The importance of the concrete in thermal pile behaviour

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Outline

• Introduction & traditional approach
• A transient approach to pile concrete
• Numerical study using real heat pump temperatures
• Initial site data
• Concrete thermal properties
• Conclusions
Pile Thermal Resistance

- Temperature change across concrete usually captured using a (steady state) resistance term

\[ R_b = R_{pconv} + R_{pcond} + R_c \]

- Empirical database of experience is absent

- \( R_{pconv} \) & \( R_{pcond} \) relatively “easy” to calculate

- \( R_c \) is often largest part of resistance due to volume of concrete

- Depends on pipe arrangements and thermal conductivity of concrete
Time to Approach Steady State

- 300mm diameter piles
- 600mm diameter piles
- 1200mm diameter piles

% of steady state resistance vs time (days)
Time to Approach Steady State

Time for a transient approach?
Piles with Centrally Placed Pipes

Upper bound case:
- 1200 mm pile; central pipes;
- $\lambda_c = 2\text{W/mK}, \lambda_g = 1\text{W/mK}$

Lower bound cases:
- 300mm pile; central pipes;
- $\lambda_c = 1\text{W/mK}, \lambda_g = 2\text{W/mK}$
Piles with Pipes near the Edge

![Graph showing % of steady state Rc against Fo (αt/r_b^2) for two cases:
- Upper bound case: 1200 mm pile, pipes near edge; \( \lambda_c=2\text{W/mK}, \lambda_g=1\text{W/mK} \)
- Lower bound cases: 300 mm pile, pipes near edge; \( \lambda_c=1\text{W/mK}, \lambda_g=2\text{W/mK} \).]
Example: Steady State vs Transient

\[ \Delta T_f = qR_p + qR_c G_c + \frac{q}{2\pi \lambda_g} G_g \]

- **Assumptions:**
  - Transient G function for ground temperature changes
  - Transient G function for pile concrete (as % of steady Rc)
  - Steady state heat transfer within and across pipes
  - 600mm dia pile, 20m long (AR=33.3); 4 pipes near the edge
- \( \lambda_c=1\text{W/mK}; \lambda_g=2\text{W/mK}; \alpha_g=1\text{E-6m2/s} \)
- \( Rc=0.075\text{mK/W}; \ Rp=0.025\text{mK/W} \)
Thermal Pile G-function

![Graph showing the thermal pile G-function with different aspect ratios (AR) indicated: AR=50, AR=33, AR=25, AR=15. The graph plots φ₉ against Fo (Foorka number) on a logarithmic scale for various aspect ratios.](image_url)
Pile Concrete G-function

- **Upper bound case:** 1200 mm pile; pipes near edge; $\lambda_c=2\text{W/mK}$, $\lambda_g=1\text{W/mK}$
- **Lower bound cases:** 300 mm pile; pipes near edge; $\lambda_c=1\text{W/mK}$, $\lambda_g=2\text{W/mK}$
Thermal Loads

The graph shows the heating/cooling demand in W/m over hours (in Year). The x-axis represents the hours ranging from 0 to 9000, and the y-axis represents the heating/cooling demand ranging from -120 to 60 W/m. The pattern indicates periods of high demand, with peaks around 4000, 5000, 6000, 7000, and 8000 hours, and lower demand in between these periods.
Thermal Loads: Daily Variation
Results: Components

Graphs showing temp change over time for:
- Ground temperature change - transient
- Pile temperature change - steady state
- Pile temperature change - transient
- Pipe temperature change - steady state
Results: Totals

![Graph showing temperature change over time with two lines: one for constant Rc and one for transient Rc.](image-url)
Results: Totals

- Total temp change - constant Rc
- Total temp change - transient Rc
Results: Totals
Real Thermal Loads
Numerical Model
(2D ABAQUS)
Results: Temperatures

\( \lambda_c = \lambda_g = 3 \text{W/mK} \)
Results: Heat Flux
Siemens USC Site Data

Central thermistors

0.7m
3.6m
7.1m
11.1m
15.1m
19.1m

Logger Temp (internal)

1200 mm
Siemens USC Site Data

Thermistors on pile cage

Graph showing temperature data from 20 Jul-12 to 18 Sep-12.
Consequences

- Importance of concrete for storage not just transfer of heat

- Thermal buffering, preventing extreme temperatures reaching the ground
  - Effect greatest when $\lambda_c$ lower than $\lambda_g$
  - Impact on geotechnical design

- More important to determine concrete thermal properties (not just $R_b$)

- Concrete properties has greatest impact in largest diameter piles as furthest from steady state
Concrete Thermal Properties

- Thermal conductivity: 1.2 to 4 W/mK
- Volumetric heat capacity: 2 to 3 MJ/m³K
- Depends on:
  - Moisture content
  - Aggregate type and ratio
  - Additives, cement replacement products
- Is rapid heat transfer desirable?
Conclusions

• Under constant q piles may take days to approach steady state.
  – Caution with thermal response tests

• Pile concrete is rarely at a thermal steady state during thermal pile operation

• Pile is being used as an energy store

• Pile is protected the ground against extreme temperatures

• Need more emphasis on determining pile properties

• Treating the pile as transient during design will improve thermal efficiency
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