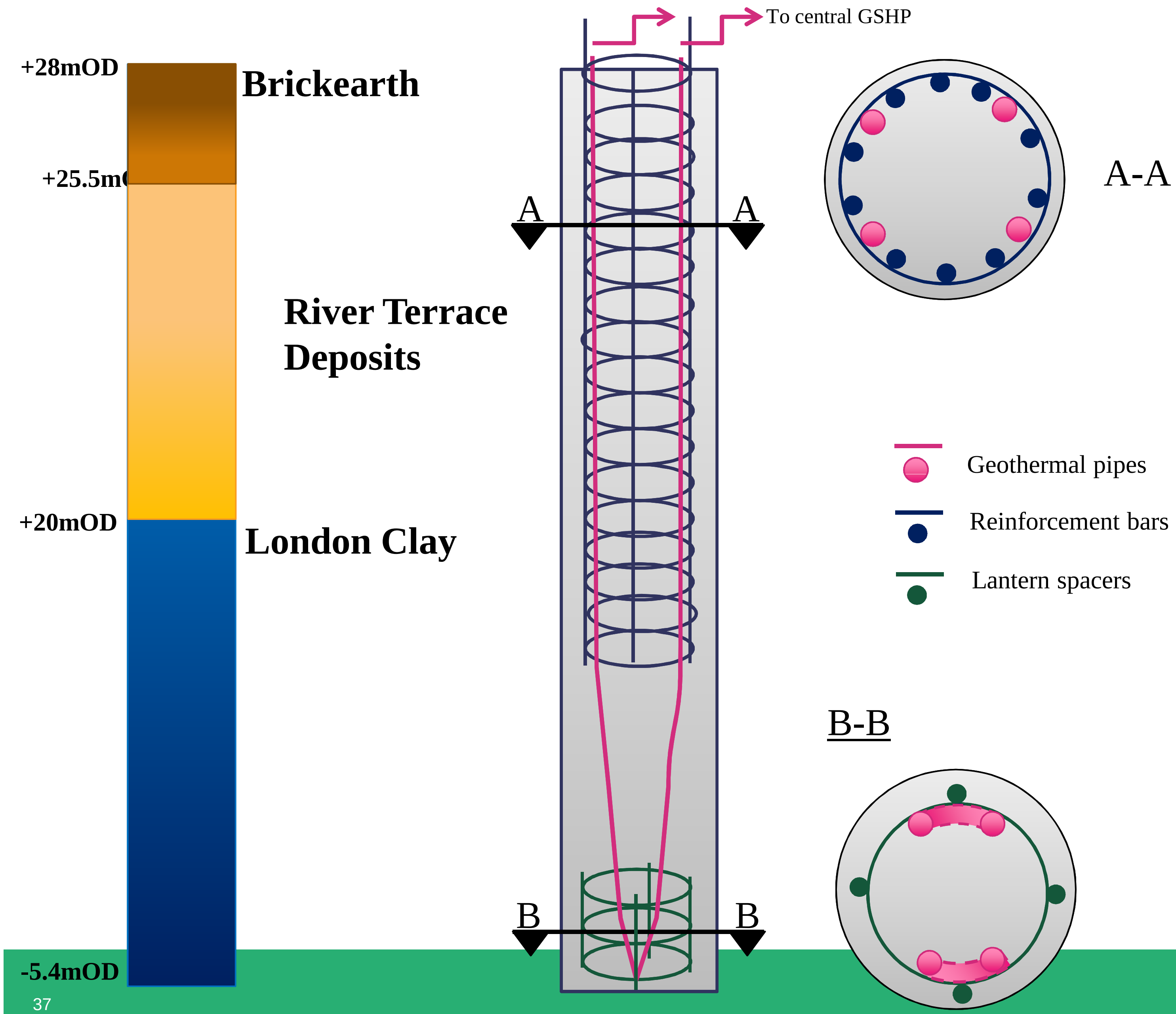
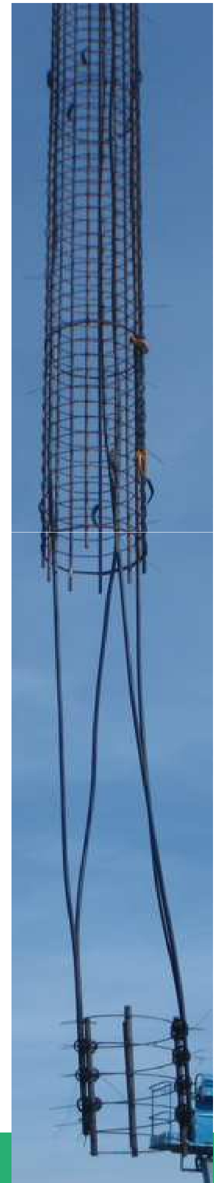
West end Green – Bored piles - Short cages





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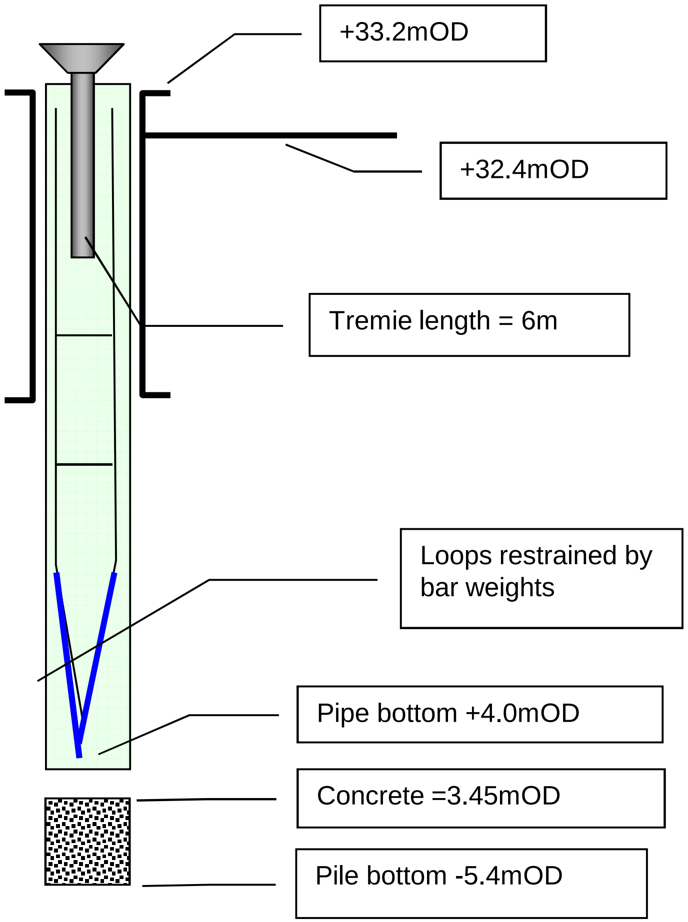
Scratch Test Trial – Freefall Concrete (2010)

Test set-up



Photos from test

Bar weights prior to testing

Ubend after test

Upper pipe after test

Lower pipe after test

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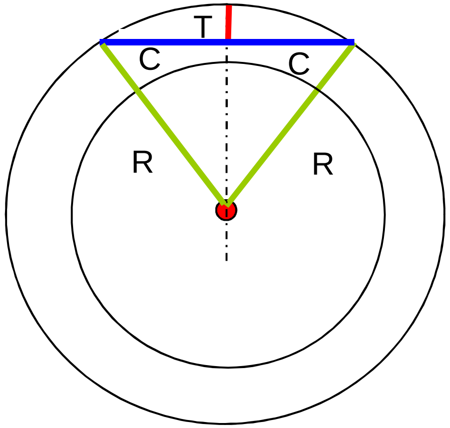
Scratch Depth

- **Assessment of damage**
  - Par off pipe until scratch just disappears
  - Measure pared width (2C)
  - Calculate scratch depth



2C – chord length (mm) - measured;
T – Depth of the scratch (mm) - calculated
R – radius of the pipe – measured

Protect to 1.5m above U-bend

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CFA Piles – U-Tube Installation

- **CFA piles (600mm dia)**
  150 No up to 25m depth
- **Loops - 4 pipes x 32mm dia**
- **Pushed with 1 x T32**

Plunging used T32 bar + 4 pipes (2 loops)

- **Heating - 188kW**
- **Cooling - 117kW**

Trimming

Cage and header pipes

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5) Thermal Walls

Thermal Effect on Moments and Prop Forces?

Crossrail

Thermal expansion of soil – increased earth pressures

Diaphragm walls

Secant piles

Sheet pile systems

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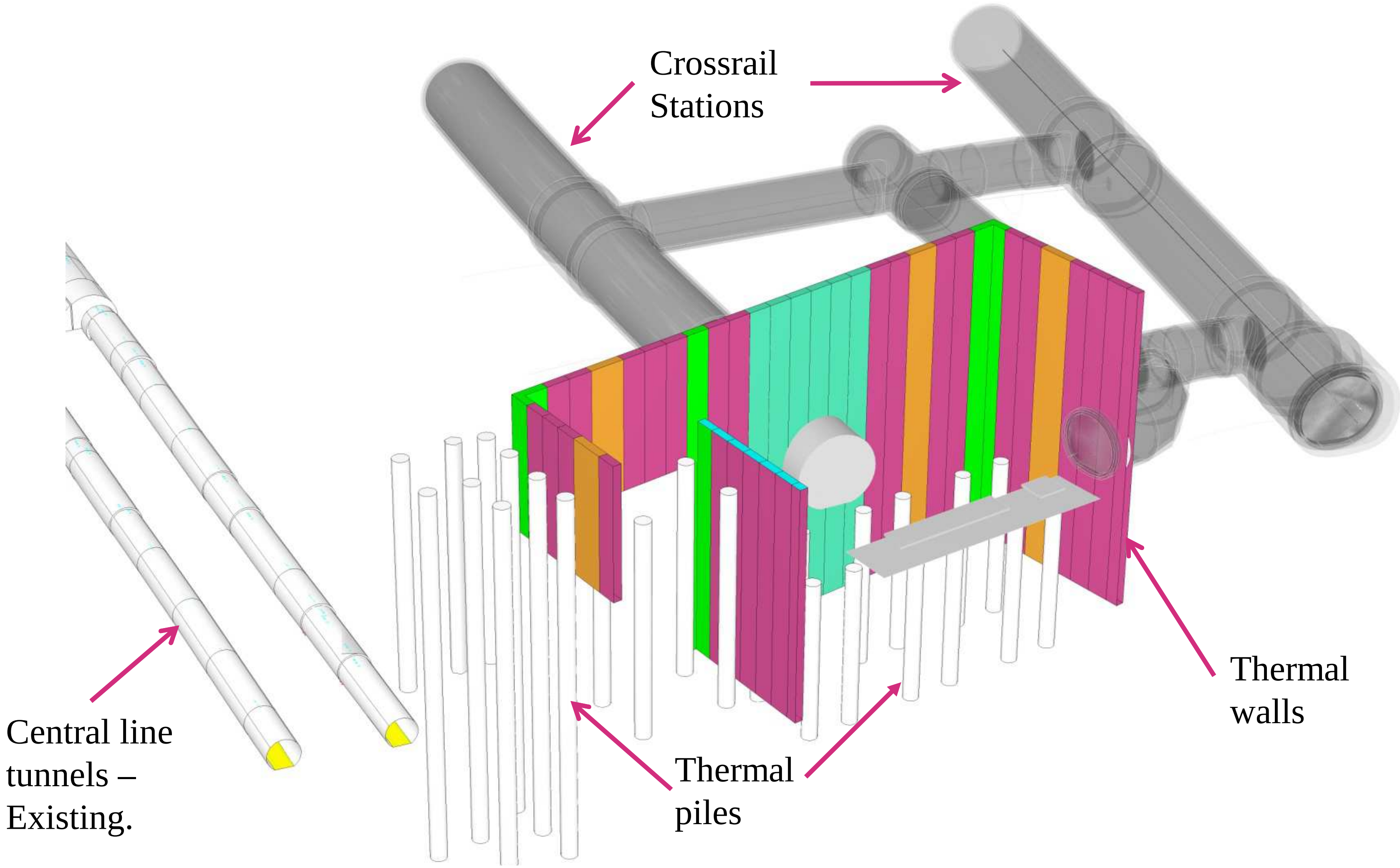
Thermal Walls –
Crossrail Dean Street Box



No Long Term Effect on Force and Movement

- **<u>Soga et al, (2015).</u>**

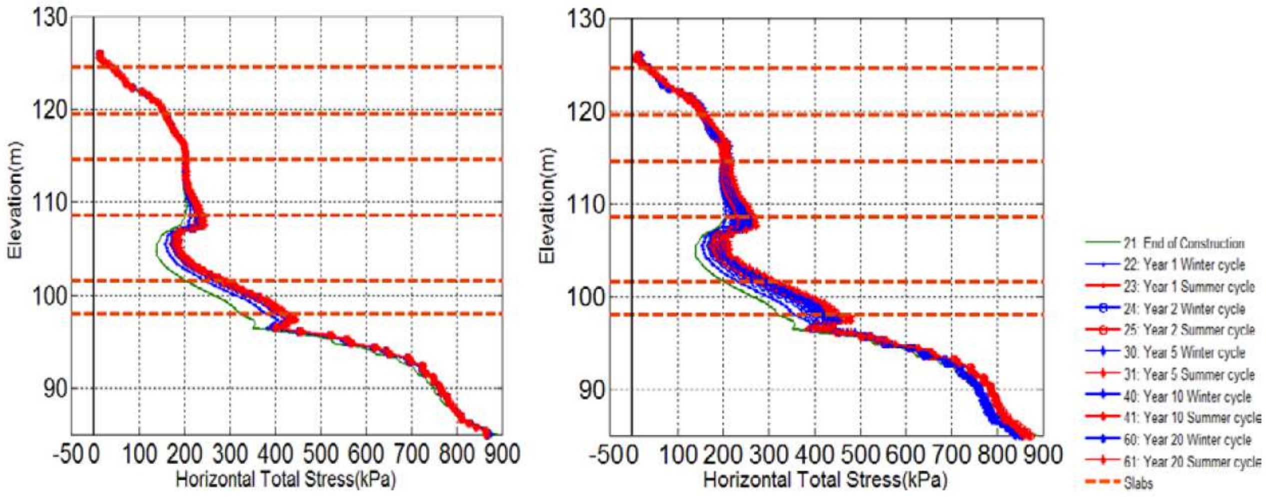
a) No GSHP

b) With GSHP

Very small effect on:-

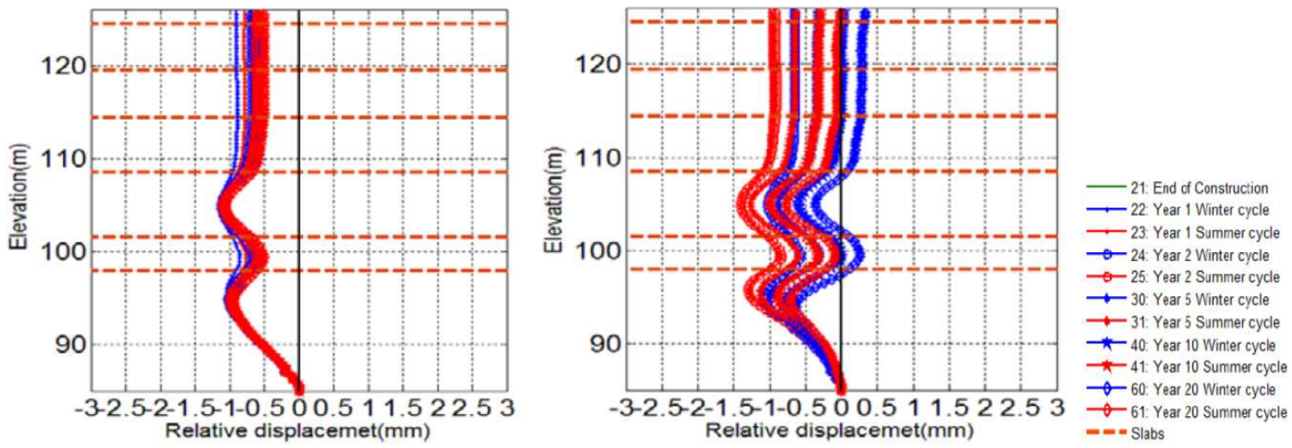
Earth pressures.
Strut forces.

Displacements.



(a) No GSHP operation (b) with GSHP operation

Figure 19 Changes in the horizontal total stress acting on the wall from the soil side

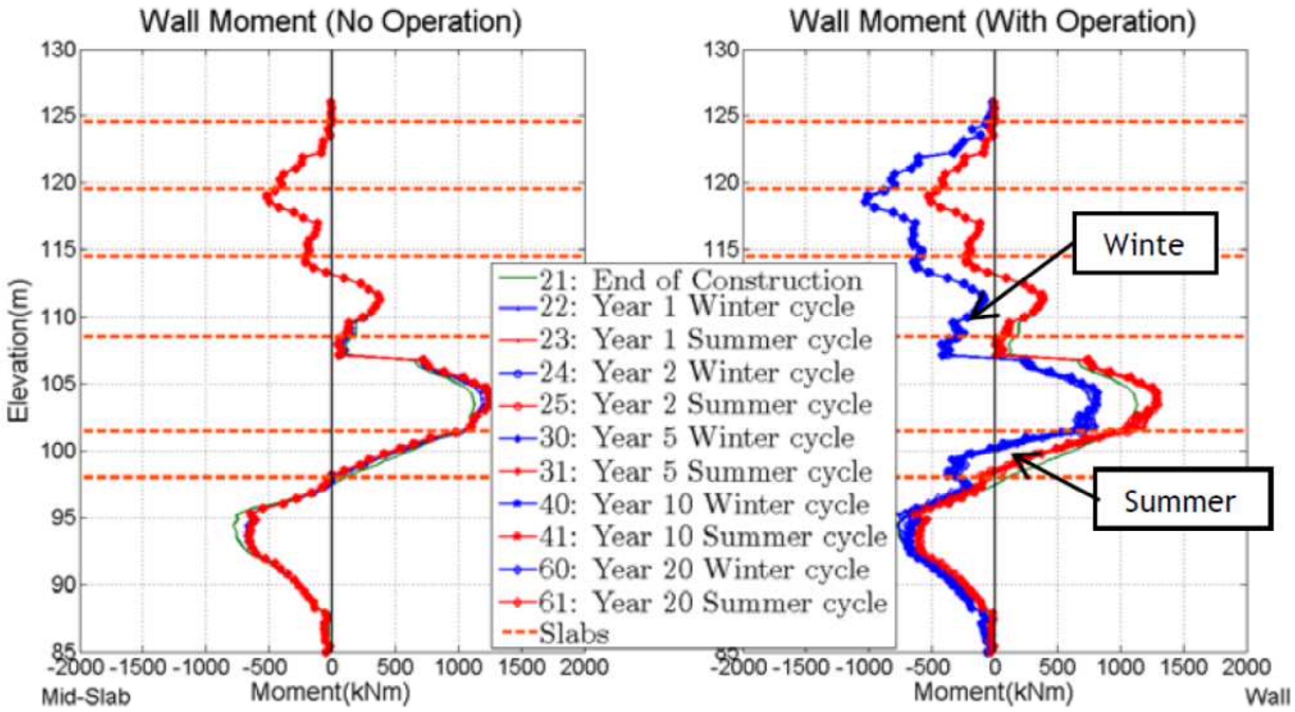


(a) No GSHP operation (b) with GSHP operation

Figure 20 Changes in the lateral displacements of the wall

Impact on Long-term Bending Moments

- **Significant induced moment due to internal wall temp gradient.**



(a) No GSHP operation (b) with GSHP operation

Figure 21 Changes in the bending moment profile with time

a) **No GSHP**

b) **With GSHP**

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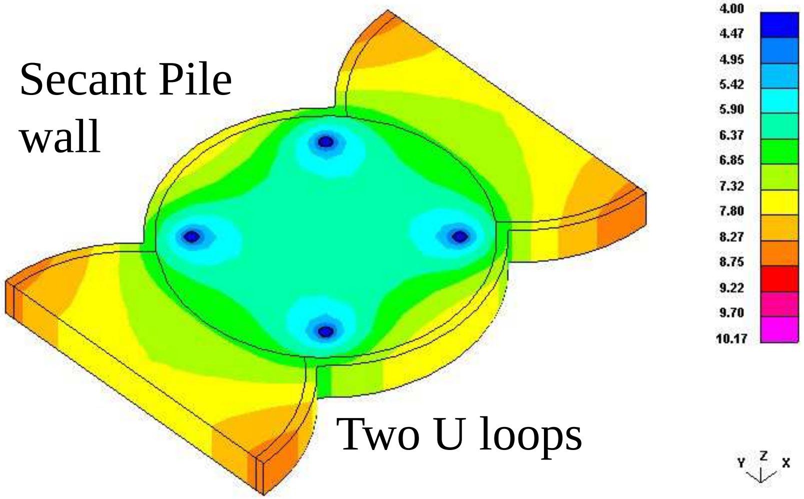
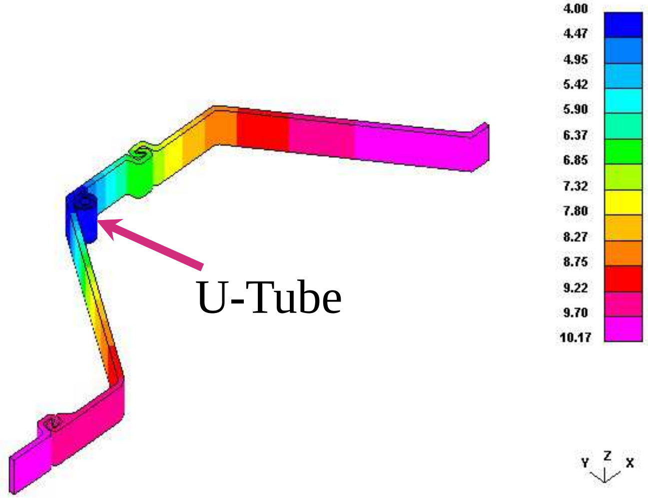
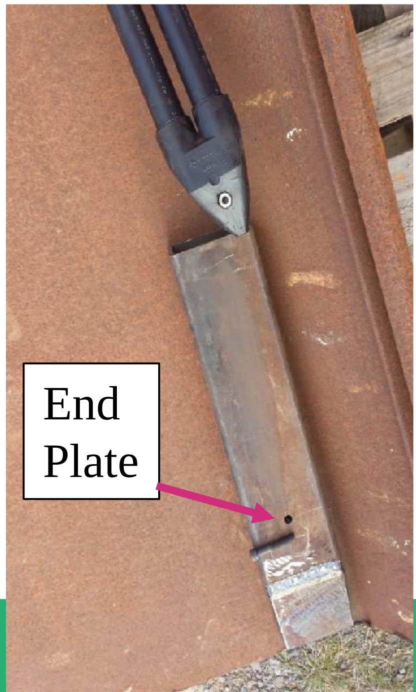
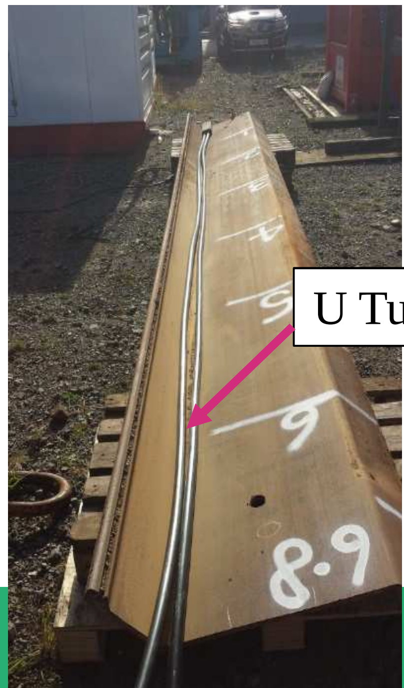
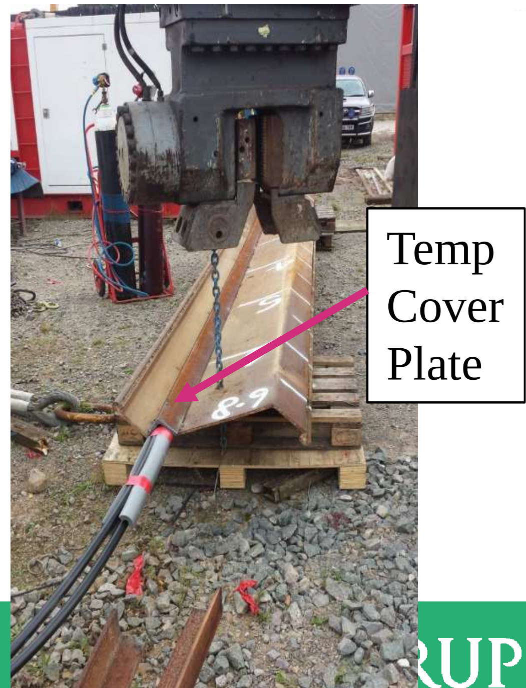
Secant and Sheetpile Thermal Walls Temperature after 100 hours











6) Operational Defects

Defects

Instrumentation

ARUP

Operational Defects

- **Access difficult.**
- **Electro fusion welding defects – Header pipe leaks.**
- **System overheats / overcools.**
- **Inadequate instrumentation.**

Defective Saddle connection - Pressure test

Plate 12 – Shows dye penetrant emerging from the void in the longitudinal axis

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Conclusions (1) - Thermal Pile Experience:-

1. **Specification and Contract**
   - GSHPA Thermal Piles Standard – Responsibilities clear.
   - Complex organisation – Lack experience working together.
   - Standard to be revised – Any feedback?
2. **Design Tools**
   - Tools OK -
   - Temperature - EED,
   - Pile loads - OASYS Pile,
   - Raft / pile / soil – THM - DYNA (NC case?)
   - Back analysis of field trials very important.
3. **Design Stages**
   - Preliminary and Detailed design stages.
   - Need for balanced seasonal heating and cooling.
   - Short piles = Lack of seasonal heat storage.

Conclusions (2) - Thermal Pile Experience:-

4. Thermal Pile Construction

- GSHP systems - Other systems are cheaper.
- Housing – Insulation improving – solar PV, Air source heat pump
- Buildings – Thermal piles – offer season heat storage
- Installation costs - Bored piles, CFA , Header piping?

5. Thermal Walls

- Analysis shows GSHP does not effect earth pressures movement
- Induced moments if U-tubes only on outside of wall

6. Operational Experience

- GSHP systems can over heat /over cool with time.
- Maintenance people do not understand systems.
- More instrumentation on ground side of Heat Pump.
- Leaks in electro fusion joints – hard to isolate in manifolds.

Thank you for your Attention

Any questions?