GSHPA
Thermal Pile Standard

GSHPA Technical Seminar, Cardiff University

Thursday 27th September 2012

Duncan Nicholson

Arup - Director and UK & MEA Skills Network Leader

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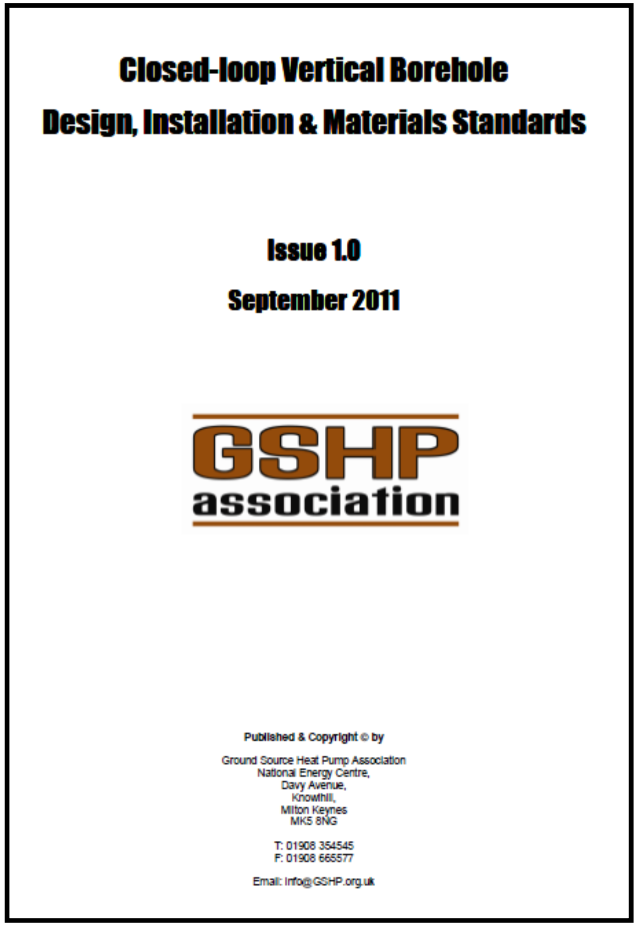
Presentation Contents

- **GSHPA thermal pile and wall standard**
  - Publish Sept 2012
- **Responsibilities - Design - Contract**
  - Engineer and Contractor designs
- **Interfaces with M&E, GSHP and Pile Designers**
  - M&E - Heating and cooling loads
  - GSHP Designer - Predicting pile temperatures
  - Pile Designer - Impact of temperature change on piles
- **Thermal /structural pile design**
  - Thermal stresses, Movements, Cyclic effects

GSHPA Technical & Standards Committee

- **Published Borehole Standard**
  - Sept 2011
- **Publishing Thermal Pile Standard**
  - September 2012
- **Scope**
  - Aimed at designers, installers, architects, engineers, and main and sub-contractors involved with ground source systems
- **Main text = Specification**
- **Appendices = Best practice**



Closed-loop Vertical Borehole

Design, Installation & Materials Standards

Issue 1.0

September 2011

GSHP association

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Ground Source Heat Pump Association
National Energy Centre,
Davy Avenue,
Knowlhill,
Milton Keynes
MK5 8NG

T: 01908 354545
F: 01908 665577

Email: info@GSHP.org.uk

Download www.gshp.org.uk

Thermal Pile Standard – Sub committee
(Started July 2011)

Duncan Nicholson	**Arup**	**(Chair)**
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Echo Ouyang	**Cambridge**	
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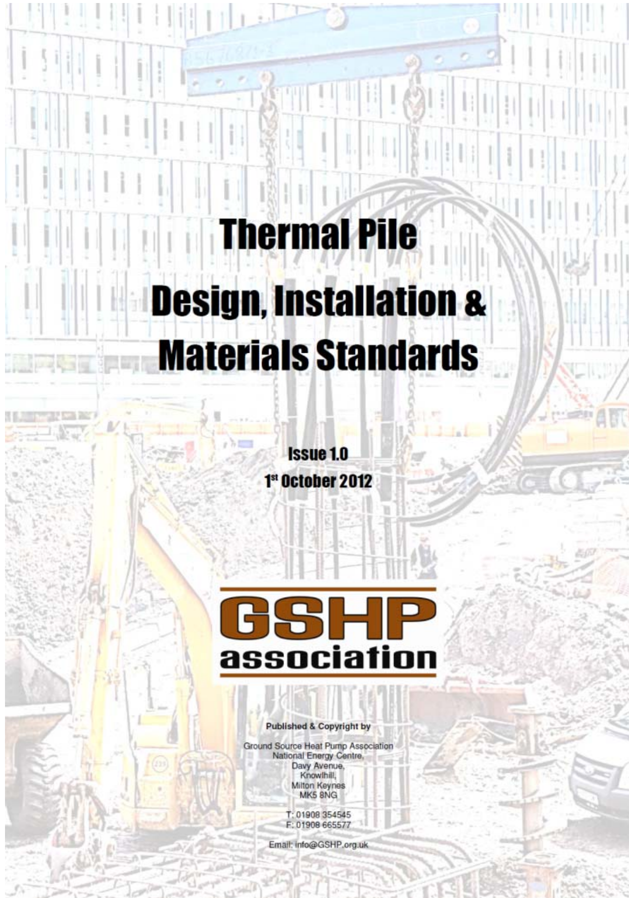
Peter Smith	**Cementation**	
Kenichi Soga	**Cambridge**	
Nic Wincott	**NeoEnergy**	
Chris Wood	**Bulliant / Nottingham Uni**	

GSHPA -Thermal Pile Standard overview

- **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



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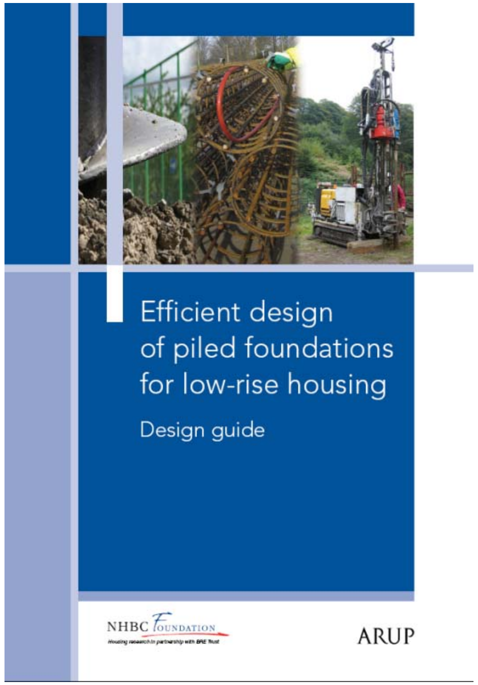
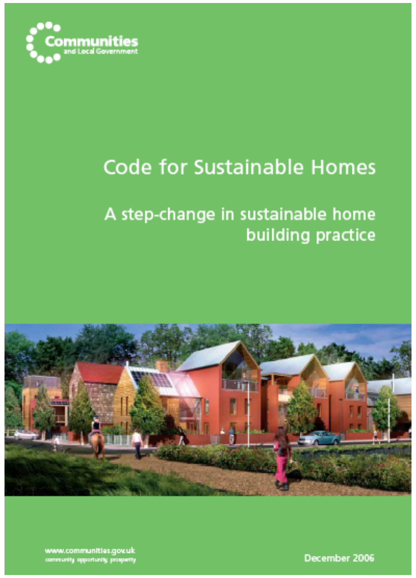
GSHPA -Thermal Pile Standard overview

- **Appendices – Guidance notes**
  - A Fluid temperatures (Fleur)
  - B Thermal soil properties (Fleur)
  - C Soil properties (Arup)
  - D Load transfer mechanisms (Kenichi)
  - E SLS design considerations (Kenichi)
  - F Design charts (Kenichi)
  - G Concrete conductivity (Fleur)
  - H Thermal loops in pile cover zone (Arup)

Other thermal pile guidance - see Appendix A

- **NHBC Guide - Section 6.6 (2010)**
  - National House Building Council – NHBC, (2010) Efficient design of piled foundations for low-rise houses
- **Links to Code for Sustainable Homes (2006)**
  - National standard for sustainable design and construction
  - Interim code levels for energy and CO2 emissions targets



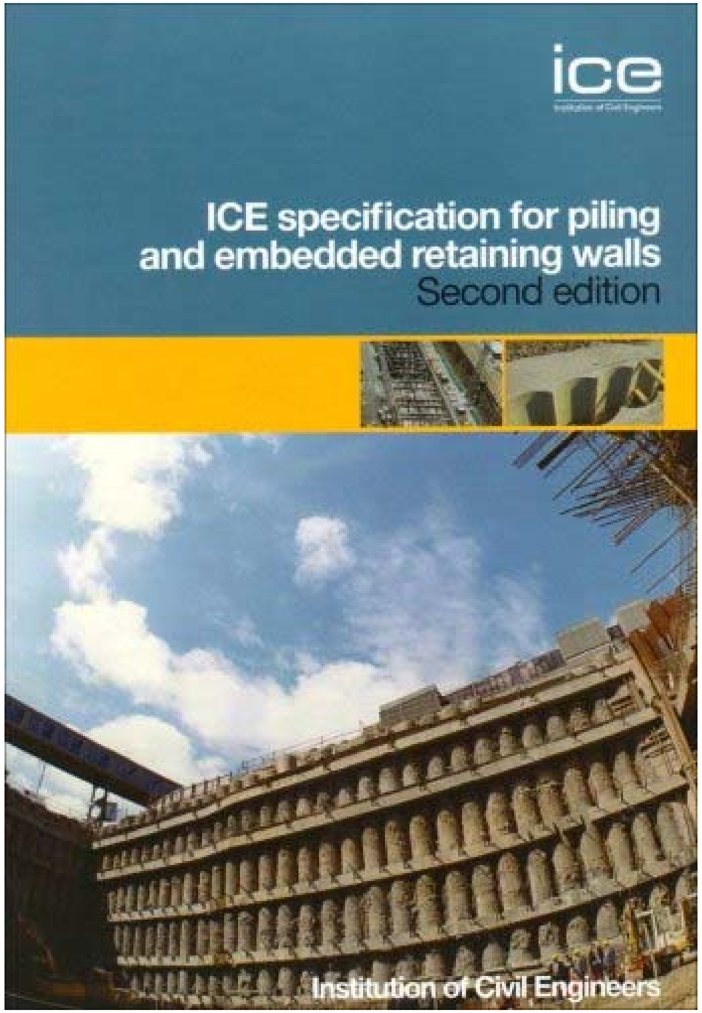


Other Codes

- **Swiss SIA D0190 (2005)**
- **German VDI 4640 (1998)**

Section 3 - Responsibilities

- **Many contractual parties – clear division of responsibilities**
- **ICE Specification for Piling and Embedded Retaining Walls (SPERW) is the starting point:**
  - Engineer design
  - Contractor design



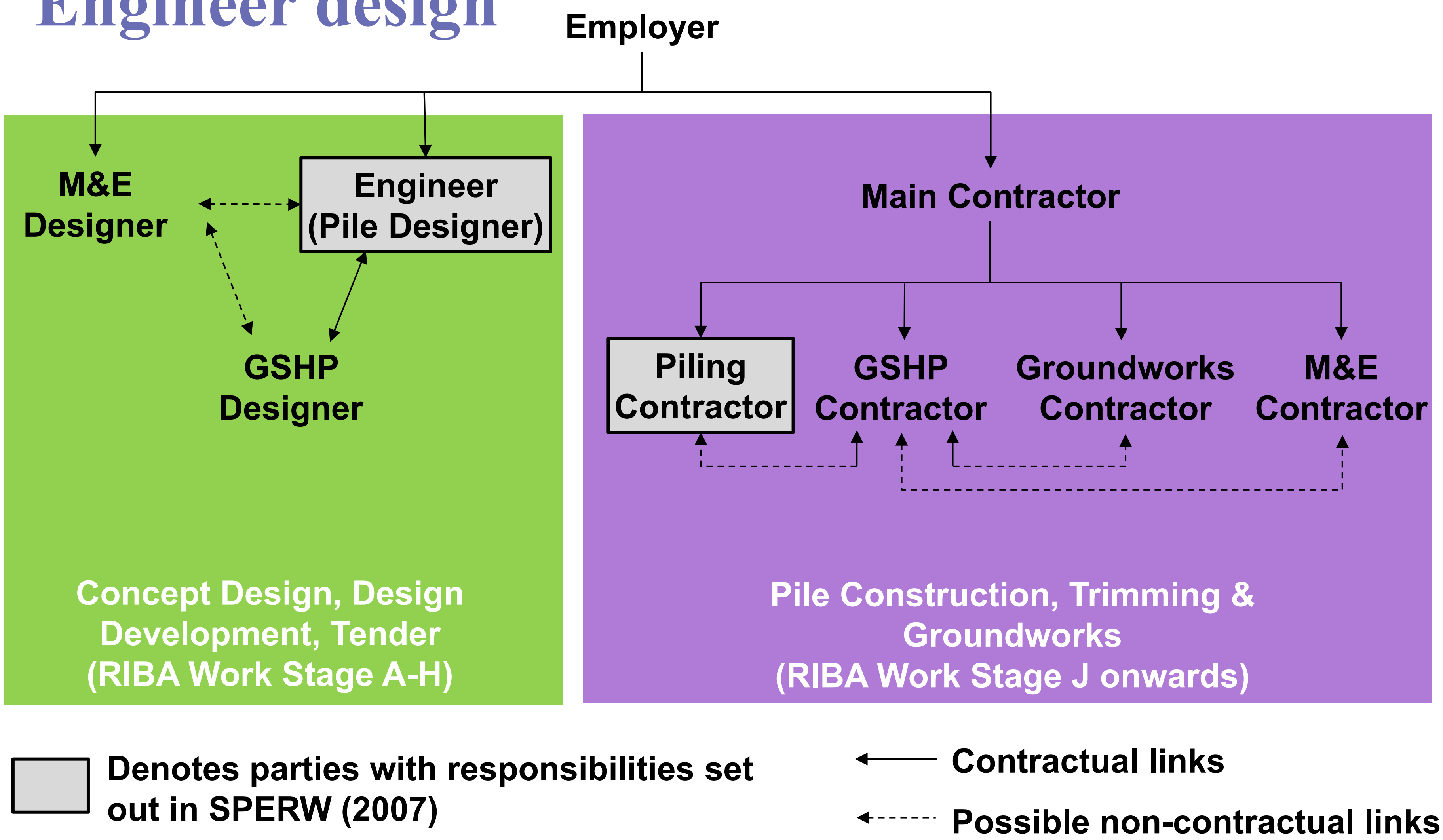
Section 3.2 - ICE SPERW Design Responsibility

- **Who is responsible for the thermal loop design?**
- **Consultant (Engineer) or Contractor**

Design Responsibility	Engineer	Contractor
1. Design of foundation scheme (including SWL and pile location)		
2. Choice of piling or walling method		
3. Design of piles of wall elements to carry Specified Loadings		
4. Design of thermal loops to provide specified thermal loading		

Table 3.1: Modifications to ICE SPERW Table C1.1 to include the thermal loop design

Section 3.2 - Contractual responsibilities Engineer design



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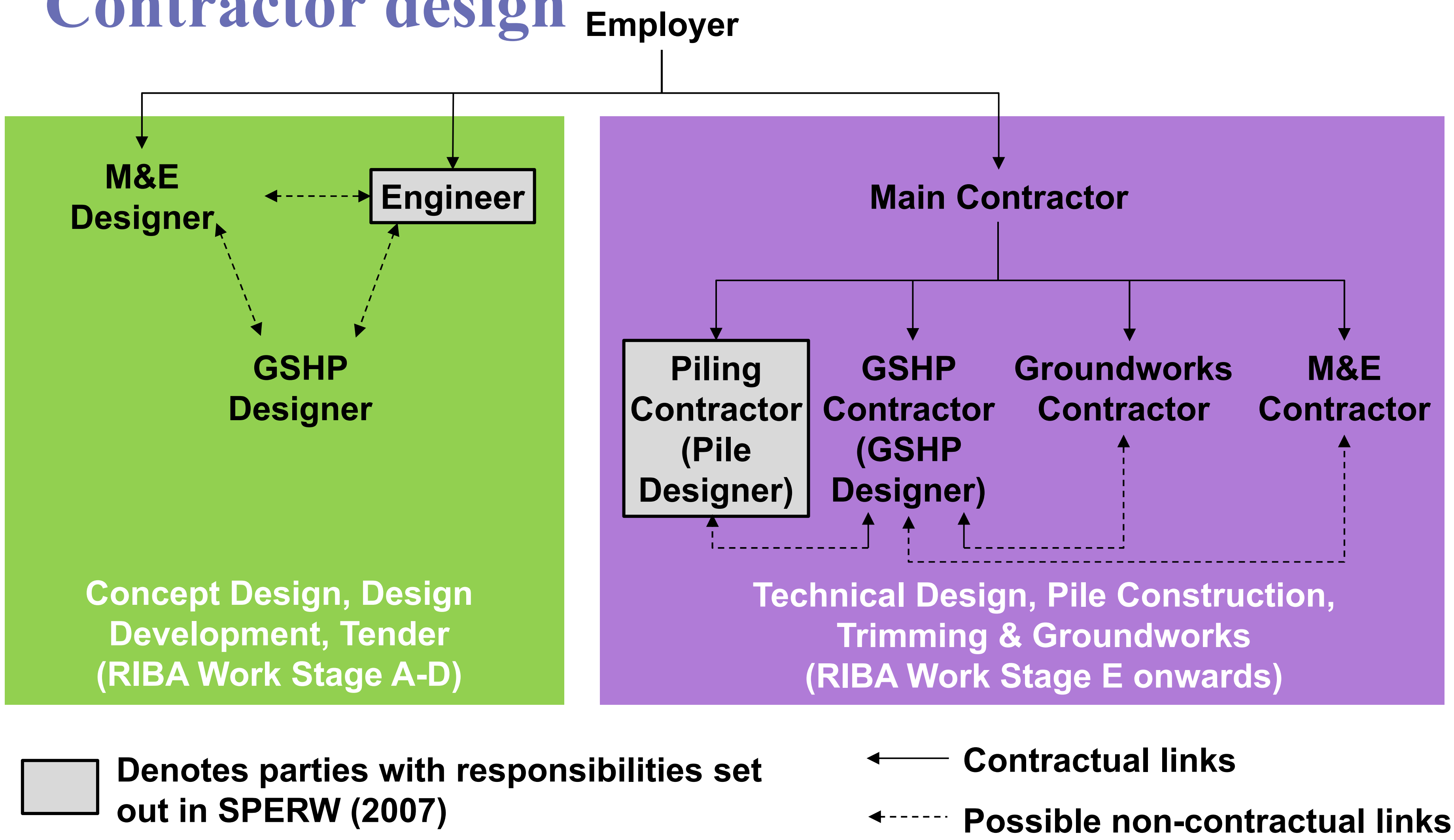
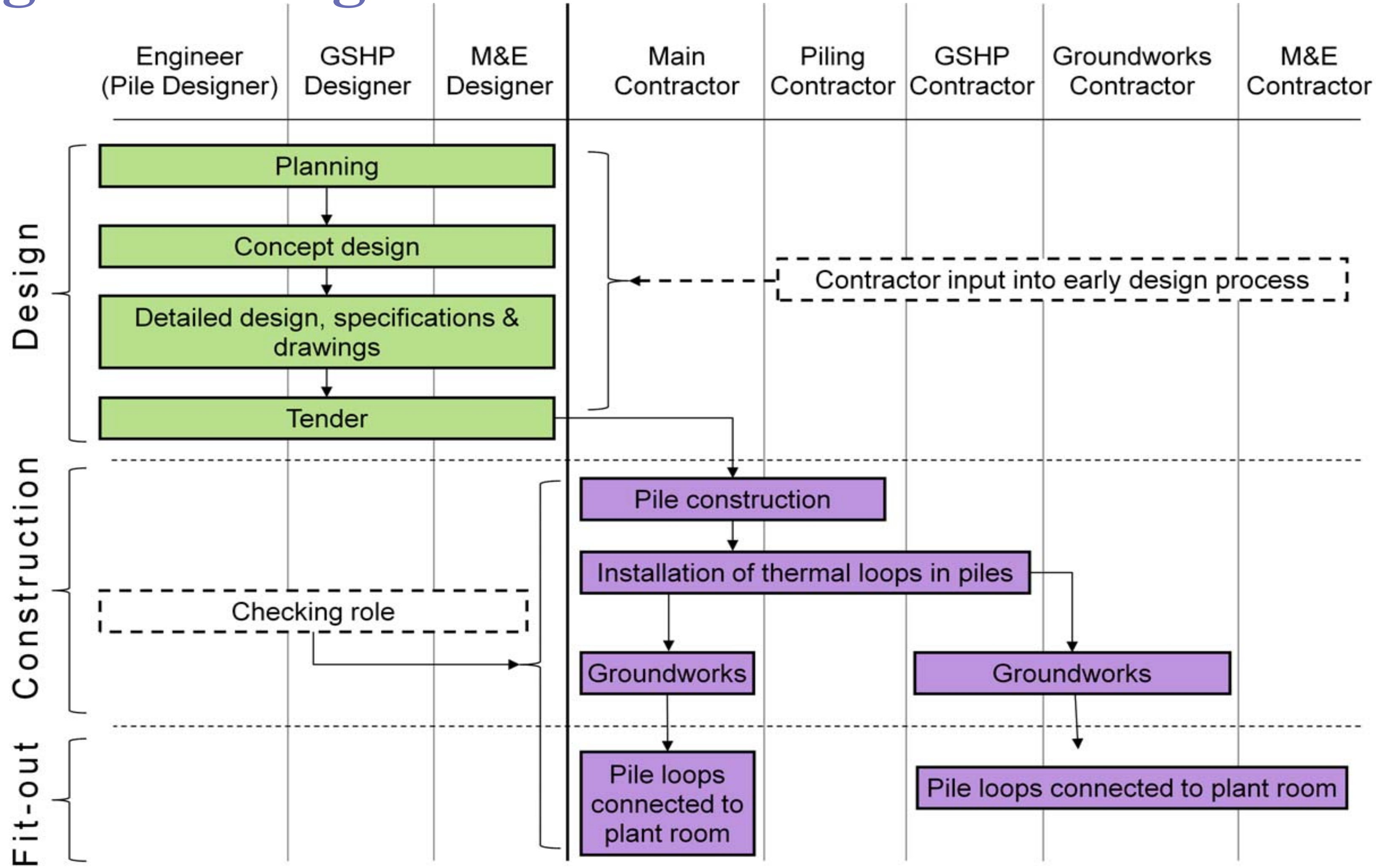
Section 3.2 - Contractual responsibilities
Contractor design



Section 3.2 - Design process responsibilities Engineer design



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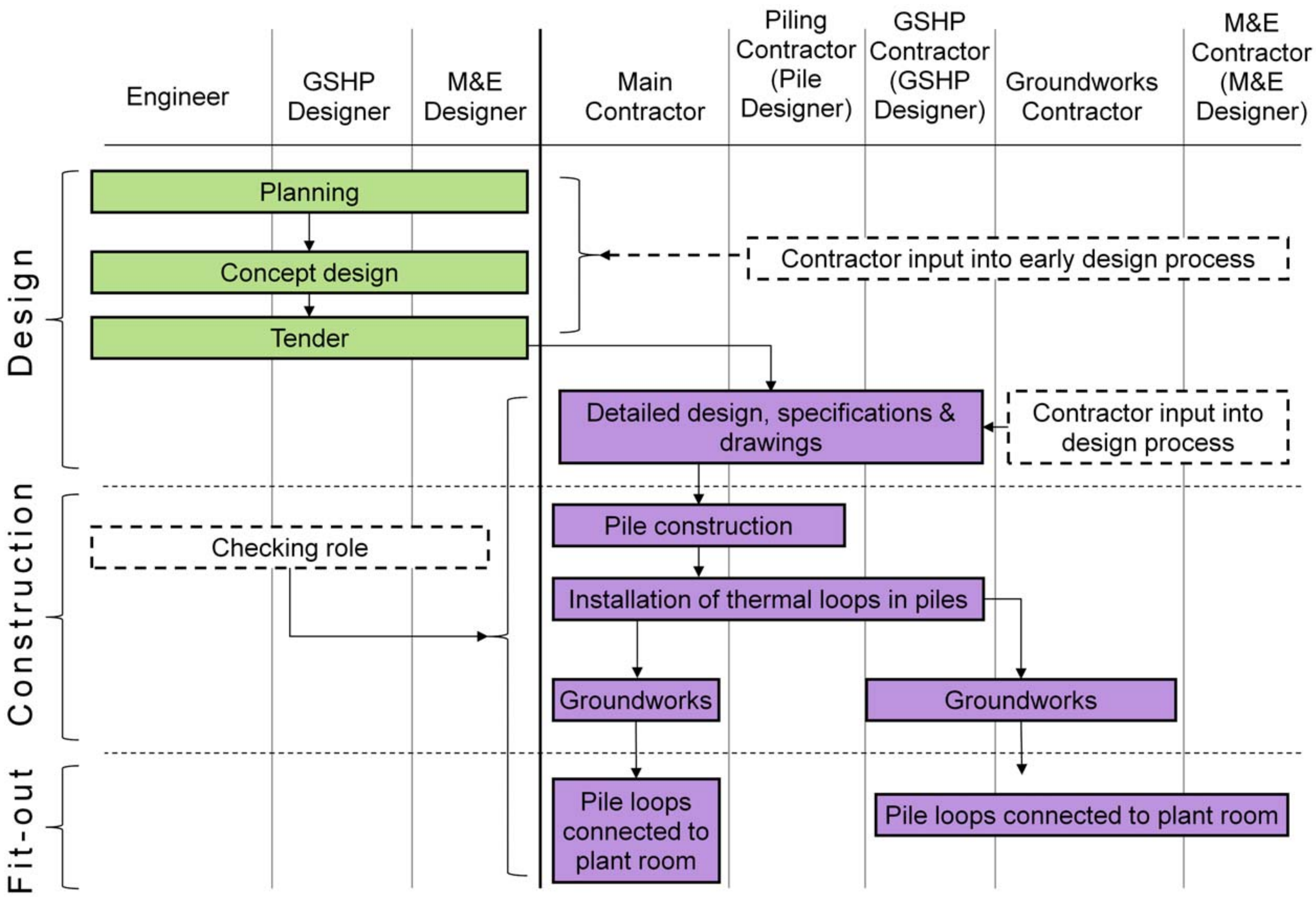

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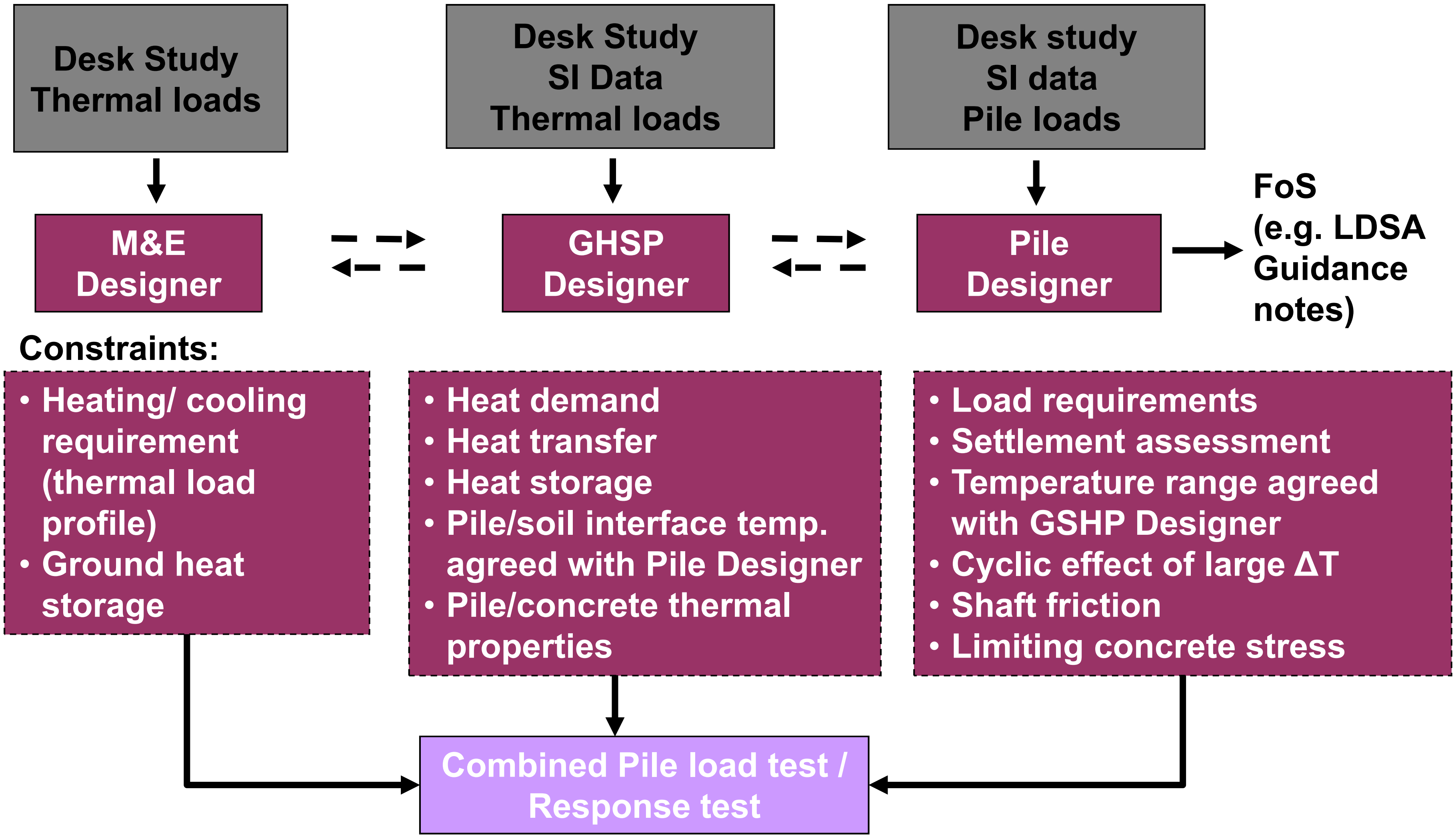
Section 5.1 - Design requirements

Thermal effects complicate traditional pile design



Section 5.5 - Interface with M&E Engineers

- **M and E heat loads (Section 5.5)**
  - Heating / Cooling loads –
- **Hourly results –**
  - Complex - Dynamic Simulation Models
    - Daily temperature fluctuations.
    - Weakness - Climate and Building occupancy changes.
- **Monthly results –**
  - Simple – Simple model
  - Average monthly heat loads
  - Superimpose daily cycles
    - Worst winter heating and summer cooling peak periods

Section 5.7 - Interface with GSHP designer (Appendix A)

- **Assessment of the hotest pile**
  - Maximum expansion and friction mobilised on pile
- **Assessment of the coldest pile**
  - Maximum contraction of pile
  - No freezing at pile soil interface
  - Circulation fluid – Single piles or series of piles.
- **Section 5.7.3 Ground must not freeze**
  1. Ensure heat pump inlet/outlet temperature above zero (tolerance of 2 degrees C)
  2. Or if inlet/outlet temperature allowed to be sub-zero for a short time then check piles give sufficient thermal buffer
- **Use Loop model for long term ground temperatures**

Section 5.6 - Interface with pile designer

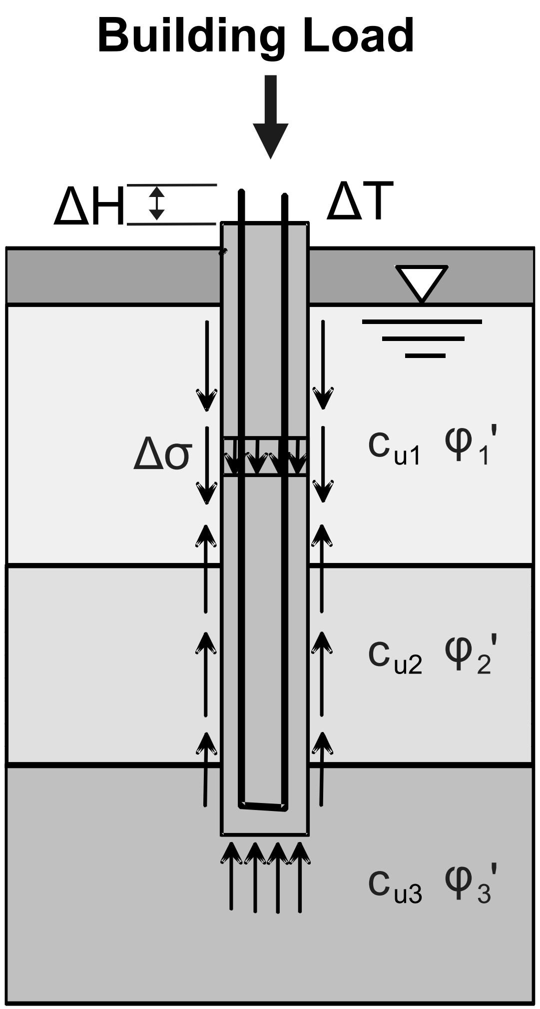
Normal pile design considerations

Ultimate LS

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

Serviceability LS

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



Additional thermal pile design considerations

ULS (Appendix C)

- 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

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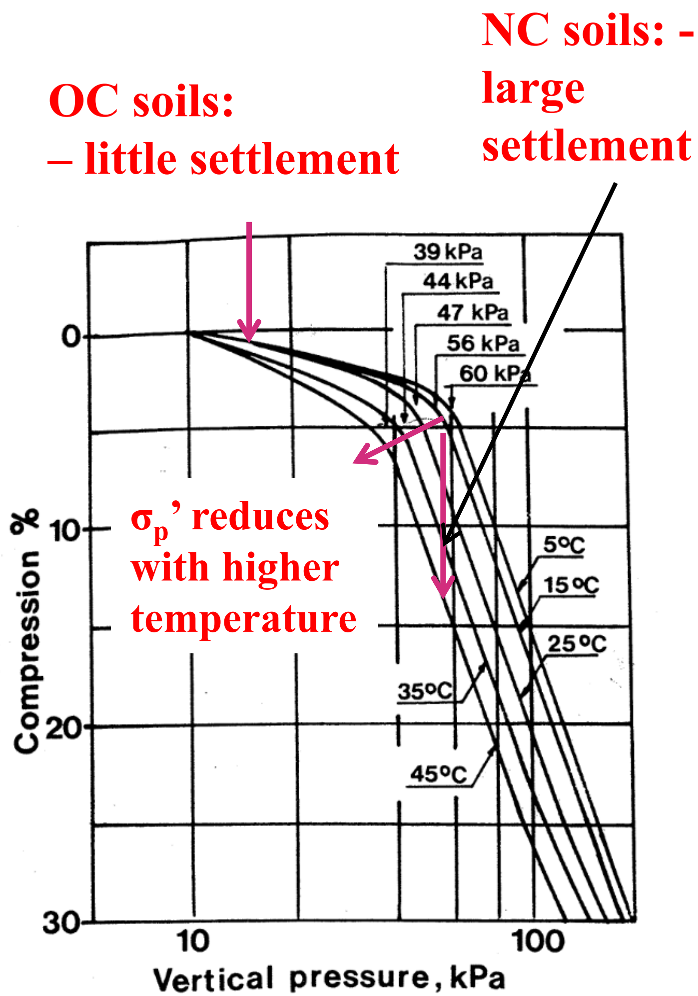
Section 5.6 - Ultimate Limit State – Soils (Appendix C)

- **Effects of heating soil**
  - Strength and stiffness reduces – from reduction in preconsolidation pressure (quasi-creep effect)
  - Consolidation regains the strength
  - Over Consolidated soils – less effect
- **Undrained**
  - Excess pore pressures
- **Drained**
  - Consolidation – regains soil strength (increased strength when cooled)



(Eriksson, 1989)

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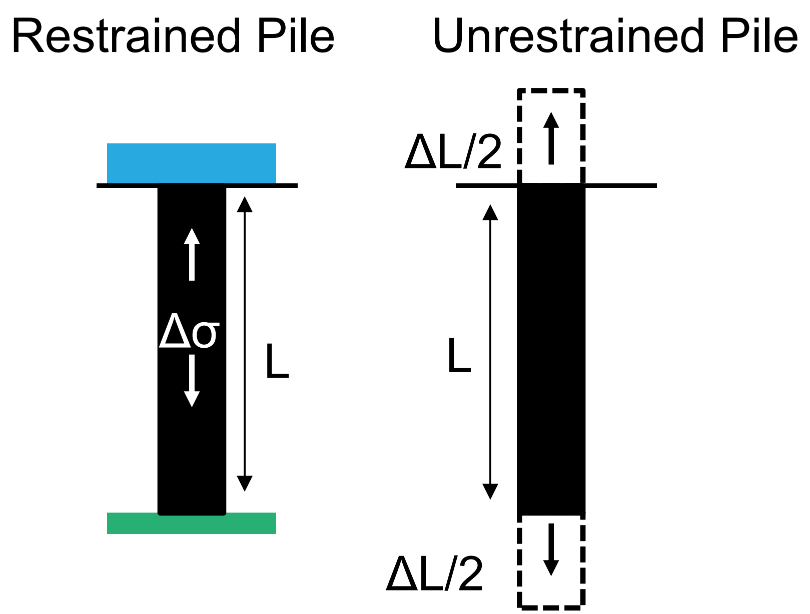
Section 5.6 - Serviceability Limit State - stresses (Appendix E)

- **Thermal pile expansion is similar to -ve skin friction**
  - Consider settlements
  - Negative skin friction design Poulos, (2008)
- **Pile head fixity increases thermal stresses**
- **Thermally induced concrete axial stresses**
  - Check concrete stress < concrete strength (q_c) / 4



$\Delta\sigma = \alpha_T \times \Delta T \times E_{conc}$ $\Delta L = \alpha_T \times \Delta T \times L$

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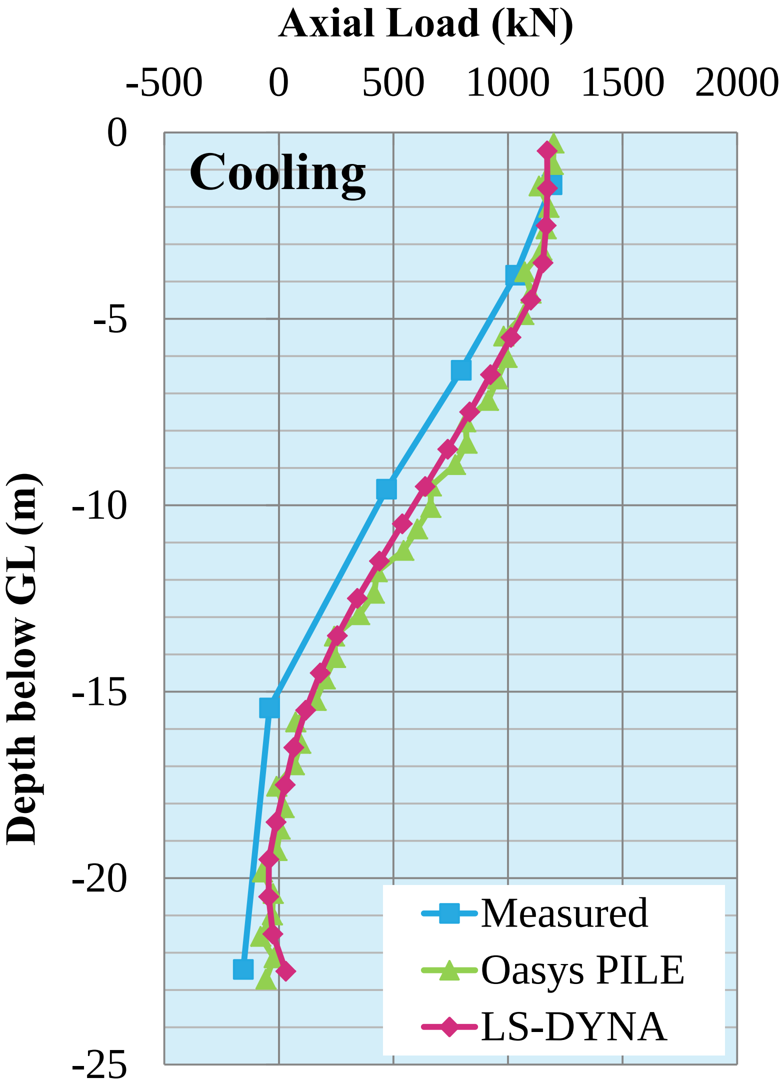
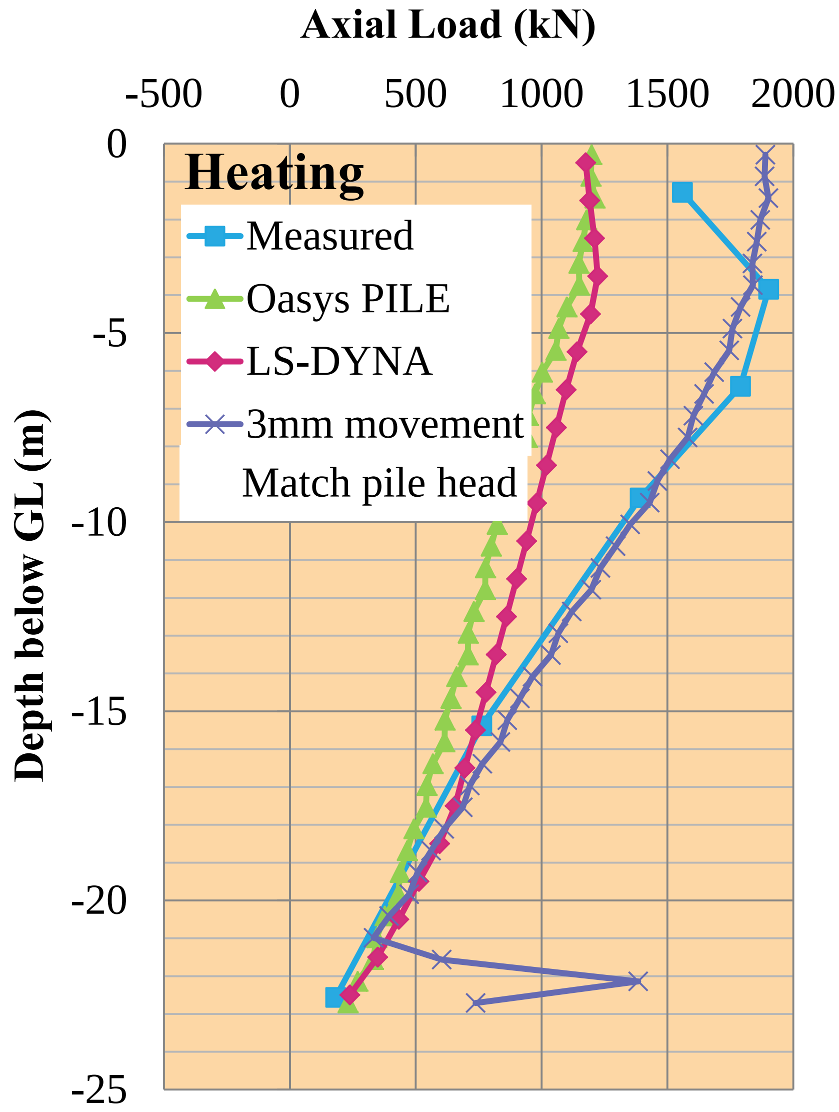
Model thermal effects – pile contracts / expands
Lambeth College – Pile Axial Loads





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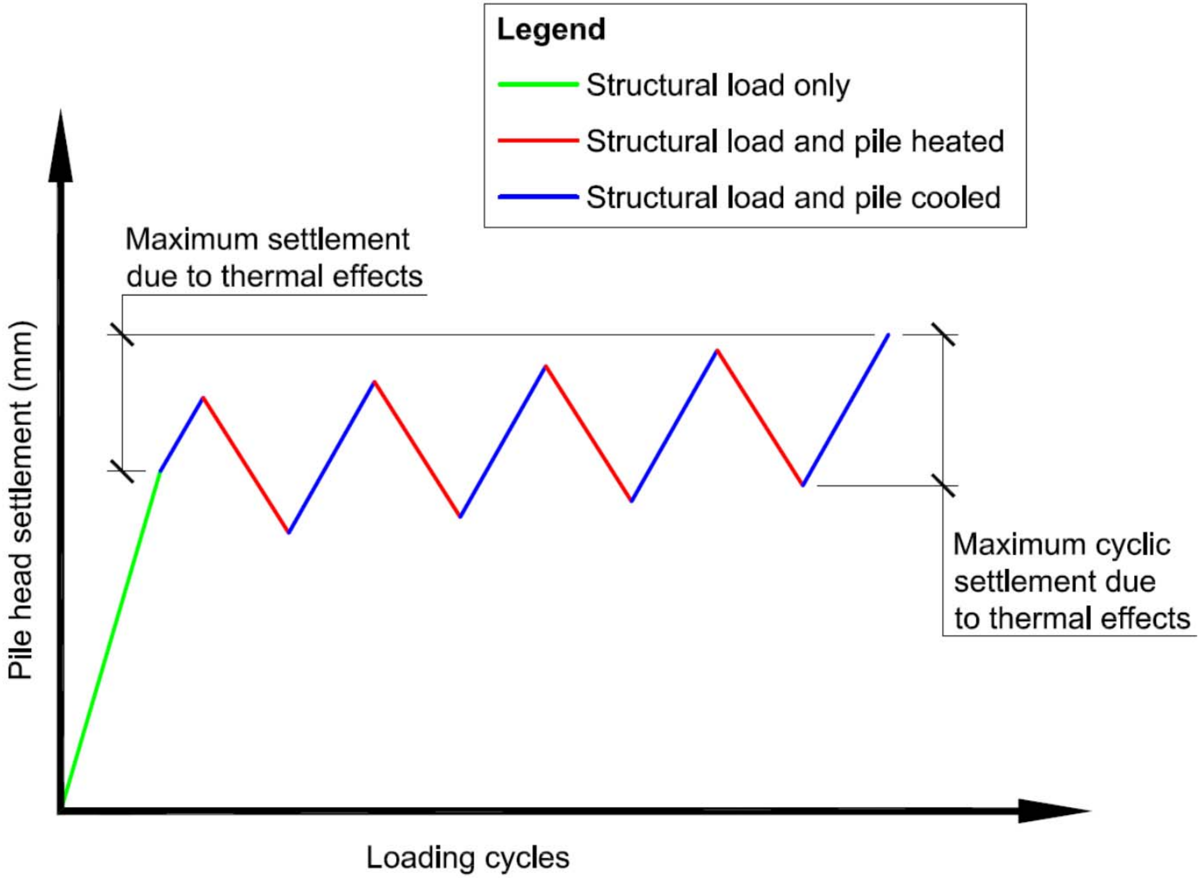
Section 5.6 - Serviceability LS - settlement (Appendix F)

- **Pile head fixity**
  - % of thermal piles in the scheme
- **Additional settlement**
  - **Thermal effects**
  - **Seasonal cyclic movement –** heating / cooling



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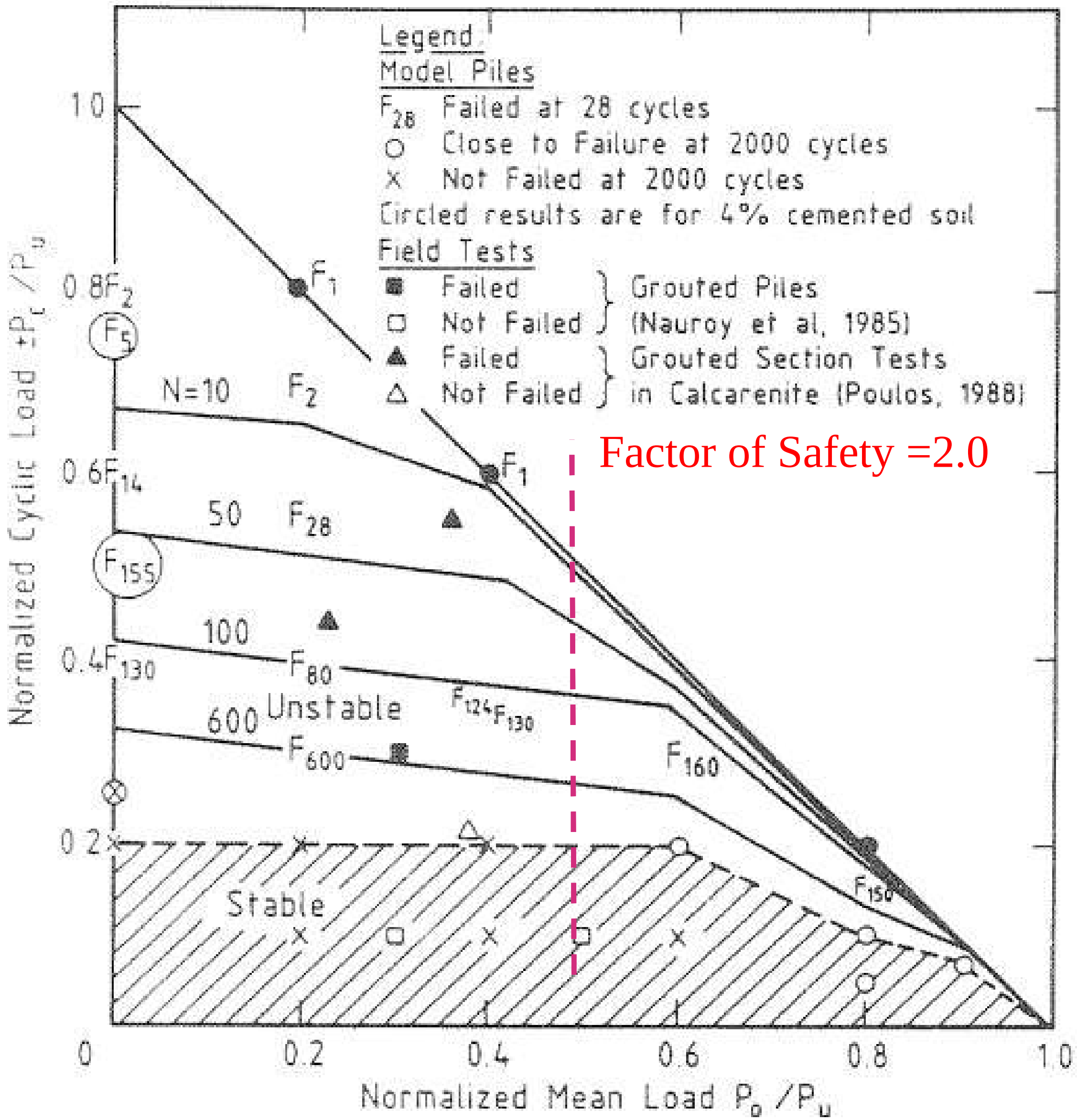
Section 5.6 - Cyclic thermal effects
(Appendix E)

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

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



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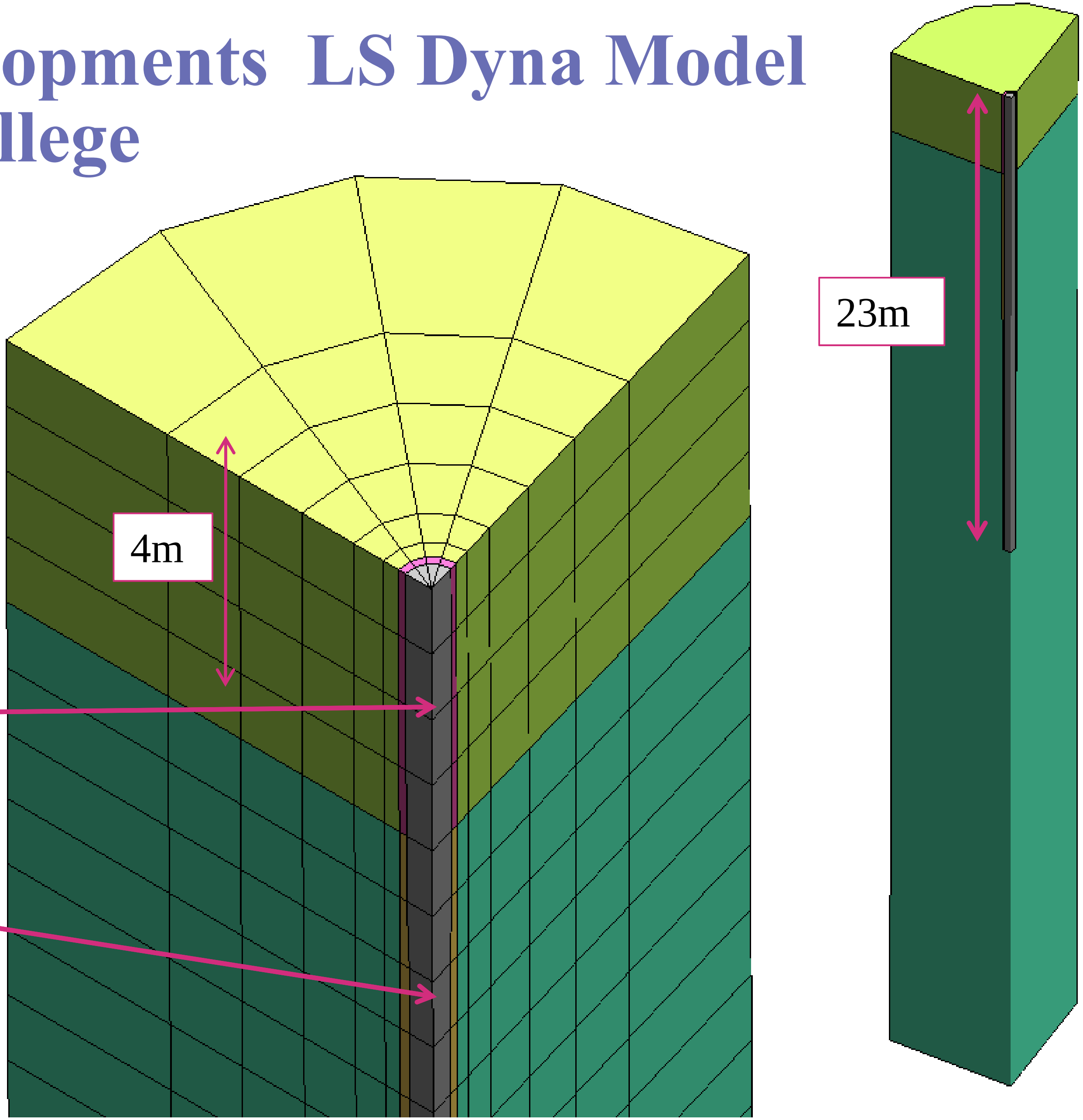
Recent developments LS Dyna Model Lambeth College

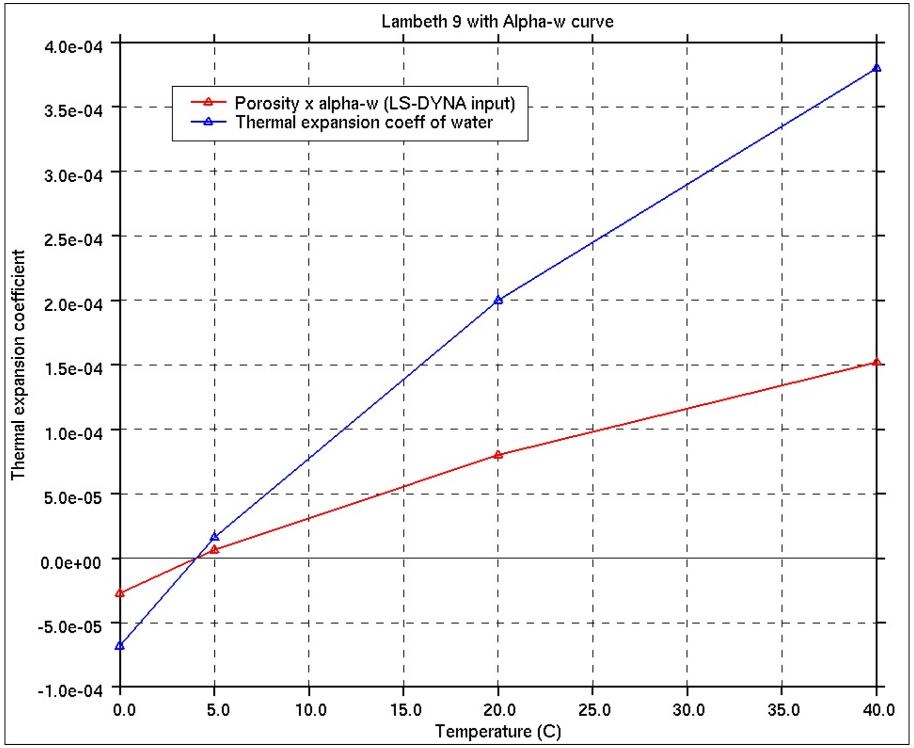


Top 5m of pile has diameter 610mm

Remainder of pile has diameter 550mm

Thermal Expansion Effects – Soil and Water

- **Thermal properties of soil:**
  - **Soil** - Linear expansion coefficient $= 1.17\times10^{-5}$ (volumetric $= 3.5\times10^{-5}$)
  - **Water** - expansion coefficient according to the curve shown.
    - **Blue** curve is α_w vs T
    - **Red** curve is the LS-DYNA input which is $n\alpha_w$ vs T
    - Porosity (n) = 0.4



- Specific heat capacity = 2000kJ/kgK
- Conductivity = 1.8W/mK

Water expands more than soil at high temperatures - hence water pressure change

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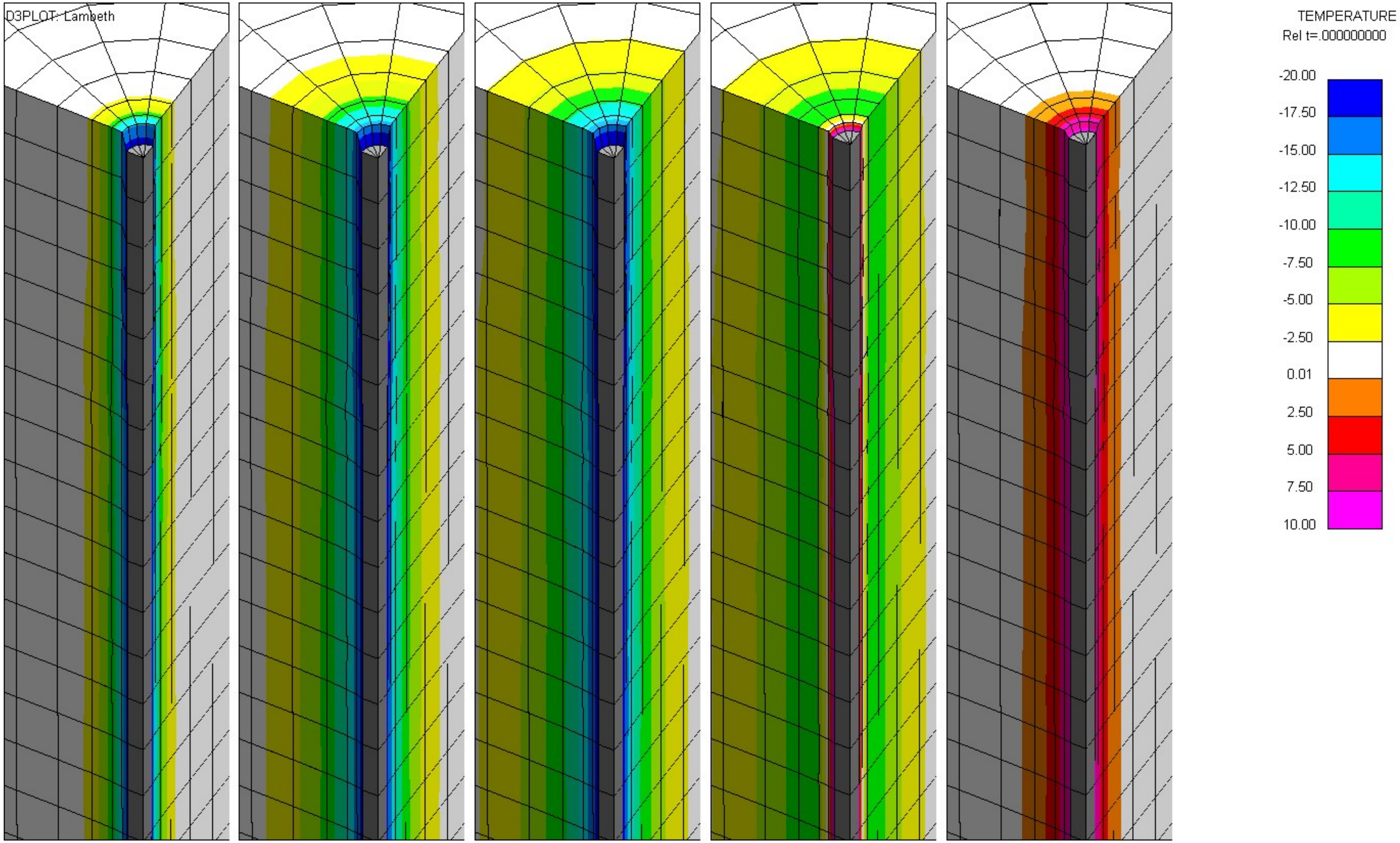
Temperature Change in Soil



Near start of cooling

Mid-way through cooling

End of cooling

Near start of heating

End of heating

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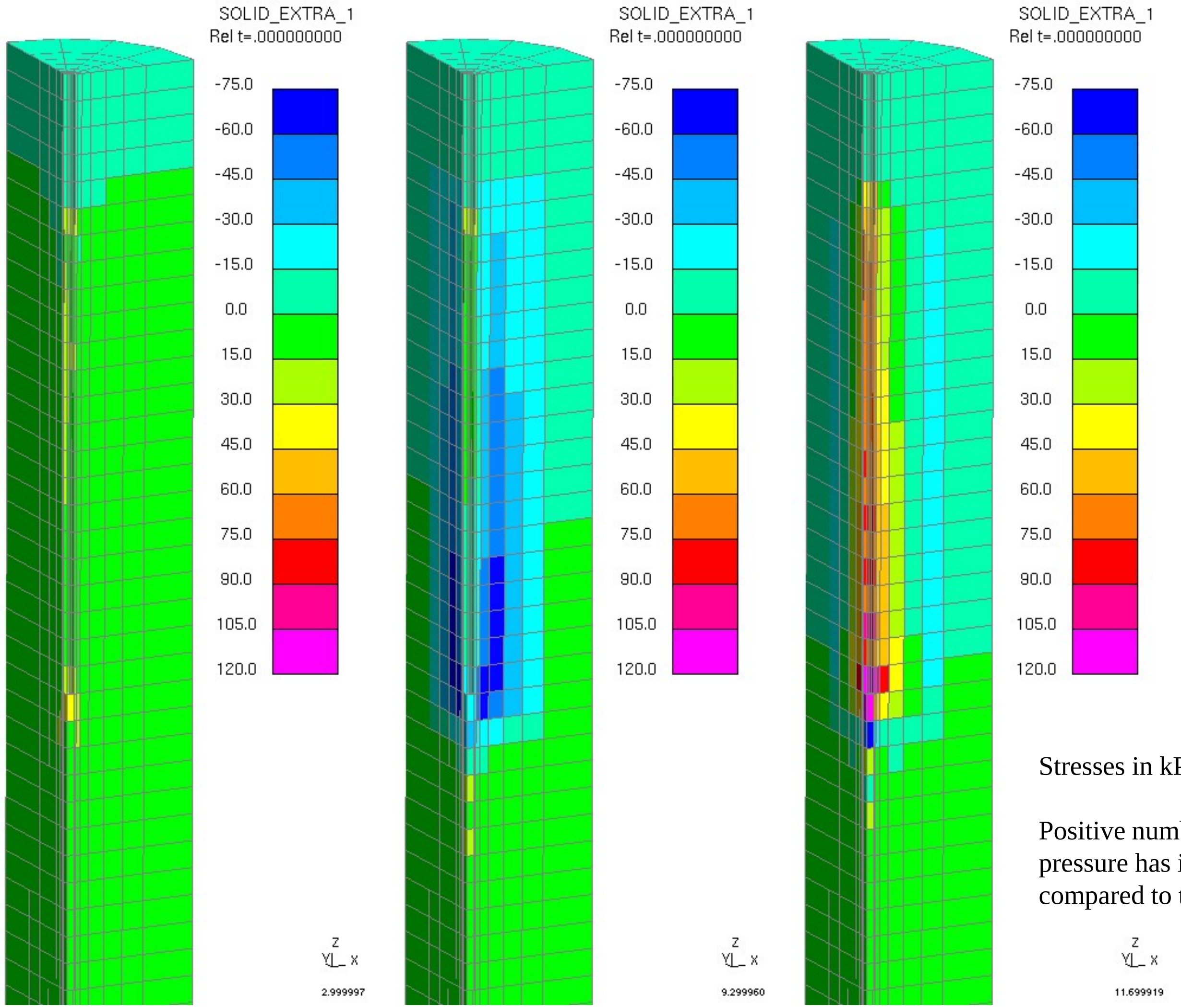
Pore Pressure Change – (Undrained)

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



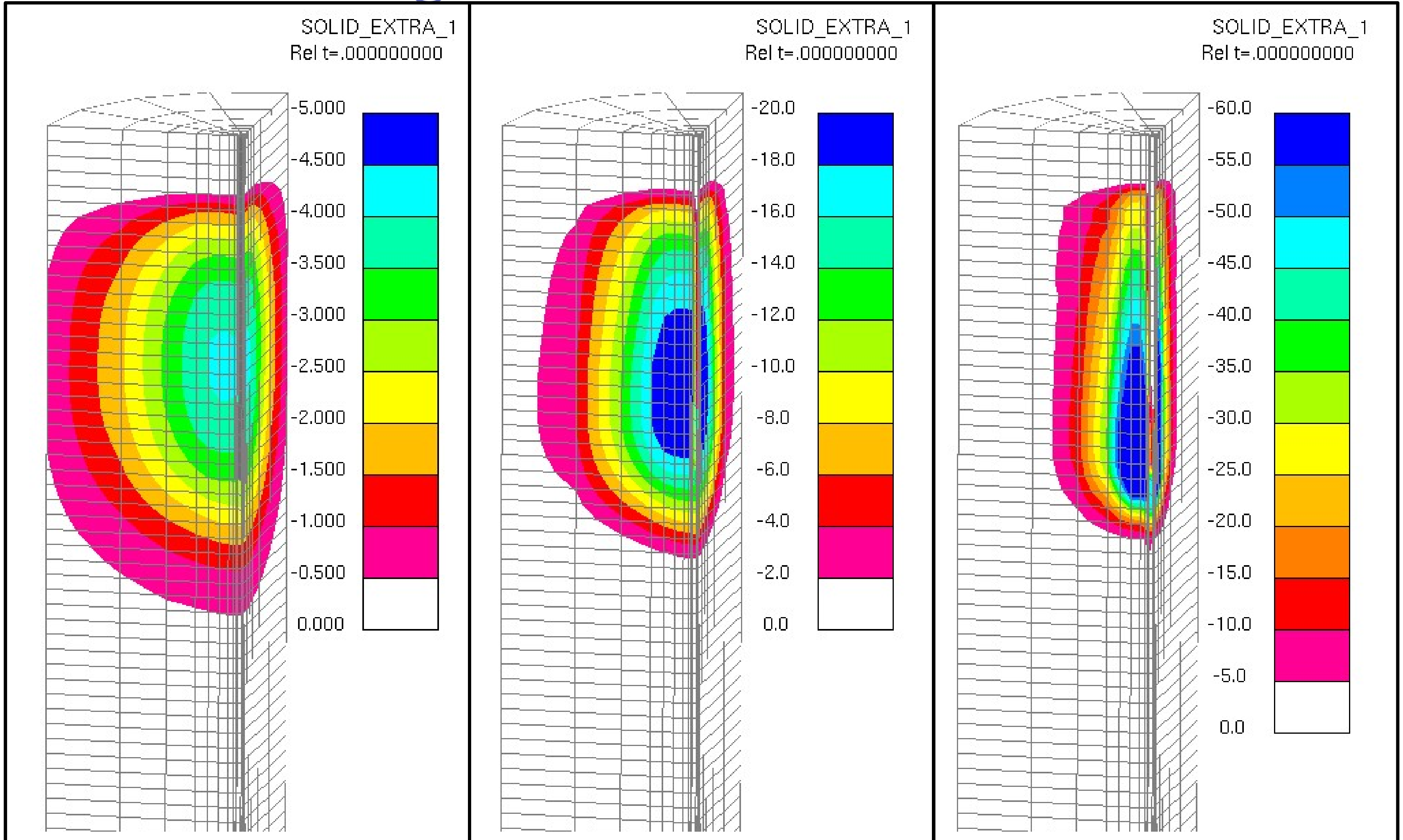
Stresses in kPa, relative to initial stress state.

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

Permeability Effect
End of Cooling

- Pore pressure (kPa), relative to initial stress state.
- Positive numbers - pore pressure has increased (more compressive) relative to initial stress state



Permeability 1.0x10^{-9} m/s | **Permeability 1.0x10^{-10}m/s** | **Undrained**

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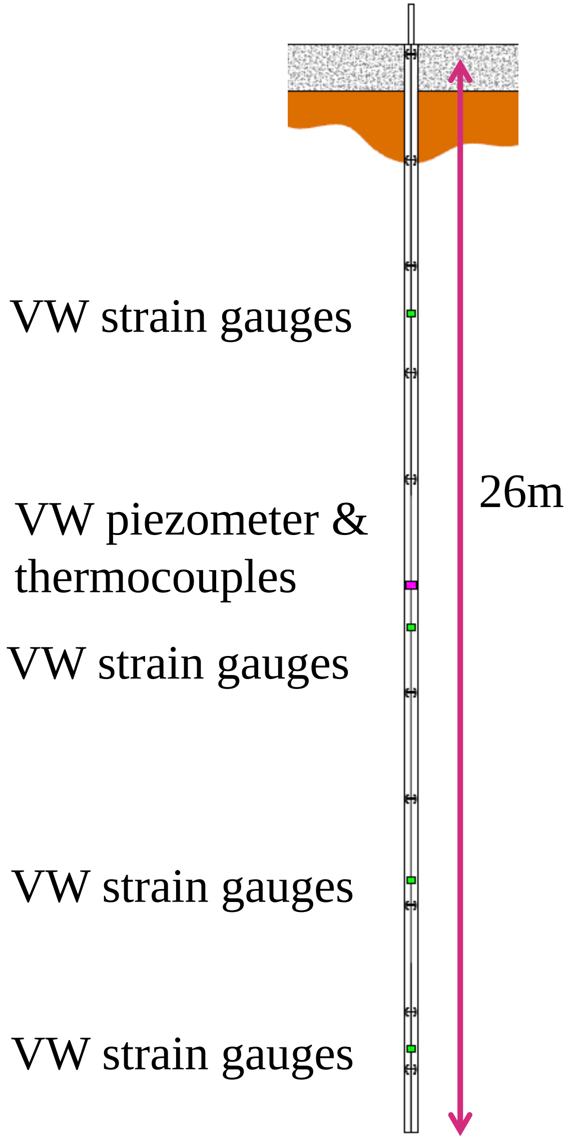
LS-Dyna Conclusions

- **Temperature changes in soil – well modelled**
- **Relative expansion of soil skeleton / water is significant**
- **Large pore pressure changes in soil**
  - Could reduce undrained shear strength
- **Consolidation occurs rapidly**
  - Soil regains strength – ULS capacity of pile increases.
- **Effect of soil expansion on axial load in pile**
- **Gravel layer (Lambeth College) hard to model**

Section 6.4 - Pile thermal response test
Shell HQ, London

- **TRT borehole converted to pile.**
- **Instrumented.**
- **Strain and soil properties**
- **Pile and soil thermal conductivity**



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Appendices and Further Work

- **Appendices summarise current knowledge and where further work is needed**
- **Further work**
  - Soil and concrete thermal conductivity - lab tests
  - Thermal response test - extended to piles
    - Soil behaviour - THM models
    - Mobilised shaft friction
    - SLS - increased concrete stresses with higher temperature.
  - Pipe tests
    - Scratch resistance – effect of concrete surround
    - Leakage tests - effect of concrete surround

Conclusions

- **Thermal Piles are established in UK – but few designers / contractors.**
- **Thermal Pile Standard provides a framework –**
  - Based on Vertical Borehole Standard
  - Main text - Specification
  - Appendices – Guidance and current state of art
- **Responsibilities - Design and Contract - linked with SPERW**
- **Design Interfaces - M&E, GSHP, Pile Designer**
- **Geotechnical design developing - soil properties & THM models**

Thank you for your attention

Any questions?

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