GSHPA Thermal Pile Standard

Ground Source Heat Pump Association

Technical Seminar

Wednesday 16 November 2011
Homerton College, Cambridge University

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ARUP

Thermal Pile Standard – sub committee

Duncan Nicholson	Arup	(Chair)
Nic Wincott	NeoEnergy	
Peter Smith	Cementation	
Tony Amis	GIL	
Chris Wood	Bullivant /	
Kenichi Soga	Cambridge University	
Fleur Loveridge	Southampton University	
Jake Salisbury	GSHPA -	(Secretary)

GSHPA -Thermal Pile Standard overview

Contents List

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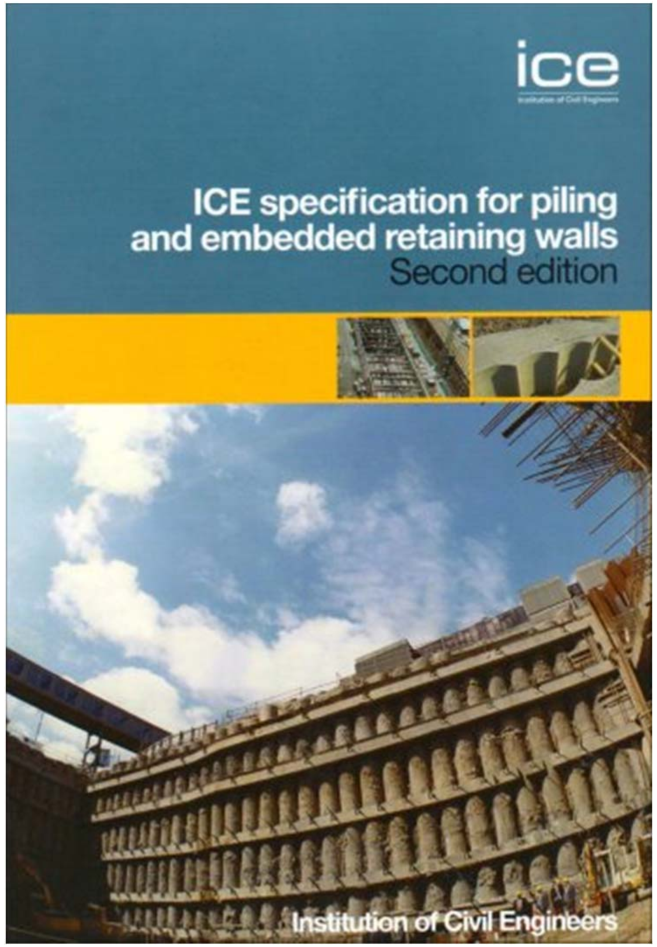
- **Appendices**
  - A Design – Geotechnical design issues
  - B Thermal response – Effect of large diameter piles
  - C Thermal pile concrete – Concrete thermal conductivity
  - E Loops Installation – Methods and scratching

Section 3 Contractual responsibilities

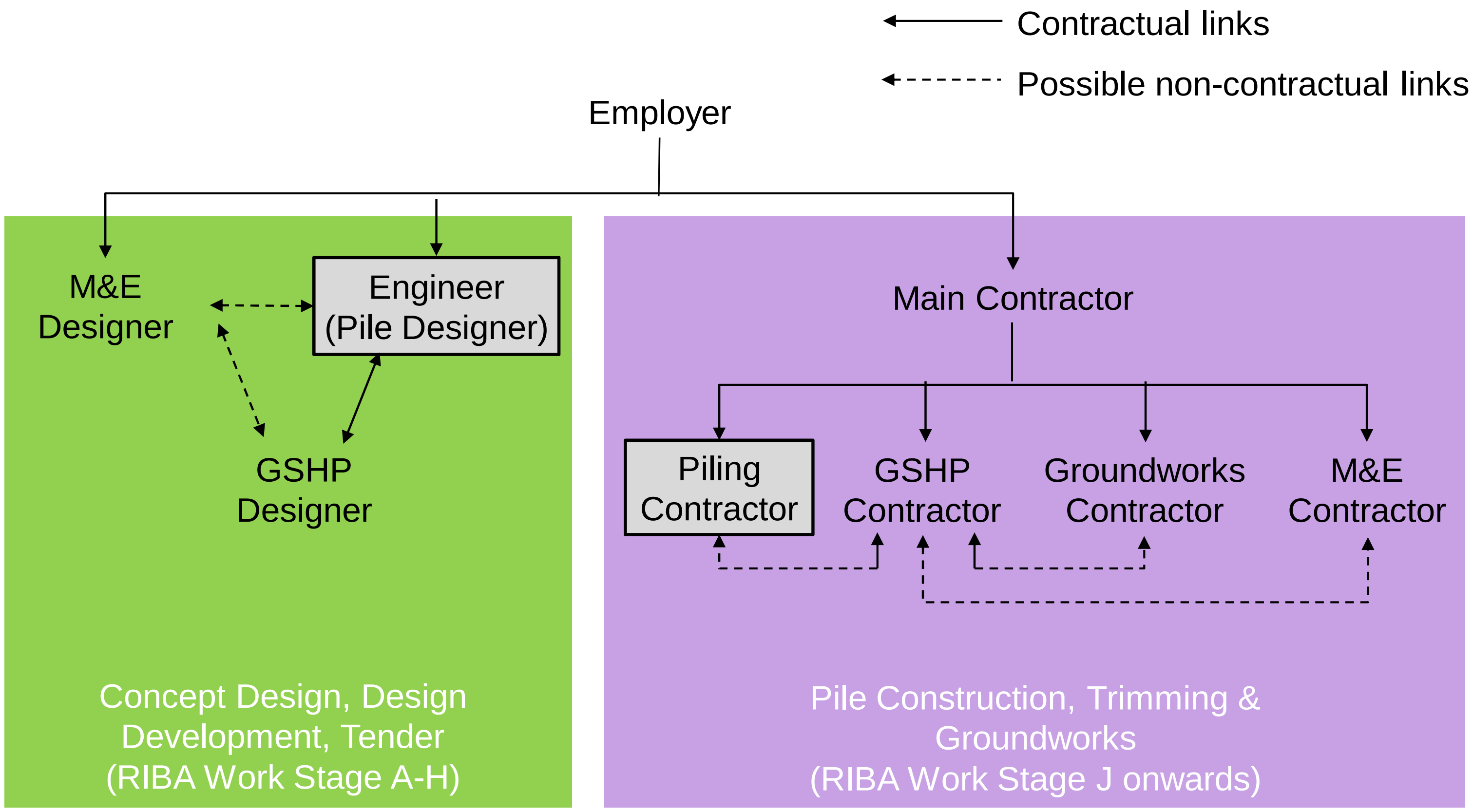
- **Many parties results in division of responsibilities.**

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



Contractual responsibilities

- **"Engineer" design piles**



Denotes parties with responsibilities set out in SPERW (2007)

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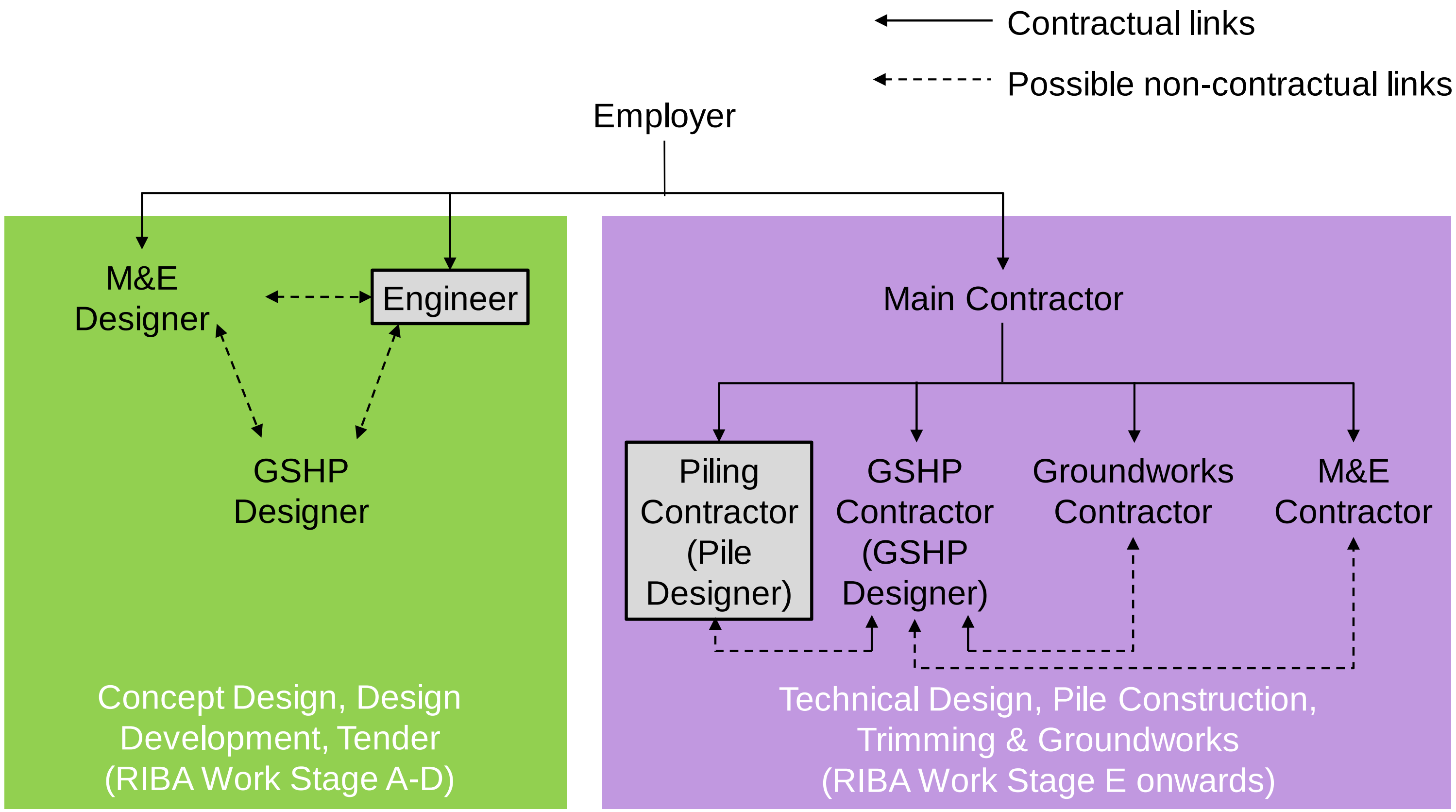
Contractual responsibilities

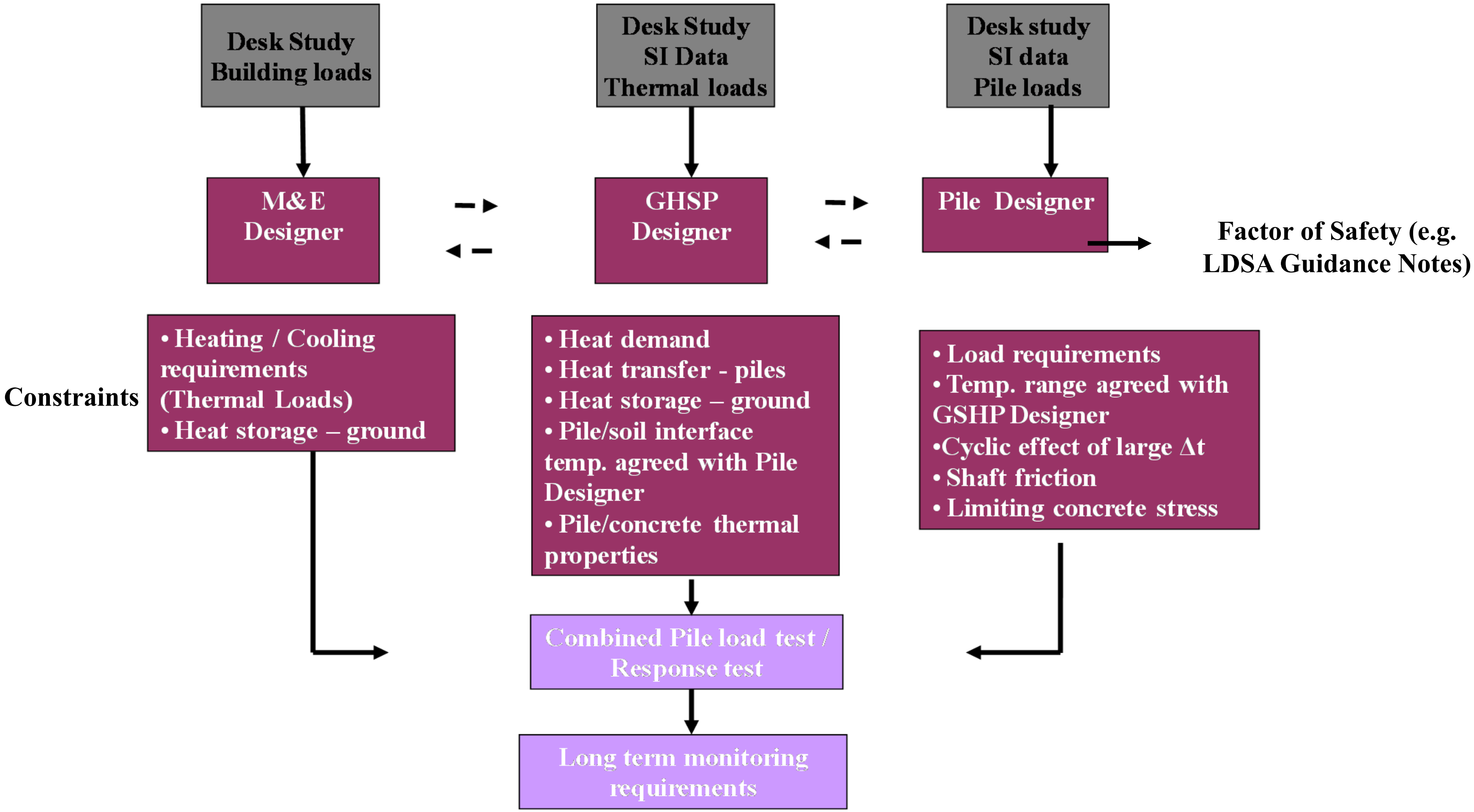
- **"Contractor" design piles**



Denotes parties with responsibilities set out in SPERW (2007)

Section 5 Design requirements

- **Thermal effects complicate traditional pile design**

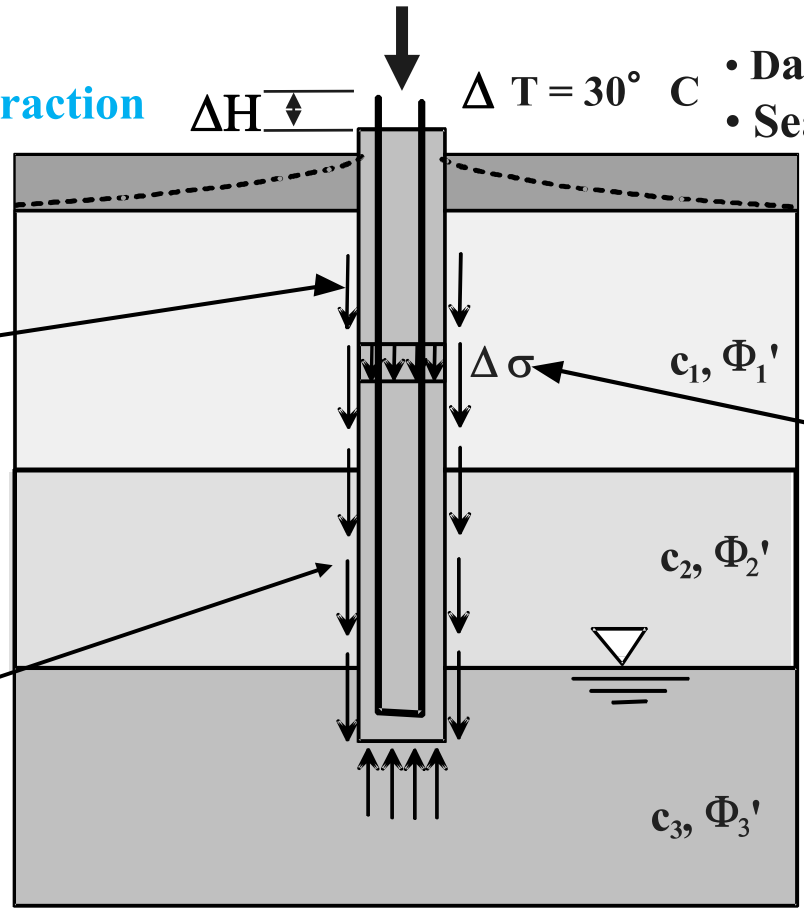


Section 5 Geotechnical Pile design – heating pile

Building Load – effect on pile F of S?

Pile expansion/ contraction

- Daily fluctuations
- Seasonal fluctuations



Ground uplift?

Shaft friction effects:
- Freezing?
- Shear stress?
- Radial stresses?
- Cyclic loads?
- W/C change?

Concrete Stress
- Stress concentrations next to pipes?

Thermal Properties:
- Soils
- Concrete

Geothermal Pile – Geotechnical Design Process

1. **Pile design for structural loads**
   - Normal F of S > 2.0 to 3.0 – (ULS Design)
   - Consider normally consolidated clays as –ve skin friction.
2. **Agree temperature range with GSHP Designer**
   - Interface must not freeze. - Pile/Soil interface eg +2 to +30^{o}C.
   - Number of thermal piles – free head / Fixed head
3. **Assess pile expansion and ground movements (Undrained)**
   - Free head and fixed head (SLS design)
4. **Assess concrete stresses – dead load and thermal**
   - Max concrete stress < Concrete strength (q_c)/4
5. **Consolidation / Quasi – thermal creep effect**
   - Check settlement
6. **Check live loads and thermal cyclic effects**
   - Treat thermal loads as cyclic live loads - 50 annual cycles

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Combined load and thermal test
- Lambeth College, London (2007)

Bourne-Webb et al, (2009) Geotechnique

- **Cementation / GIL / Cambridge**
- **Pile loading test undertaken incorporating cyclic temperature effects**
- **Optical fibre sensor (OFS) system**
- **Conventional vibrating-wire strain gauges (VWSG), thermistors and external load control elements**

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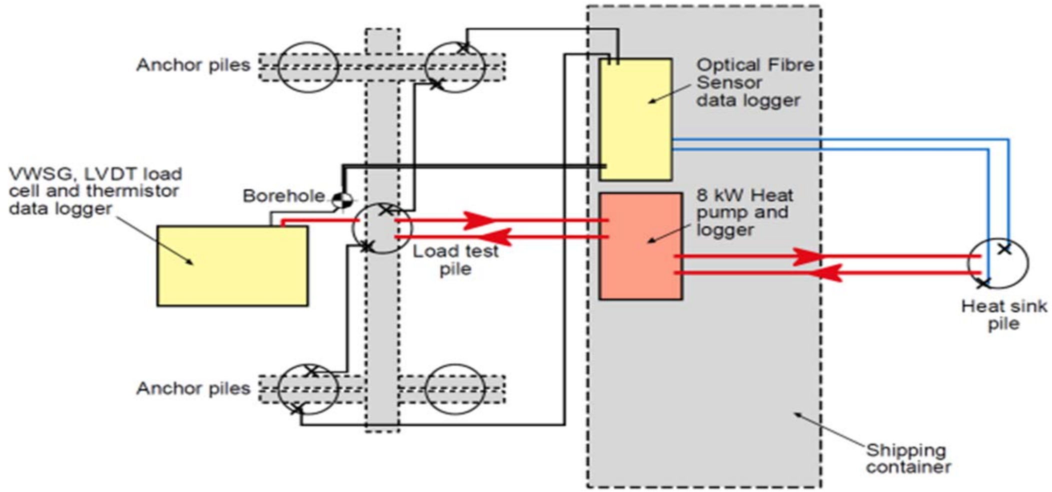
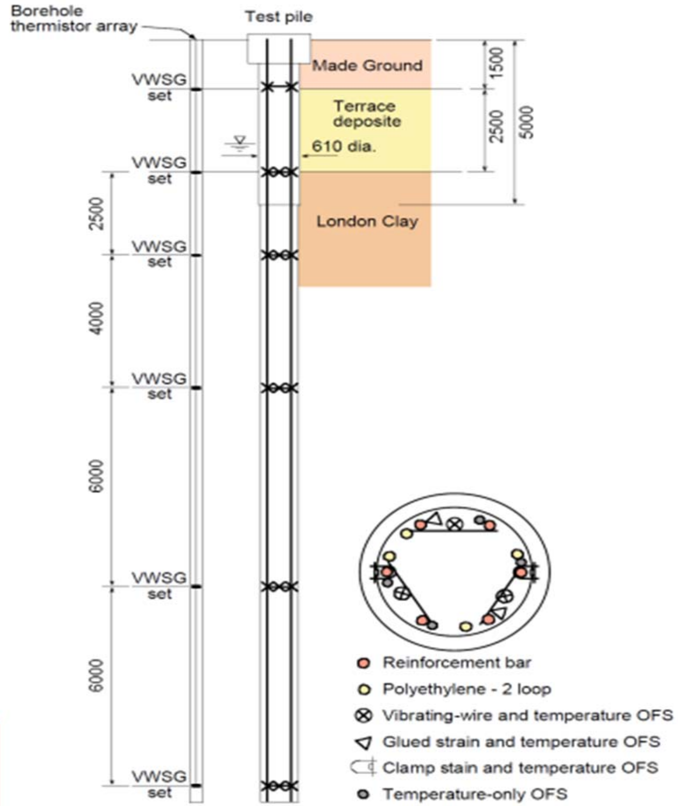
Lambeth College - Geotechnical Assessments

- **Rapid (Undrained0 response –**
  - Expansion of pile - Lambeth College
- **Long term (Drained) response –**
  - Dissipation of pore pressure
- **Quasi Creep effect**
  - Reduction in Preconsolidation pressure with increased temp.
- **Cyclic thermal loading**
  - Annual thermal cycle

Lambeth College Pile Test

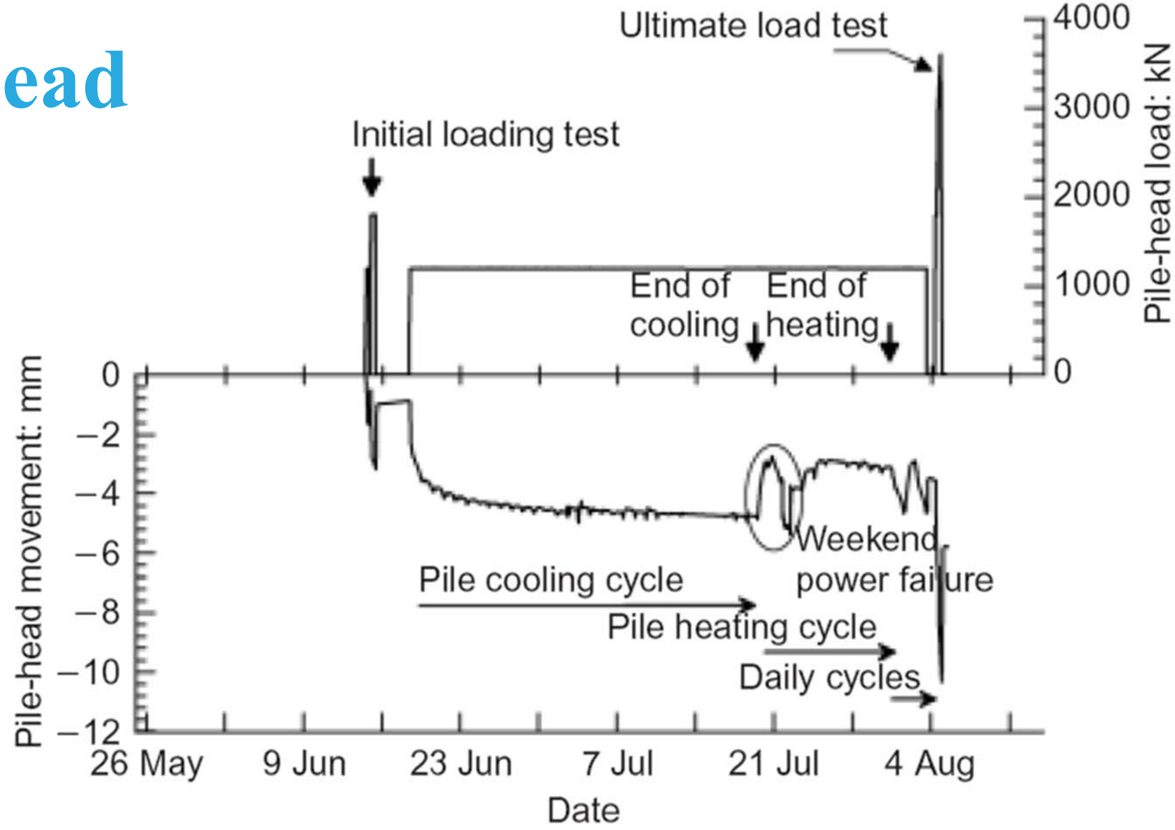
- **Layout and Instrumentation**

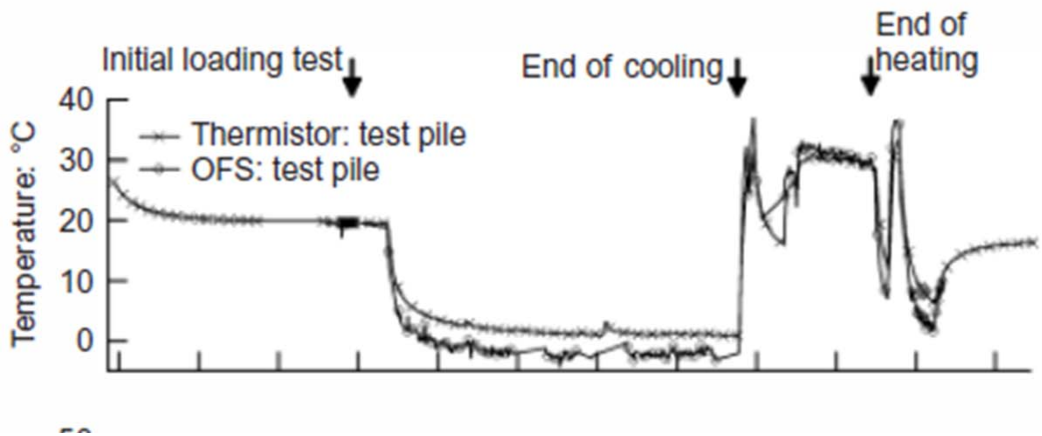




Pile Temp and head movement

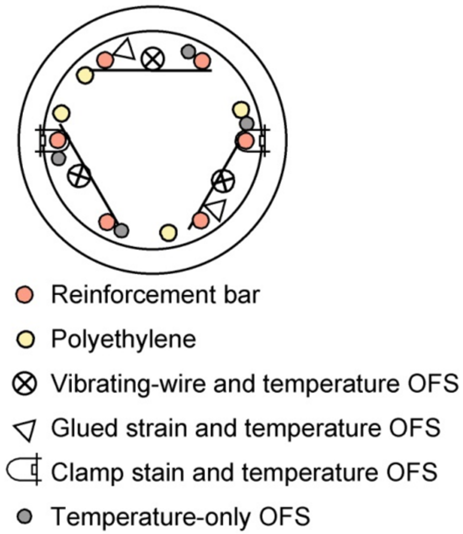
- **Design load -1mm settlement**
- **Cooling – 3mm change**
- **Heating – 2mm change**
- **Little heave during heating**

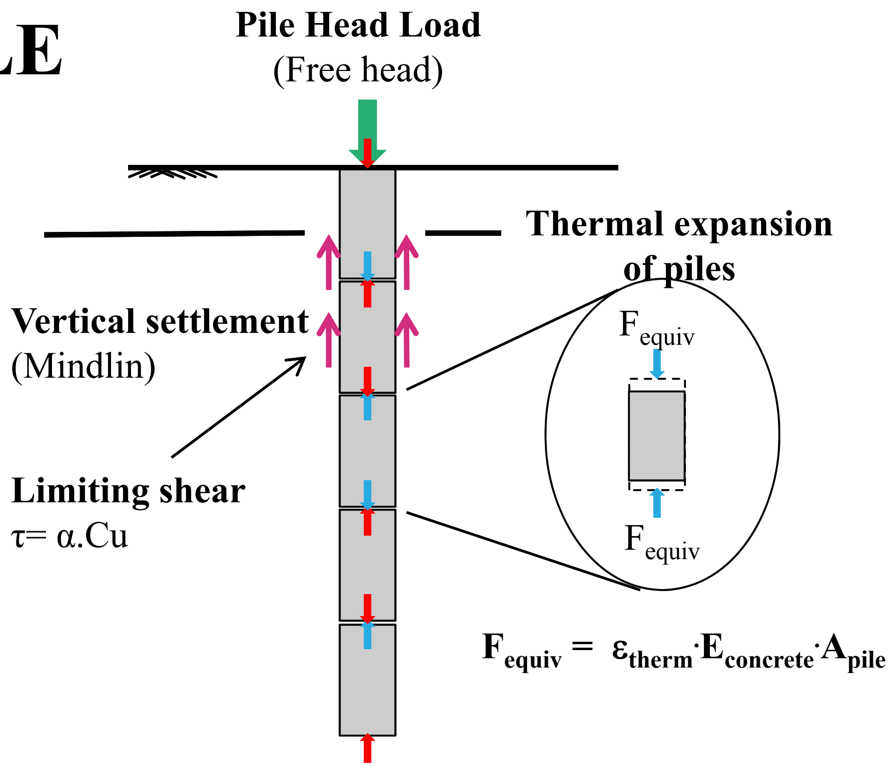




Lambeth College Modelling using DYNA and OASYS PILE

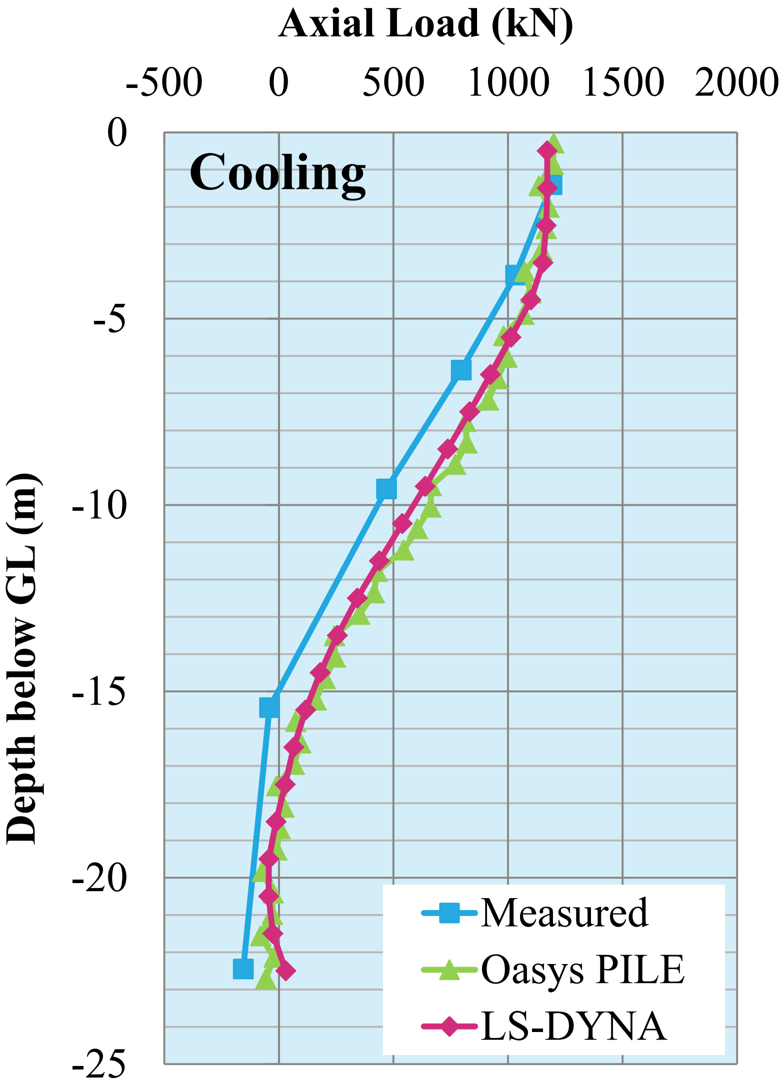
- **Both external load and heating/cooling cycle applied to pile**
- **LS-DYNA and Oasys PILE used to model behaviour**

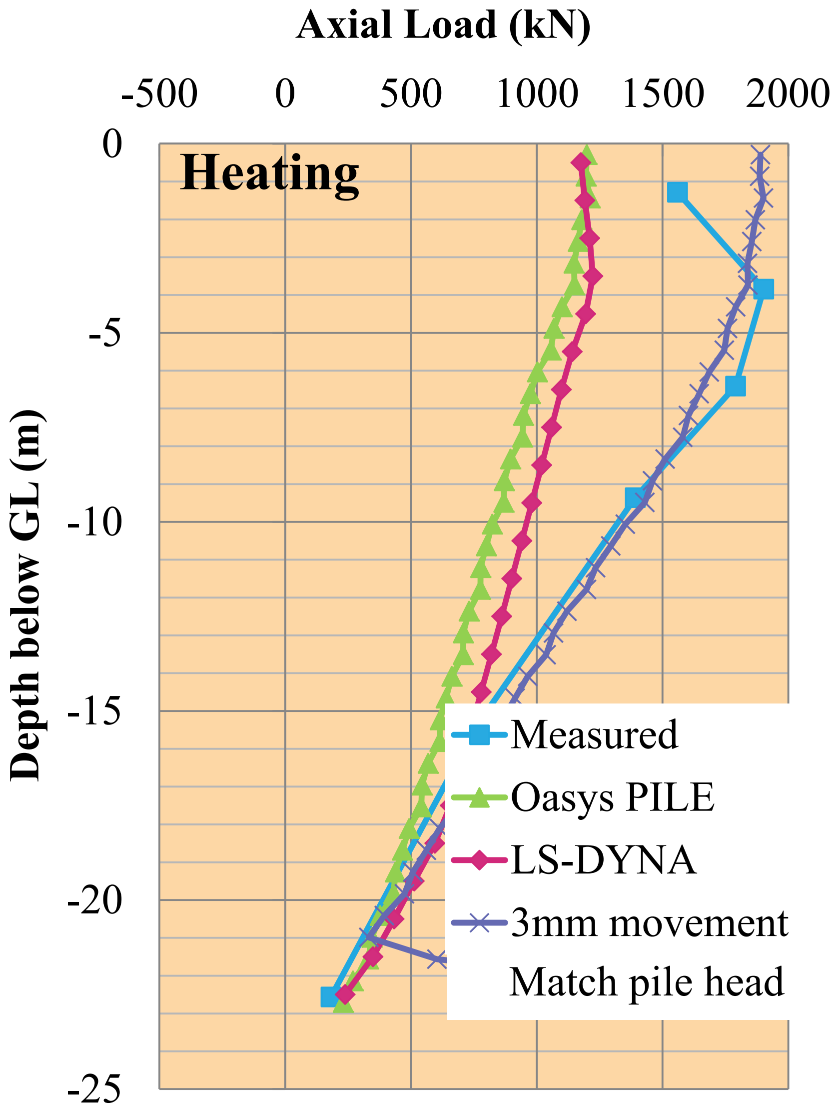




Lambeth College – Pile Loads

Fixed pile head generated large axial load





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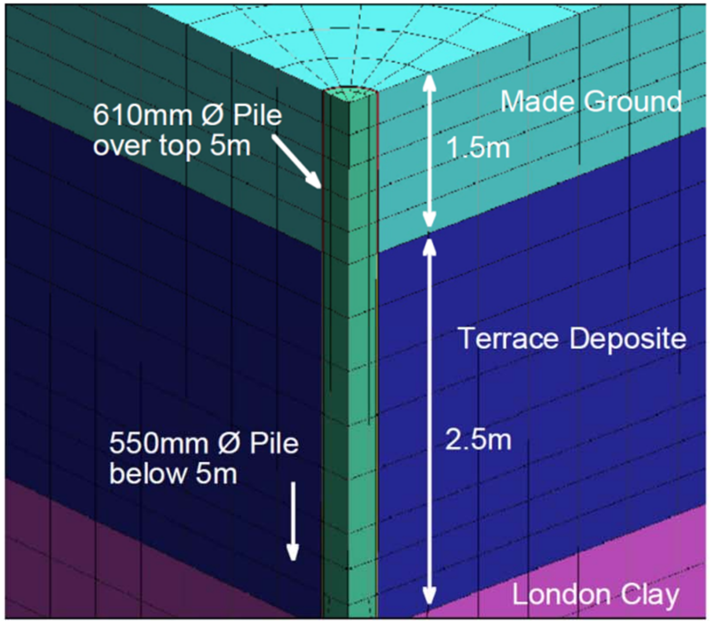
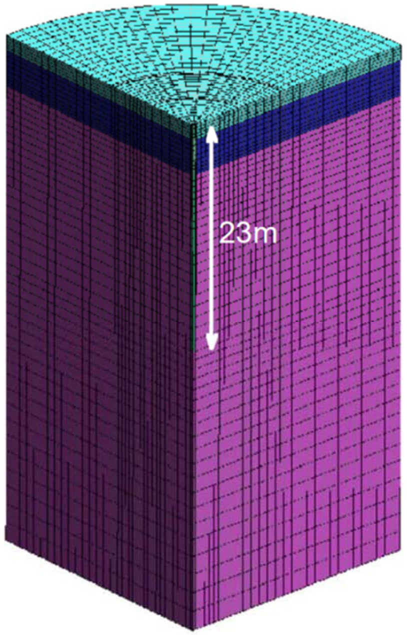
Lambeth College – Modelling pore pressures (In progress)

- **LS-Dyna calculates excess pore pressures due to:-**
  - Undrained pile loading 1200kN
  - Thermal effects
- **Dissipation of water pressures allows consolidation**





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Section 5 - GSHP Design of thermal piles

- **Fleur Loveridge has addressed issues**
- **Pile Modelling Assumes**
  - line source – piles up to 0.3m – Use standard packages
  - Uniform temperature source – larger piles – Use Pile Sim or Orphius
  - Finite element models
- **Number of loops in pile**
- **Low thermal conductivity concrete – similar to soil**
- **High thermal conductivity concrete – reduces thermal resistance**

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Lab Testing – pore pressures

- **Difference in soil/porewater thermal expansion generates excess pore pressures on heating**
- **Discussed in literature:**
  - Campanella & Mitchell (1968)
  - Hueckel, Francois and Laloui (2009)

α_s = thermal expansion of mineral solids

α_w = thermal expansion of soil water

α_{st} = physico-chemical structural volume change

$$\Delta u = \frac{n\,\Delta T\,(\alpha_s - \alpha_w) + \alpha_{st}\,\Delta T}{m_v}$$

(Campanella & Mitchell, 1968)

m_v = soil compressibility

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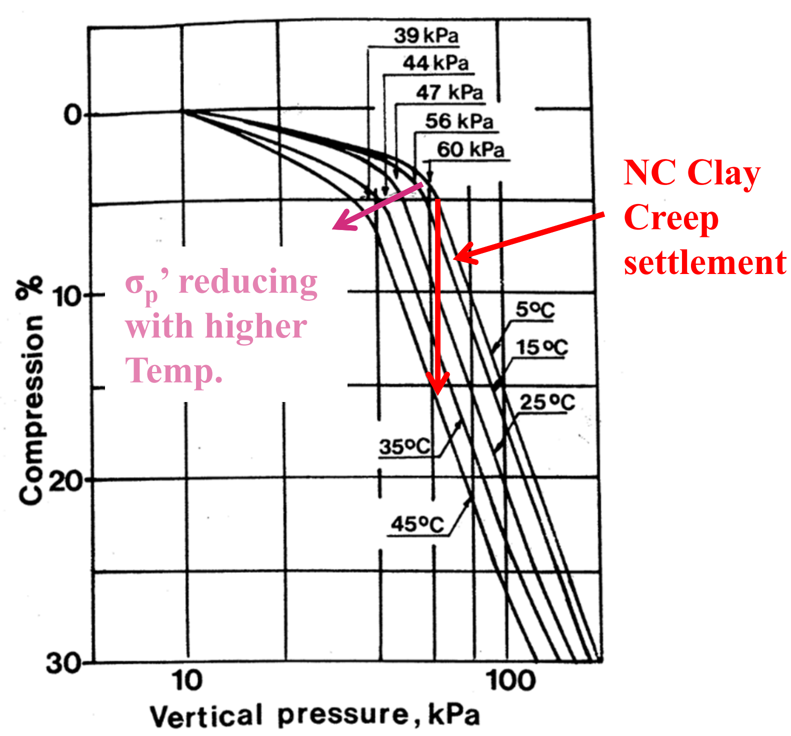
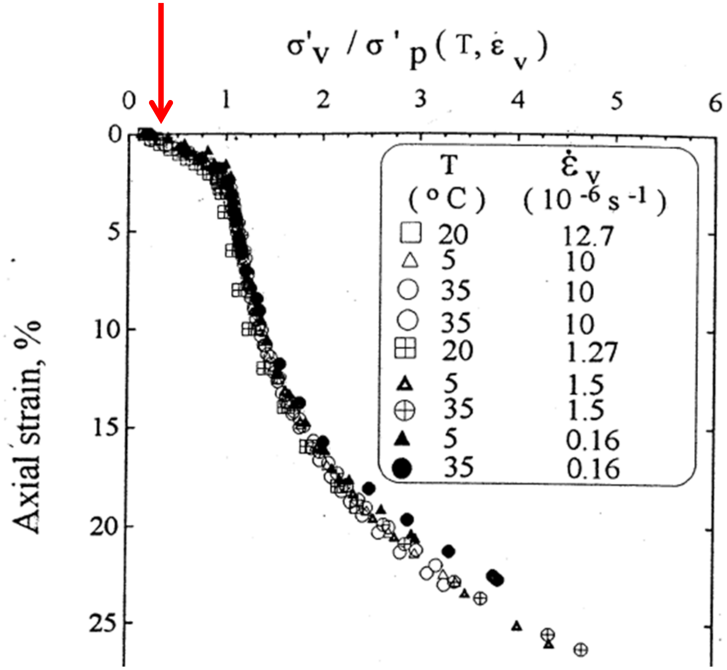
Thermal-creep effect on preconsolidation

- **Heating reduces preconsolidation pressure (σ_p') and stiffness**
- **Creep ignored in OC clays NOT in NC clays.**

London Clay is very over-consolidated.



(Eriksson, 1989)



(Boudali, Leroueil & Srinivasa Murthy, 1994)

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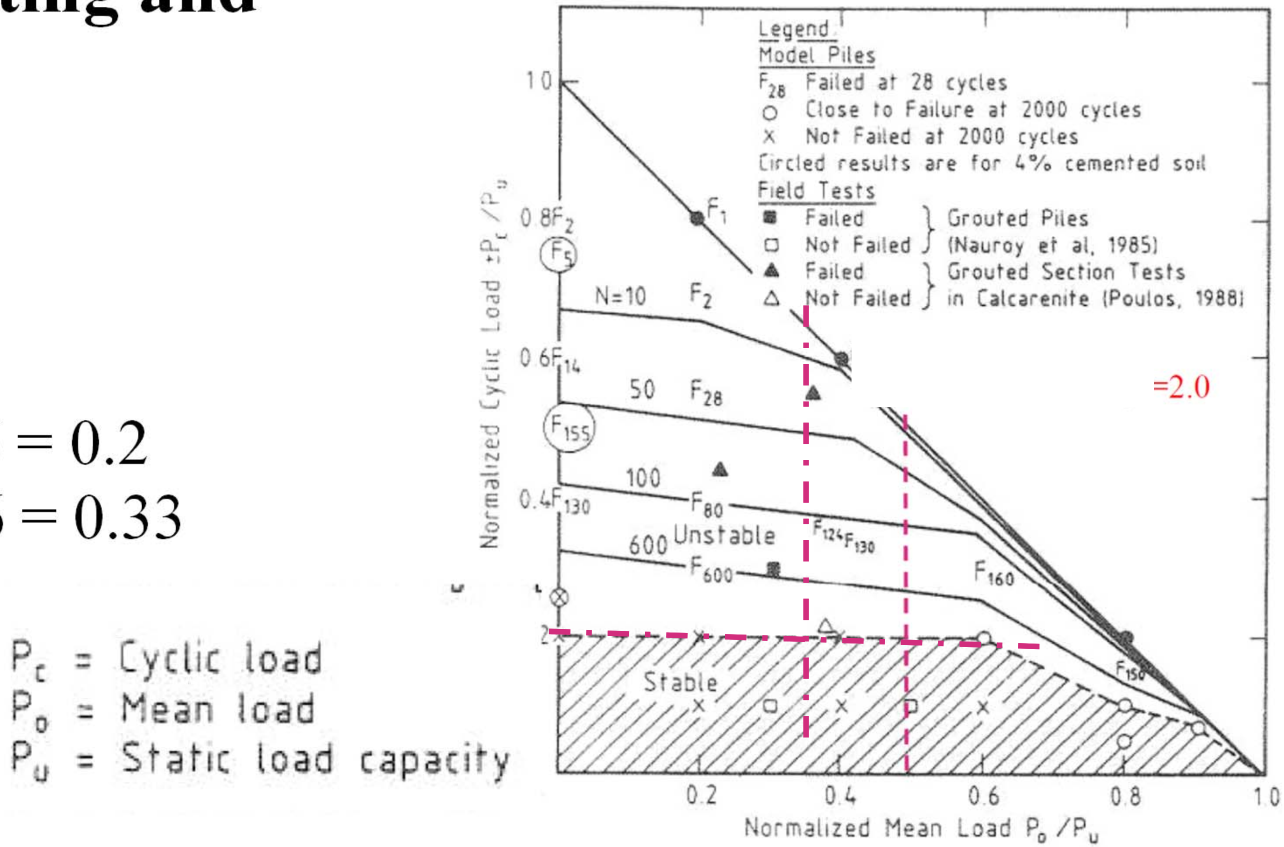
Cyclic loading

- **Cyclic thermal load caused by heating and cooling pile**
  - Pu = 3.6MN
  - Po = 1.2MN
  - Pc = 0.7MN

  - Pc/Pu = 0.7/3.6 = 0.2
  - Po/Pu = 1.2/3.6 = 0.33



Poulos Stability Diagram

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Section 6 – Response Tests for thermal piles

- **How Long should the test take?**
- **Consider Loops on Centreline or round perimeter**
- **Thermal conductivity of concrete relative to soil**
- **Temperature at soil concrete interface**
- **Response test – shallow depth**
  - Part of Geotechnical Investigation
  - Part of pile test eg reaction pile
- **Combine with strain gauges mid depth – thermal stress in piles**

Section 7 Pipe Materials

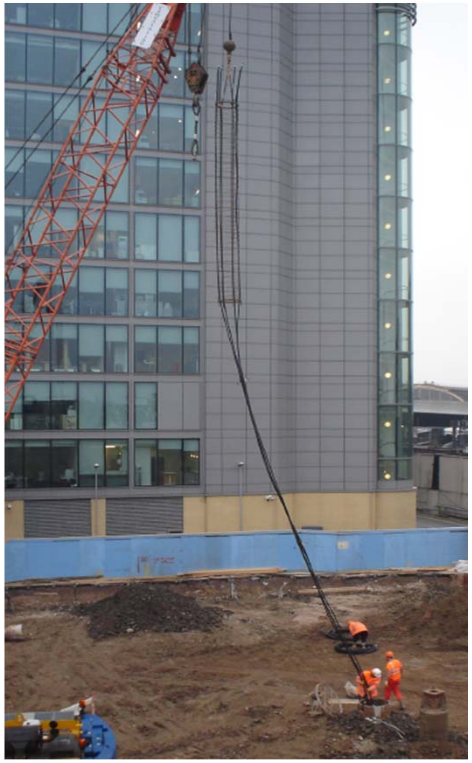
- **Plastic pipes - Bend Radius - PEX at 20°C**
  - **15/??mm -- ??m pile Can a 15mm PEX pipe fit in a 0.45m pile?**
  - **20/1.9 mm - 0.6m pile (20cm)**
  - **25/2.3mm - 0.75m pile. (25cm)**
  - **32/2.9mm - 0.90m pile (32cm)**
  - **40/3.7mm - 1.0m pile cage (40cm)**
- **PE100 or PE100+ at 20°C**
  - **15/??mm -- ??m pile**
  - **20/1.9 mm – 1.0m pile (40cm)**
  - **25/2.3mm - 1.2m pile. (50cm)**
  - **32/2.9mm - 2.2m pile (100cm)**
  - **40/3.7mm - N/A**
  - PEX bends to about half the radius of PE100 or PE100+.
  - Colder temperatures increase min bend radius
  - PEX is more expensive but does not need U bends at the top and bottom of loops.

Section 10 Loop Installation

- **Loops on long cages – Long tremie pipe**
  - Inside cage
  - Outside cage
- **Loops on short cages – Short Tremie**
  -

Section 10 Borehole Loops installation

- **Historically – Europe**
  - Long cages
  - Internal pipes with looped pipes
- **In London - dry bored piles**
  - Use short cages
  - Use borehole U-tubes



- **Paddington Basin – GIL and Cementation**
  - Two pairs of U-tubes

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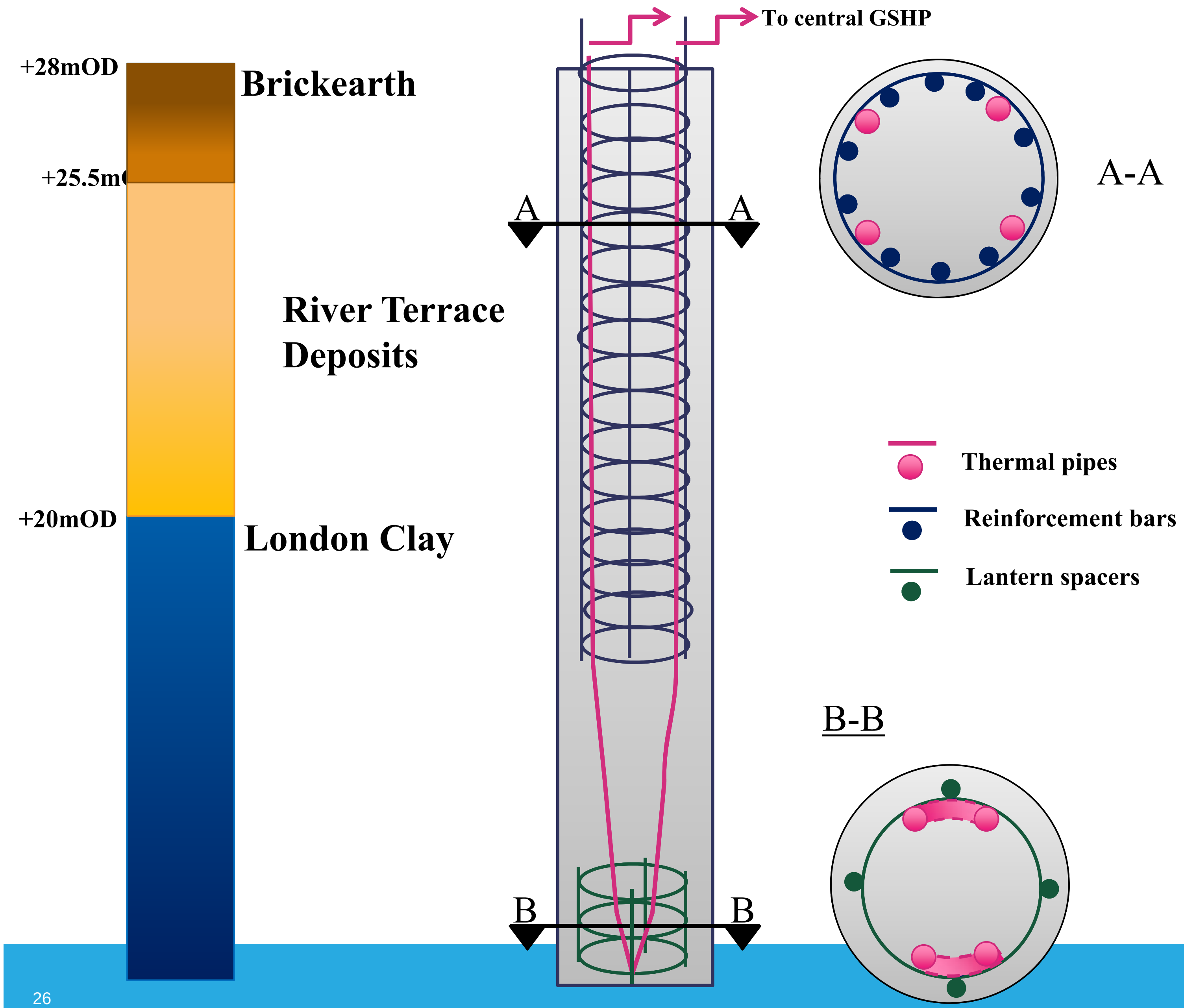
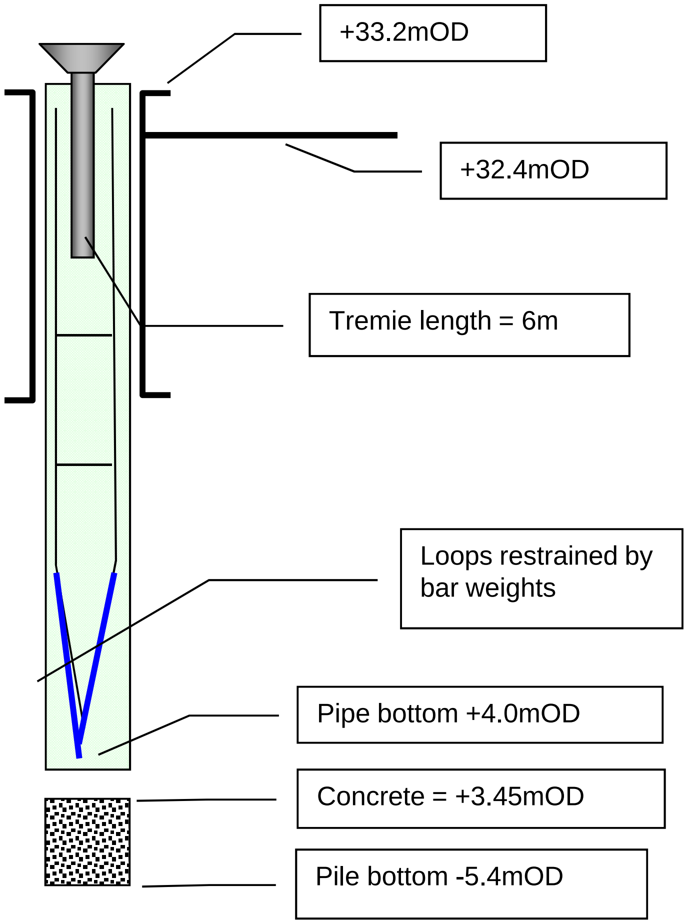
West End Green – Use of lantern spacers (2010)



Short or long tremie – Scratching test (2010)

Test set-up



Photos from test


Bar weights prior to testing

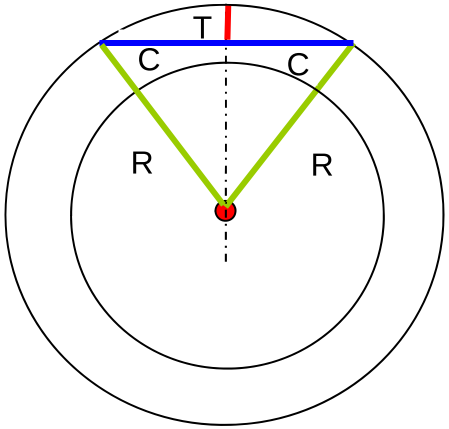

U bend after test


Upper pipe after test


Lower pipe after test

Scratch depth measurement on 32mm pipes

- **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

Conclusions

– Vertical pipes – <1mm scratches

- Splayed pipes - 1 to 2mm scratches



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CFA Piles, Cambridge (Bachy Web site)

- **Pile design - Motts**
- **Pile Contractor – Bachy**
- **Loop design / build – GIL**
- **CFA piles (600mm dia)**
  150 No up to 25m depth
- **Loops - 4 pipes x 32mm dia**
- **Pushed with 1 x T32**
- **Heating - 188kW**
- **Cooling - 117kW**

Plunging used T32 bar + 4 pipes (2 loops)

Trimming

Cage and header pipes

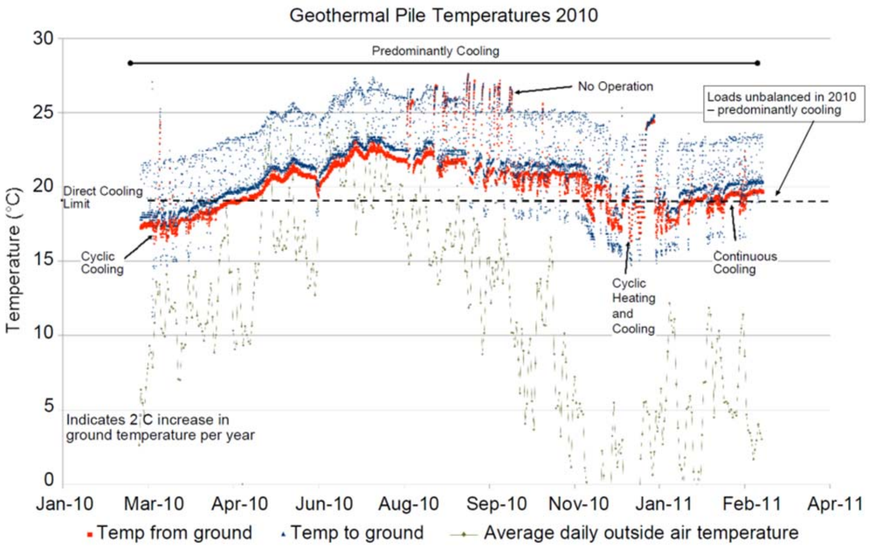
Section 11 Pressure testing

- **Checks for loop leakage**
  - During installation
  - Contract interfaces
- **Pressurise loops during installation**
  - European contractors pressurise loops during installation
  - UK does not do this?
- **Relevance of pressure test in concrete**
  - Pipe relaxation at high pressures
  - Stiff response increases test sensitivity
  - Pipe pressure can increase – Pile concrete heats water - expansion

Section 15 Monitoring and triggers

- **No freezing at Soil/Pile interface**
- **Little data on relationship between circulation fluid temp and interface temperature**
- **Adopt conservative minimum temperature from heat pump**
- **Monitor**
- **Use trigger values**
- **Under discussion**

Keble College - Oxford



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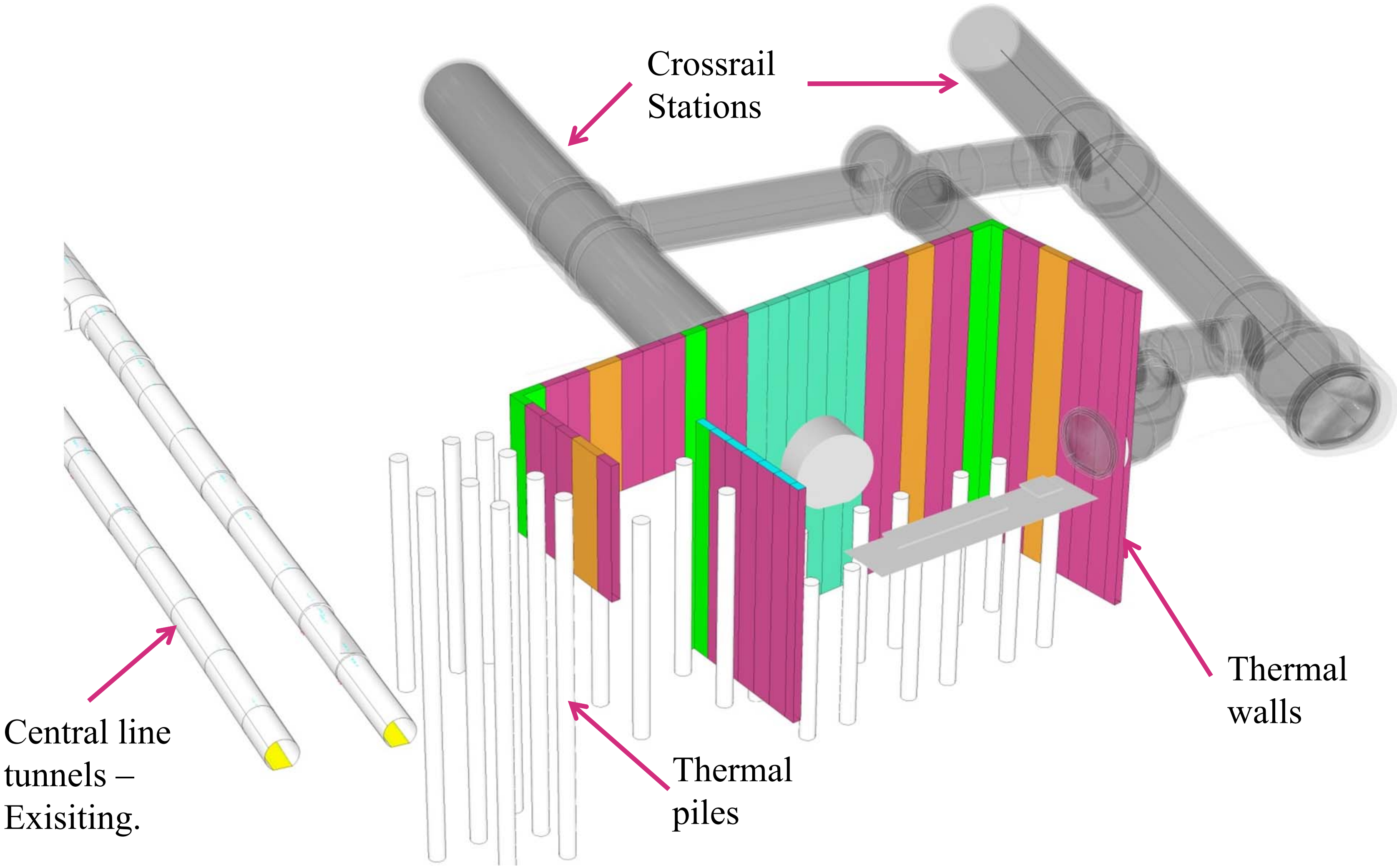
Thermal Walls – Crossrail Dean Street Box



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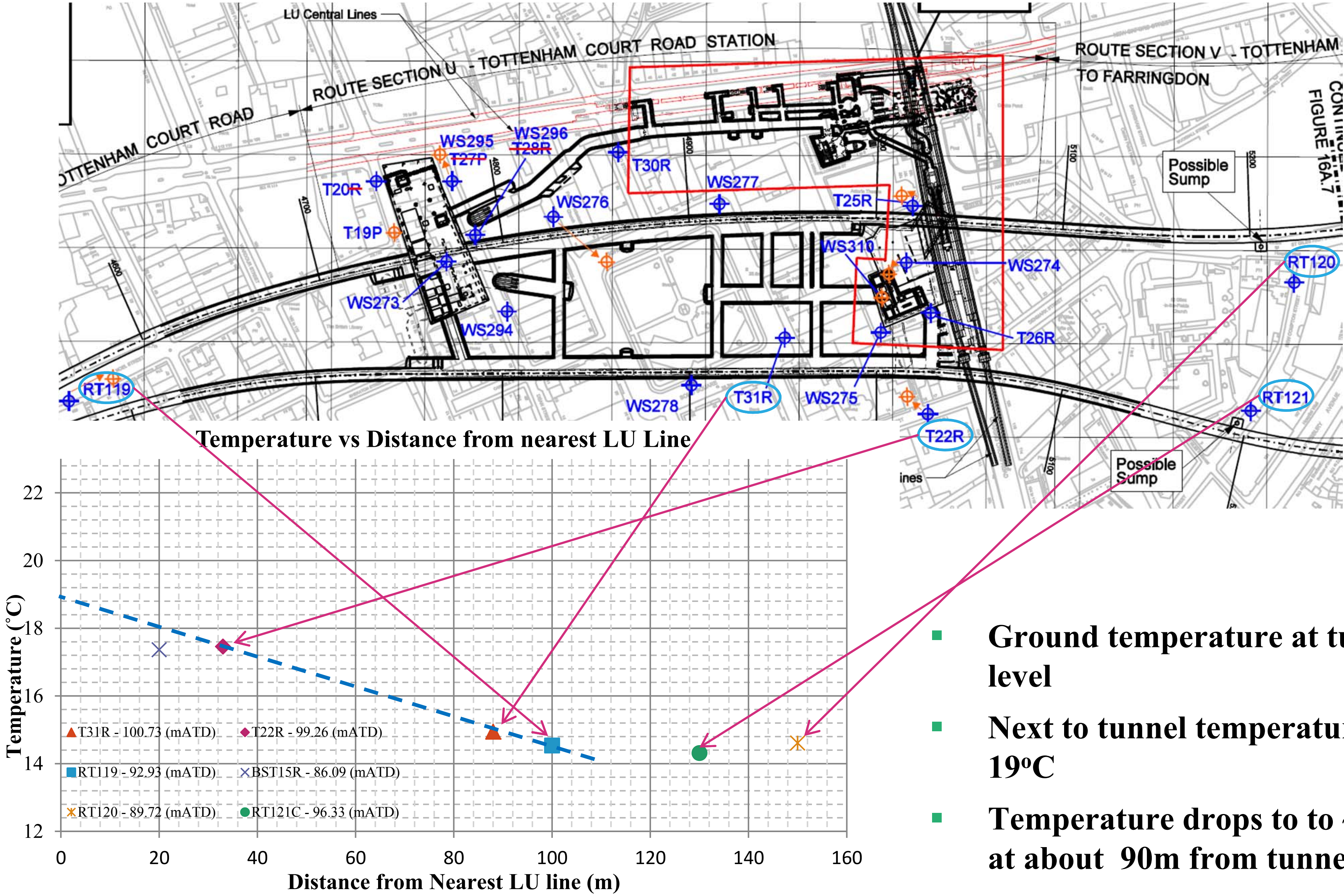
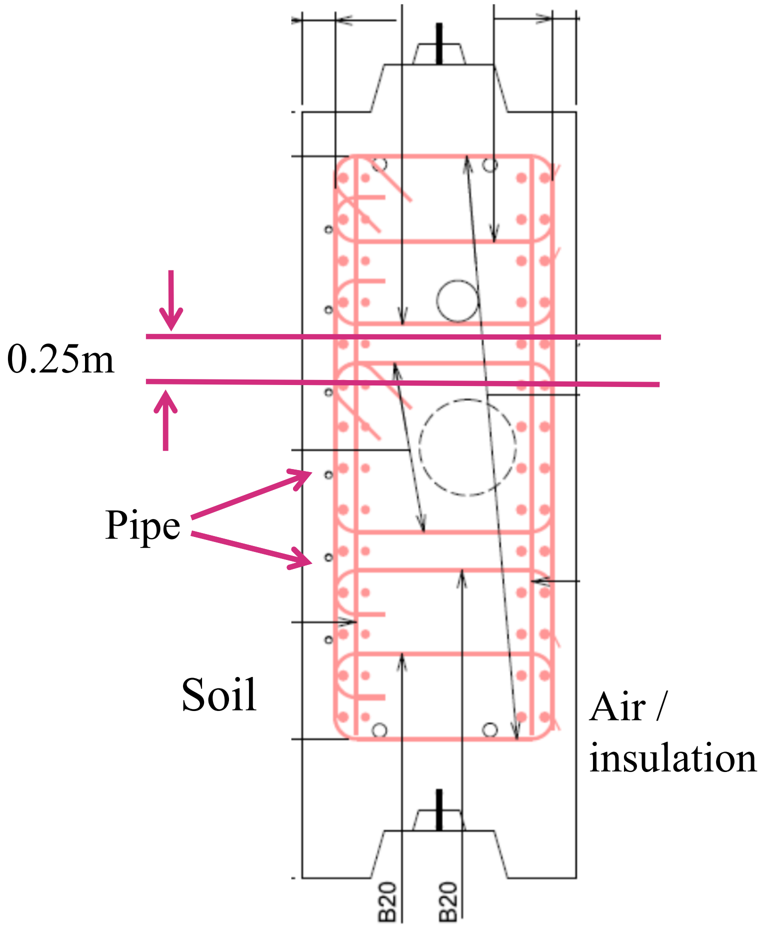
Crossrail - Ground temperatures at Oxford Street

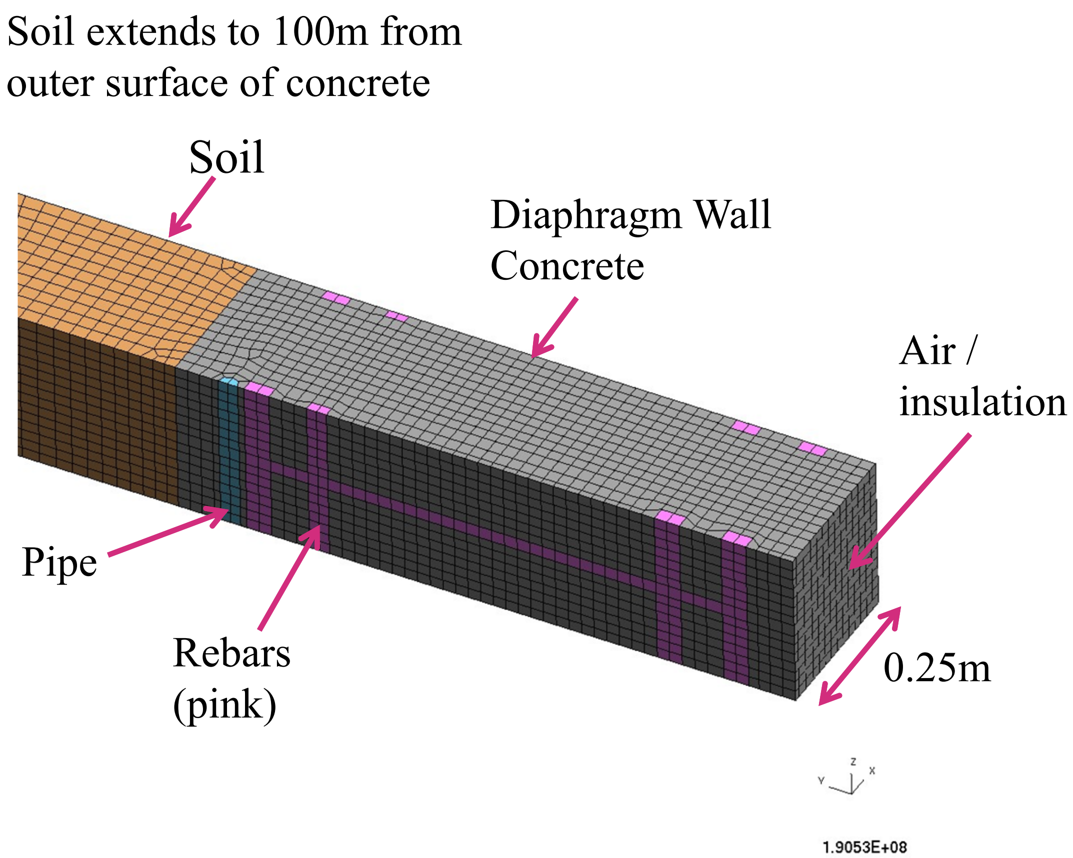


- Ground temperature at tunnel level
- Next to tunnel temperature 19^{o}C
- Temperature drops to to ~15^{o}C at about 90m from tunnel

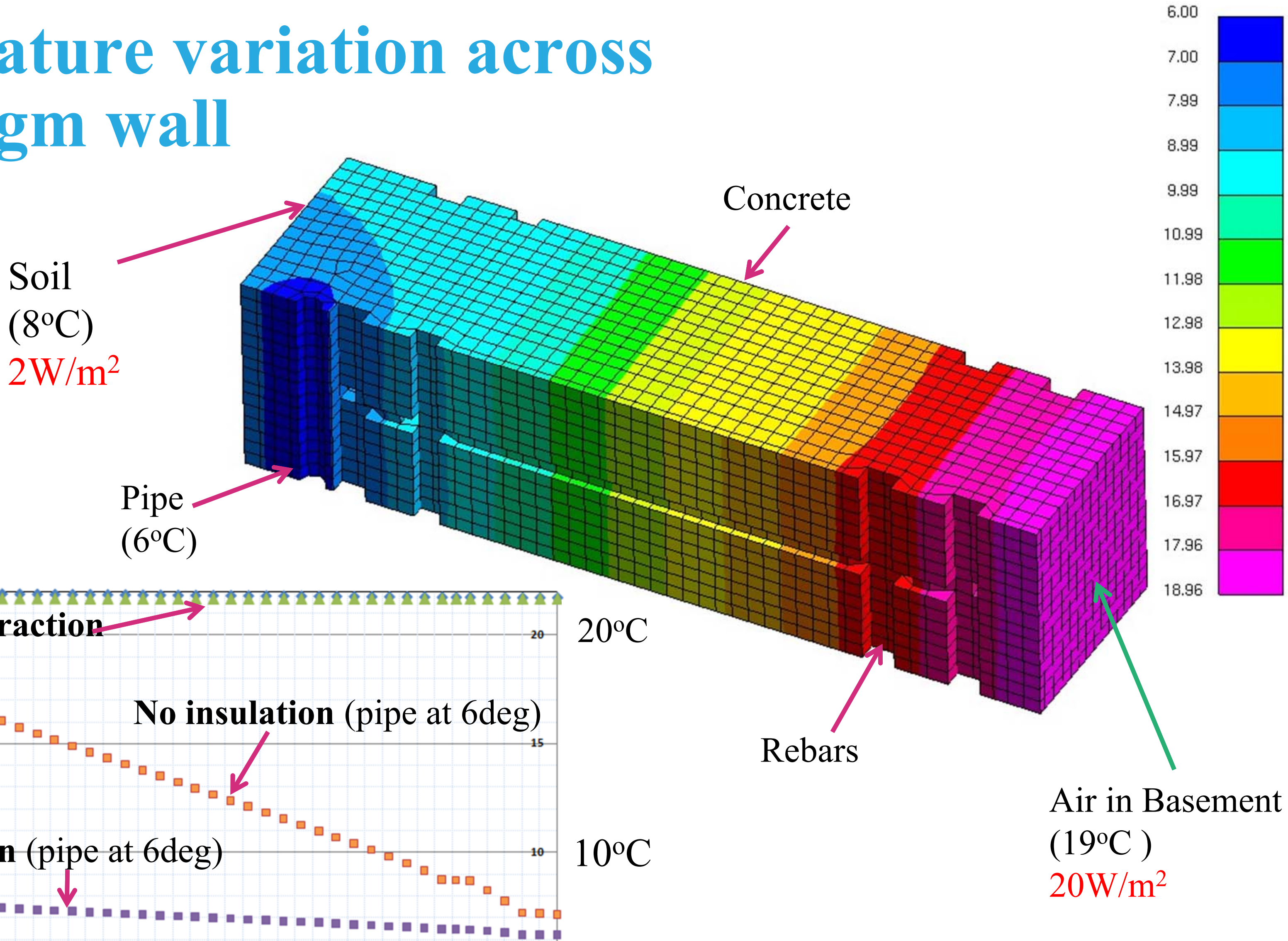
Diaphragm wall
Dyna Model - Temperature effect on wall

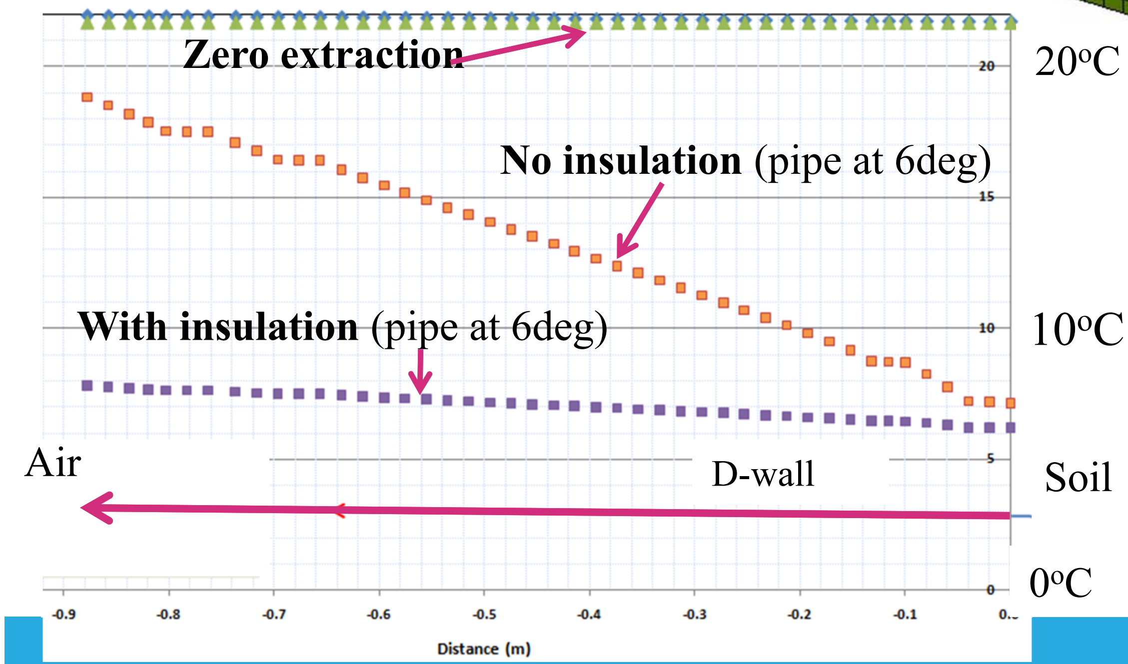


PLAN VIEW



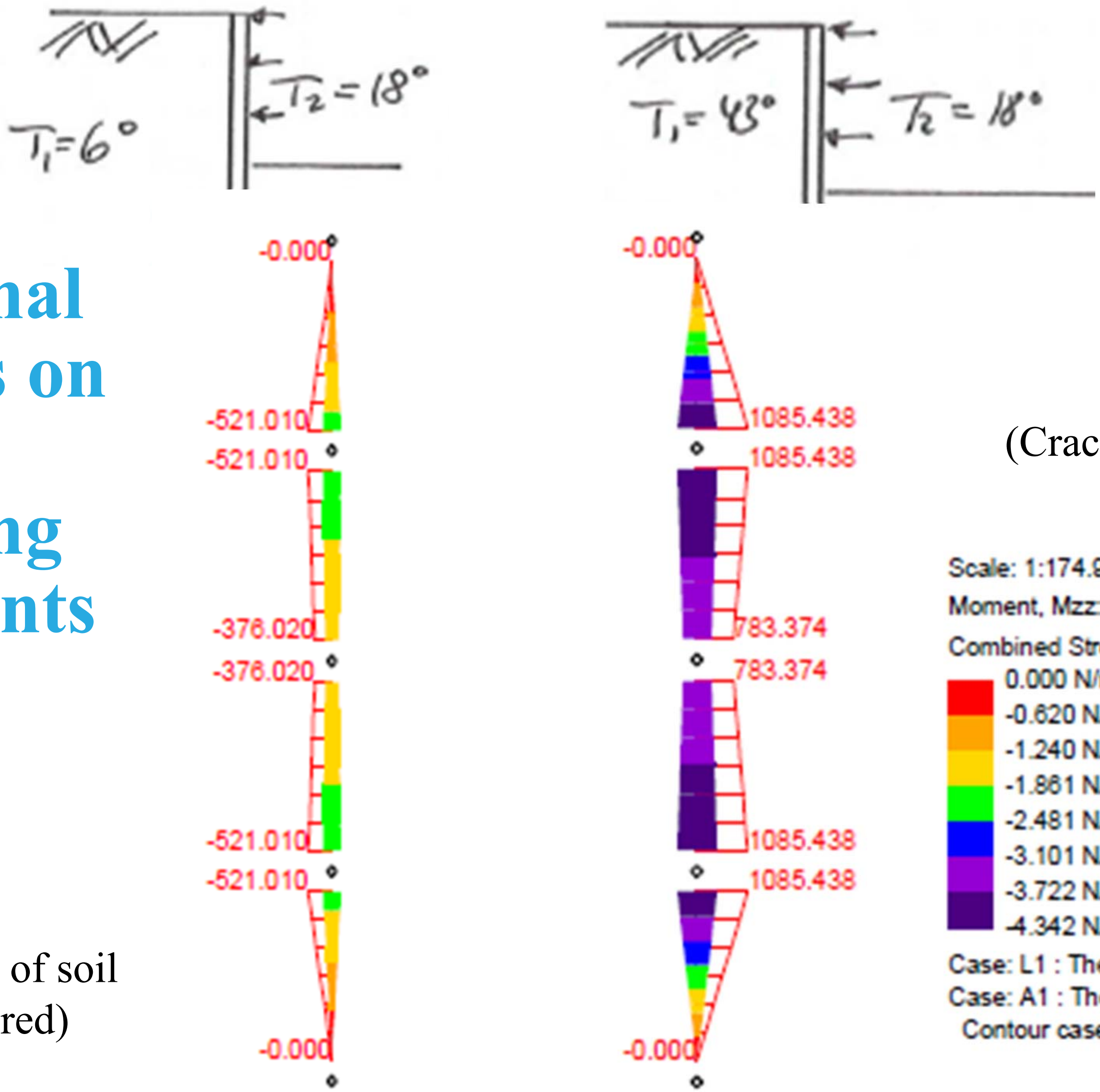
Temperature variation across diaphragm wall





(6 months cooling)

Thermal effects on wall bending moments



(Cracked sections)

Scale: 1:174.970
Moment, Mzz: 2000.000 kNm/pic.cm
Combined Stress, C2: 10.000 N/mm²/pic.cm
0.000 N/mm²
-0.620 N/mm²
-1.240 N/mm²
-1.861 N/mm²
-2.481 N/mm²
-3.101 N/mm²
-3.722 N/mm²
-4.342 N/mm²
Case: L1 : Thermal Gradient
Case: A1 : Thermal Gradient
Contour case

(Expansion of soil not considered)

Conclusions -Thermal pile standard advances

- **Contents List**
  - Sec 1 Preamble (as VBS)
  - Sec 2 Regulations and governments (as VBS)
  - Sec 3 Contractual setup
  - Sec 4 Training requirements (Link with FPS for piles)
  - Sec 5 Design
  - Sec 6 Thermal response
  - Sec 7 Pile materials and methods
  - Sec 8 Pipe Jointing (as VBS)
  - Sec 9 Thermal pile concrete
  - Sec 10 Loops installation
  - Sec 11 Pressure testing
  - Sec 12 Indoor piping /values (as VBS) – Header pipes
  - Sec 13 Thermal Transfer fluids (as VBS) – High loop temps – use water as Europe?
  - Sec 14 Design drawings
  - Sec 15 Monitoring and checking
  - Sec 16 Alterations

Thank you for your attention

- **Any Questions?**

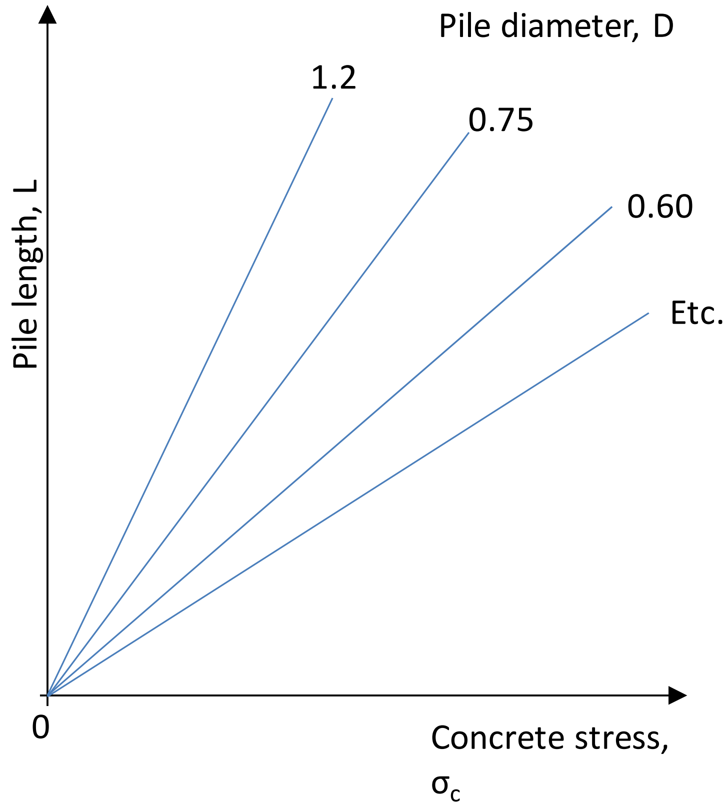
Thank you!

- **References**

  - Campanella, R.G. & Mitchell, J.K. (1968) Influence of temperature variations on soil behaviour, Journal of the Soil Mechanics and Foundations Division, 94(SM3), ASCE, pp 709-734.
  - Boudali, M., Leroueil, S. & Srinivasa Murthy, B.R. (1994) Viscous behaviour of natural clays, Proc. 13th Int. Conf. Soil Mechanics and Foundation Engineering, New Delhi, pp 411-416.
  - Eriksson, LG, (1989) Temperature effects on consolidation properties of sulphide clays, Proc. 12th Int. Conf. Soil Mechanics and Foundation Engineering, Rio de Janeiro, Vol. 3: pp 2087-2090

Design requirements – design charts

- **Design basis**
  - Thermal pile load test
  - Computer model
- **Typical temperature range to consider**
  - ±5 to 10ºC daily
  - ±20ºC seasonal
- **Model of varying length/diameter of piles and study effect on concrete stress, FOS.**



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Further work

- **Ongoing research provided in Appendices to the Thermal Pile Standard**
  - Soil and concrete thermal conductivity
  - Thermal response test interpretation for larger diameter piles
  - Change in soil behaviour / shaft friction / concrete stress with temperature variations
  - Pile / soil interface zone temperature and thermal conductivity
- **Knowns and unknowns in producing the design guidance clearly stated**
- **Several further revision cycles required to finalise the document with the T&SC**

Conclusions

- **Thermal Piles are established in UK.**
- **Thermal Pile / Heat pump systems - compete with gas boilers, biomass, CHP.**
- **Thermal pile installation methods developing.**
  - Need to check installation damage.
- **Geothermal design based on borehole loops guidance.**
- **Geotechnical design developing.**
- **Ownership of design responsibilities unclear.**
- **Few designers and contractors able to tender for work.**
- **Thermal walls – Design processes under development**
  - Basement insulation, thermal stresses on wall moments, earth pressures.

Design requirements – laboratory testing

- **Thermal conductivity - concrete**
  - Soil, concrete and interface zone
  - Eurocode or ASTM methods (eg Guarded hot plate)