



Energy everywhere
The implications of using geotechnical infrastructure as energy infrastructure

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TU Delft

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Energy usage – typical NL

Electricity usage

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Usage (MWh)	13000	13000	13000	13000	13000	13000	13000	13000	13000	13000	13000	13000

Gas usage

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Usage (MWh)	45000	45000	40000	15000	10000	5000	5000	5000	5000	15000	30000	45000

Electricity and gas usage

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Electricity (MWh)	13000	13000	13000	13000	13000	13000	13000	13000	13000	13000	13000	13000
Gas (MWh)	32000	32000	27000	12000	7000	2000	2000	2000	2000	12000	17000	32000

Electricity (incl. for heatpump) usage

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Usage (MWh)	25000	25000	20000	15000	10000	5000	5000	5000	5000	15000	20000	25000

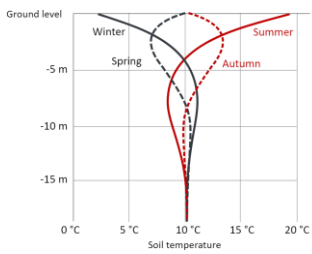
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There is no energy problem.

There is an exergy problem.



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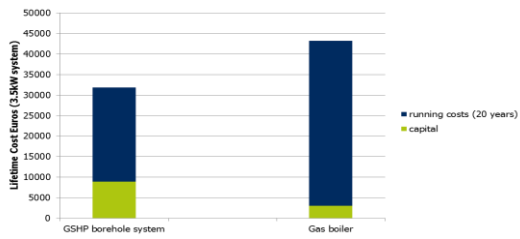
Shallow geothermal – heat and/or cooling



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Why is shallow geothermal not already used everywhere?



- COP = 3.5 (assumed, conservative for good system)
- 4% increase per year for electricity and gas (electricity ~ 2x gas price)

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Energy geostructure (pile)

The diagram illustrates an energy geostructure (pile) system. On the left, a schematic shows a vertical pile with two internal tubes (red and blue). In the center, a refrigeration cycle diagram shows a compressor, condenser, expansion valve, and evaporator connected to the tubes. On the right, a 3D rendering shows a modern building with several such piles extending into the ground. Below the rendering is a photograph of a physical pile structure with rebar reinforcement.



Energy geo-structures

Vardon, 2020

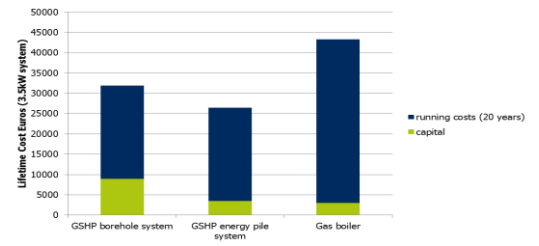
Barla et al., 2016

Geothermal International, 2011

Labels: Equipped lining segment, Main conduit, Equipped lining rings



Why is shallow geothermal not already used everywhere?



- COP = 3.5 (assumed, conservative for good system)
- 4% increase per year for electricity and gas (electricity ~ 2x gas price)

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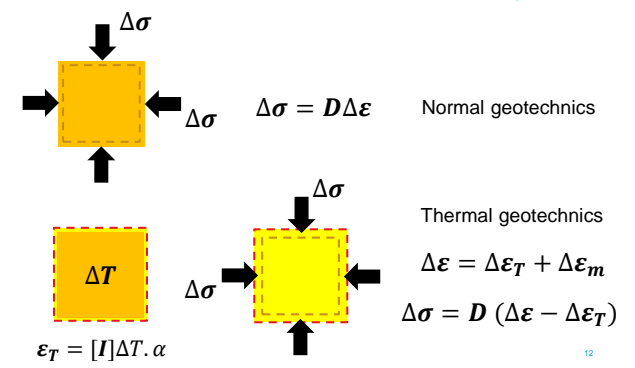
Design

- Energy:
 - Material properties: methods exist
 - Heat is stored, spacing is important
 - New well-insulated buildings means energy geo-structures are very possible
 - *Much work is available: not discussed today*
- Impact on structures
 - Design structure, then energy system
 - Structure dependent
 - Slow cyclic loads (days and years)



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Thermal expansion and stress changes



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Thermal expansion and stress changes

$$\Delta\sigma = D (\Delta\varepsilon - \Delta\varepsilon_T) \quad \varepsilon_T = -[I]\Delta T \cdot \alpha$$

Extreme 1: fully constrained

$$\Delta\varepsilon = \Delta\varepsilon_m + \Delta\varepsilon_T = 0 \quad \Delta\varepsilon_m = -\Delta\varepsilon_T \quad \Delta\sigma = -D\Delta\varepsilon_T$$

Extreme 2: fully free

$$\Delta\sigma = 0 \quad \Delta\varepsilon - \Delta\varepsilon_T = 0 \quad \Delta\varepsilon = [I]\Delta T \cdot \alpha$$

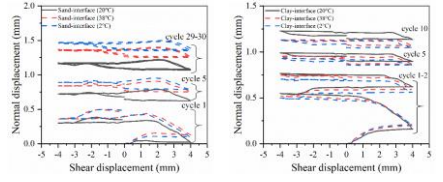
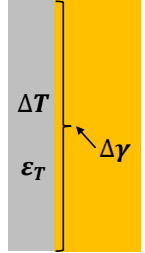
Most situations are between these two.



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Thermal expansion - structure

Extreme: time = 0



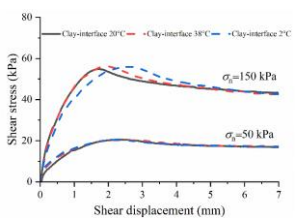
$$\frac{\Delta L}{L} = \Delta T \cdot \alpha \approx 0.01 \text{ mm/m/}^\circ\text{C}$$



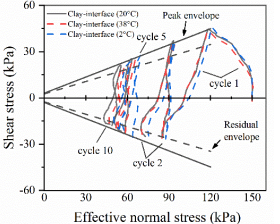
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Thermal strength and stress changes

CNL



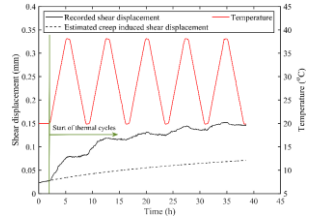
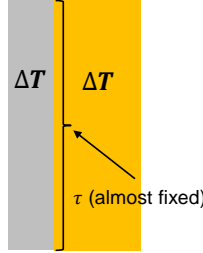
CNS



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Thermal creep

Extreme: many thermal cycles

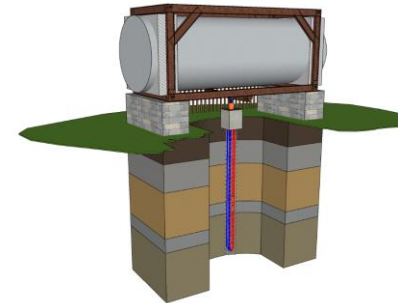


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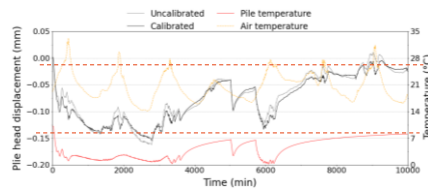
Material thermo-mechanics

- Materials do not change strength (much) with temperature (in this range)
- Confining stresses can reduce with cyclic shear strain cycles – need large cycles
- Thermal creep exists

Thermal pile test

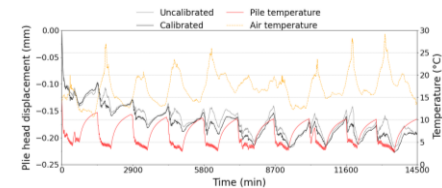


Pile head displacement – fixed loads



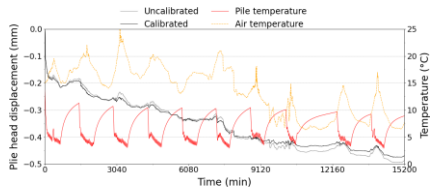
- Zero applied load: elastic
- Impacted by surface and ground temps

Pile head displacement – fixed loads



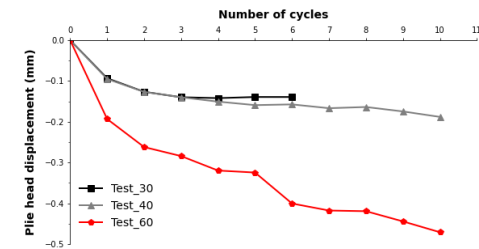
- 40% maximum load: thermal creep, 5 cycles, then elastic

Pile head displacement – fixed loads



- 60% maximum load: thermal creep, continuous

Thermal pile test: thermal creep



Implications for thermal pile design

- Long term thermal loads: soil and pile expand/contract: moderate structure displacement.
- Displacements are more critical than shear strength in most normal situations.
- Reasonable safety factors restrict thermal creep, and soil compaction (CNS)

Energy quay wall

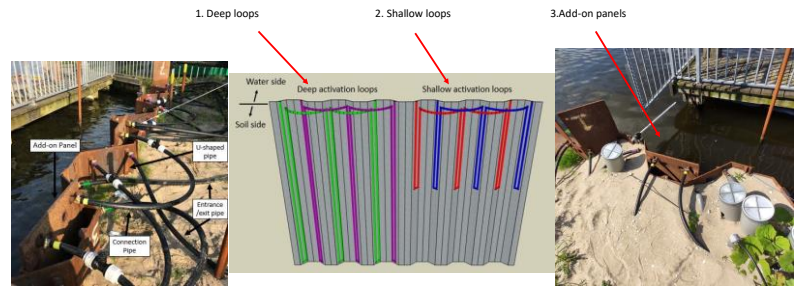


Energy quay wall

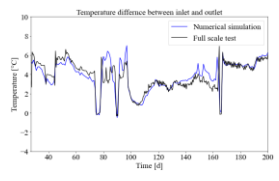
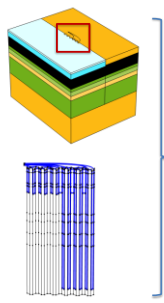
- Don't rely on confining stress, or shear strength
- Energy can come from ground/water:
 - Where is the exergy best?



Energy quay wall – field test



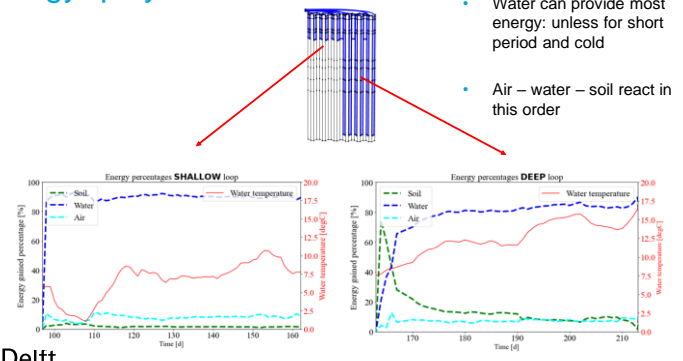
Energy quay wall – field test



- Model and field data agree. Field test has valuable data.
- Thermo-mechanical changes very small – adding sand backfill more significant.



Energy quay wall – field test



- Water can provide most energy: unless for short period and cold
- Air – water – soil react in this order



Summary

- Useful energy is all around...we are in a position to make it useable (and cost-effective).
- There are additional geotechnical loads, but in most reasonable cases do not change the structural design.

A photograph of a TU Delft campus with modern buildings, green lawns, and trees under a blue sky with clouds. A semi-transparent white box is overlaid on the image, containing contact information and acknowledgements.

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The TU Delft logo is located in the bottom left corner of the slide image.