GSHPA Thermal Pile Standard

Ground Source Heat Pump Association
Technical Seminar

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Homerton College, Cambridge University

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Thermal Pile Standard – sub committee

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- Jake Salisbury GSHPA - (Secretary)
GSHPA - Thermal Pile Standard overview

- **Contents List**
  - Sec 1 Preamble (as in the Vertical Borehole Standard)
  - 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
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

- Concept Design, Design Development, Tender (RIBA Work Stage A-H)

- Pile Construction, Trimming & Groundworks (RIBA Work Stage J onwards)

- Denotes parties with responsibilities set out in SPERW (2007)
Contractual responsibilities

- “Contractor” design piles

Denotes parties with responsibilities set out in SPERW (2007)
Section 5  Design requirements

- Thermal effects complicate traditional pile design

- Desk Study Building loads → M&E Designer
  - Heating / Cooling requirements (Thermal Loads)
  - Heat storage – ground

- Desk Study SI Data Thermal loads → GHSP Designer
  - Heat demand
  - Heat transfer - piles
  - Heat storage – ground
  - Pile/soil interface temp. agreed with Pile Designer
  - Pile/concrete thermal properties

- Desk study SI data Pile loads → Pile Designer
  - Load requirements
  - Temp. range agreed with GSHP Designer
  - Cyclic effect of large ΔT
  - Shaft friction
  - Limiting concrete stress

- Combined Pile load test / Response test
  - Long term monitoring requirements

Factor of Safety (e.g. LDSA Guidance Notes)
Section 5 Geotechnical Pile design – heating pile

Building Load – effect on pile F of S?

Pile expansion/ contraction

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

Thermal Properties:
- Soils
- Concrete

Ground uplift?

Concrete Stress
- Stress concentrations next to pipes?

- Daily fluctuations
- Seasonal fluctuations

$\Delta T = 30^\circ C$
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°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 \( \frac{q_c}{4} \)

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
Combined load and thermal test  


- 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
Lambeth College - Geotechnical Assessments

- **Rapid (Undrained) 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

\[ F_{equiv} = \varepsilon_{therm} E_{concrete} A_{pile} \]

- Vertical settlement (Mindlin)
- Limiting shear \( \tau = \alpha C_u \)

- Pile Head Load (Free head)

- Thermal expansion of piles

- Reinforcement bar
- Polyethylene
- Vibrating-wire and temperature OFS
- Glued strain and temperature OFS
- Clamp stain and temperature OFS
- Temperature-only OFS
Lambeth College – Pile Loads

Fixed pile head generated large axial load

Axial Load (kN)

Depth below GL (m)

Cooling

-500 0 500 1000 1500 2000

Heating

-500 0 500 1000 1500 2000

3mm movement

Match pile head

Axial Load (kN)

Depth below GL (m)

Measured

Oasys PILE

LS-DYNA
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
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**
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)

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

\( \alpha_s \) = thermal expansion of mineral solids

\( \alpha_w \) = thermal expansion of soil water

\( \alpha_{st} \) = physico-chemical structural volume change

\( m_v \) = soil compressibility
Thermal-creep effect on preconsolidation

- Heating reduces preconsolidation pressure ($\sigma_p'$) and stiffness
- Creep ignored in OC clays, NOT in NC clays.

London Clay is very over-consolidated.

$\sigma_p'$ reducing with higher Temp.

NC Clay Creep settlement

(Eriksson, 1989)

(Boudali, Leroueil & Srinivasa Murthy, 1994)
Cyclic loading

- Cyclic thermal load caused by heating and cooling pile
  - \( P_u = 3.6 \text{MN} \)
  - \( P_o = 1.2 \text{MN} \)
  - \( P_c = 0.7 \text{MN} \)
  - \( P_c/P_u = 0.7/3.6 = 0.2 \)
  - \( P_o/P_u = 1.2/3.6 = 0.33 \)

Poulos Stability Diagram
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 20ºC**
  - 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 20ºC**
  - 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
West End Green – Use of lantern spacers (2010)

+28mOD  
+25.5mOD  
+20mOD

Brickearth

River Terrace Deposits

London Clay

To central GSHP

A-A

Thermal pipes
Reinforcement bars
Lantern spacers

B-B

AA

BB
**Short or long tremie – Scratching test (2010)**

**Test set-up**
- Concrete = +3.45mOD
- Pipe bottom +4.0mOD
- Pile bottom -5.4mOD
- Tremie length = 6m
- Loops restrained by bar weights

**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

\[ 2C \text{ – chord length (mm) - measured; } \\
T \text{ – Depth of the scratch (mm) - calculated } \\
R \text{ – radius of the pipe – measured } \]

**Conclusions**
- Vertical pipes – <1mm scratches
- Splayed pipes - 1 to 2mm scratches
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
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
Thermal Walls – Crossrail Dean Street Box

Central line tunnels – Existing.

Crossrail Stations

Thermal piles

Thermal walls

ARUP
Crossrail - Ground temperatures at Oxford Street

- Ground temperature at tunnel level
- Next to tunnel temperature 19°C
- Temperature drops to to ~15°C at about 90m from tunnel
Diaphragm wall
Dyna Model - Temperature effect on wall

PLAN VIEW

Soil extends to 100m from outer surface of concrete
Temperature variation across diaphragm wall

Soil (8°C) 2W/m²

Pipe (6°C)

Concrete

Rebars

Air in Basement (19°C) 20W/m²

With insulation (pipe at 6deg)

No insulation (pipe at 6deg)

Zero extraction

Air

D-wall

Soil

(6 months cooling)
Thermal effects on wall bending moments

(Expansion of soil not considered)

(Cracked sections)
Conclusions - Thermal pile standard advances

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Thank you for your attention

- Any Questions?
References


Design requirements – design charts

- **Design basis**
  - Thermal pile load test
  - Computer model

- **Typical temperature range to consider**
  - ±5 to 10°C daily
  - ±20°C seasonal

- **Model of varying length/diameter of piles and study effect on concrete stress, FOS.**
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)