Energy everywhere
The implications of using geotechnical infrastructure as energy infrastructure

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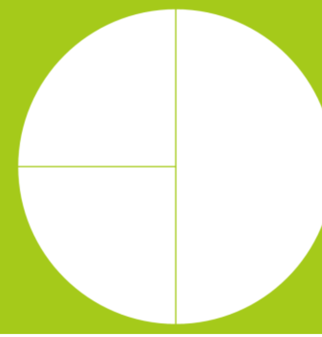
ENERGY CONSUMPTION IN NETHERLANDS



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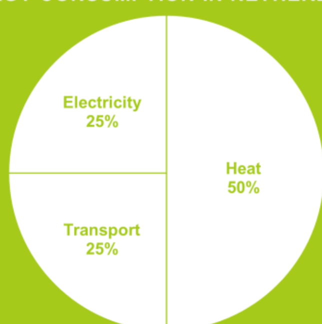
ENERGY CONSUMPTION IN NETHERLANDS



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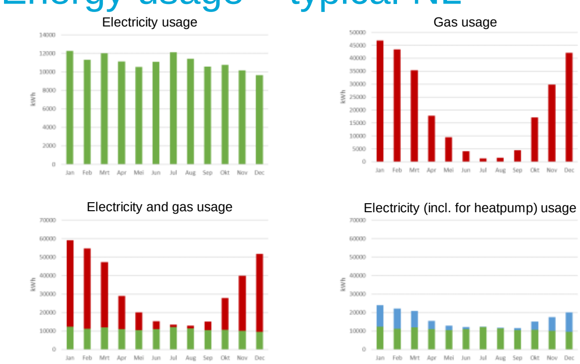
Energy usage – typical NL



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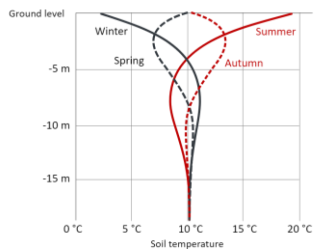
There is no energy problem.

There is an exergy problem.



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Shallow geothermal – heat and/or cooling

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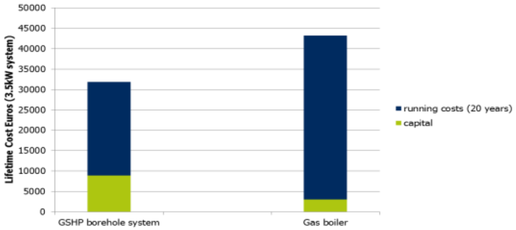
Why is shallow geothermal not already used everywhere?



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

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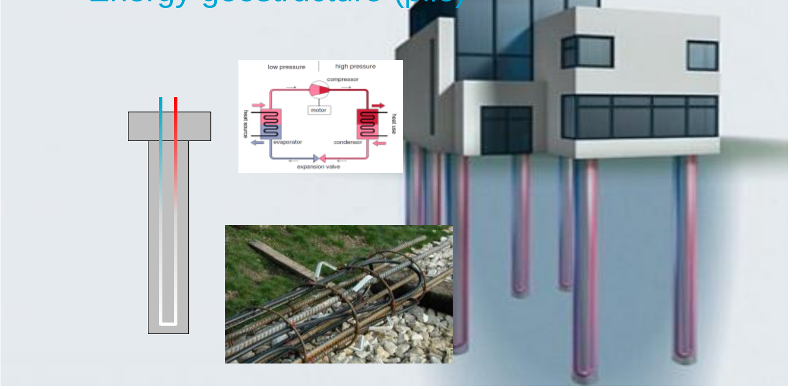
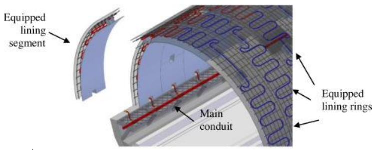
Energy geostructure (pile)



Energy geo-structures

Vardon, 2020



Barla et al., 2016

Geothermal International, 2011

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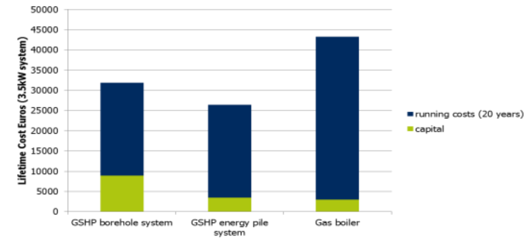
Why is shallow geothermal not already used everywhere?



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

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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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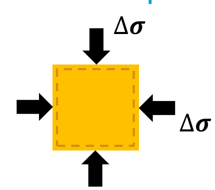
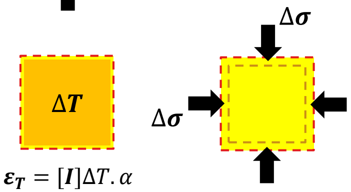
Thermal expansion and stress changes



$\Delta\sigma = D\Delta\varepsilon$ Normal geotechnics



$\varepsilon_T = [I]\Delta T.\alpha$

Thermal geotechnics

$\Delta\varepsilon = \Delta\varepsilon_T + \Delta\varepsilon_m$

$\Delta\sigma = D\,(\Delta\varepsilon - \Delta\varepsilon_T)$

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Thermal expansion and stress changes

$$\Delta\boldsymbol{\sigma} = \boldsymbol{D}\,(\Delta\boldsymbol{\varepsilon} - \Delta\boldsymbol{\varepsilon_T}) \qquad \boldsymbol{\varepsilon_T} = -[\boldsymbol{I}]\Delta T.\alpha$$

Extreme 1: fully constrained

$\Delta \boldsymbol{T}$

$$\Delta\boldsymbol{\varepsilon} = \Delta\boldsymbol{\varepsilon_m} + \Delta\boldsymbol{\varepsilon_T} = 0$$
$$\Delta\boldsymbol{\varepsilon_m} = -\Delta\boldsymbol{\varepsilon_T}$$
$$\Delta\boldsymbol{\sigma} = -\boldsymbol{D}\Delta\boldsymbol{\varepsilon_T}$$

Extreme 2: fully free

$\Delta \boldsymbol{T}$

$$\Delta\boldsymbol{\sigma} = 0 \quad \Delta\boldsymbol{\varepsilon} - \Delta\boldsymbol{\varepsilon_T} = 0 \quad \Delta\boldsymbol{\varepsilon} = -[\boldsymbol{I}]\Delta T.\alpha$$

Most situations are between these two.

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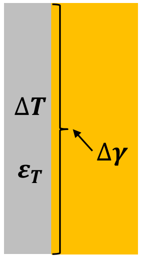
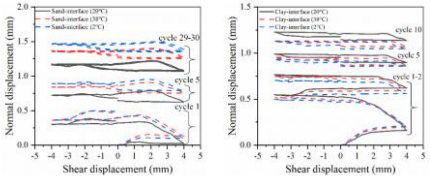
Thermal expansion - structure

Extreme: time = 0





$$\frac{\Delta L}{L} = \Delta T.\alpha \approx 0.01mm/m/°C$$

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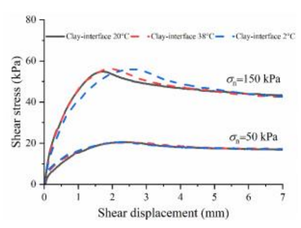
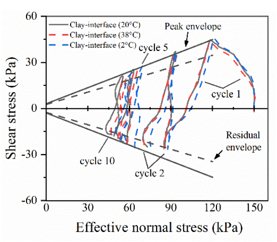
Thermal strength and stress changes





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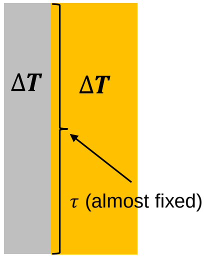
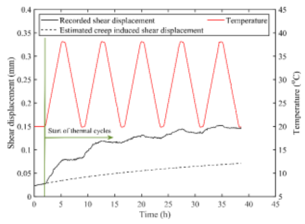
Thermal creep

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

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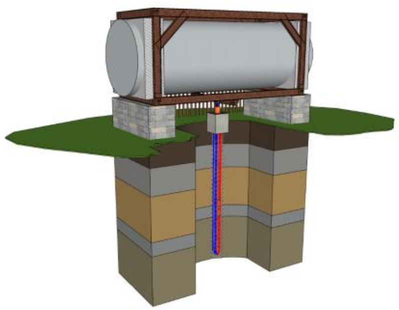
Thermal pile test



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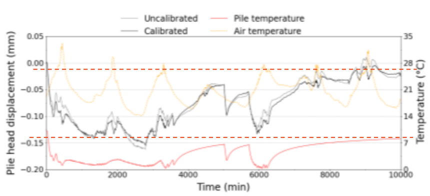
Pile head displacement – fixed loads



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

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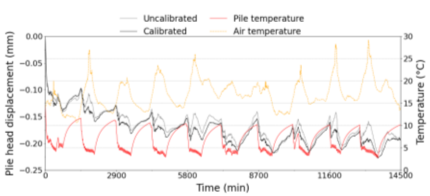
Pile head displacement – fixed loads



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

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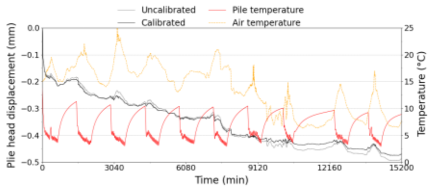
Pile head displacement – fixed loads



- 60% maximum load: thermal creep, continuous

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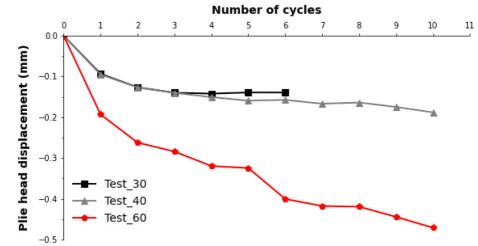
Thermal pile test: thermal creep



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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)

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Energy quay wall

CRUX · Duurzame energie · TU/e Technische Universiteit Eindhoven University of Technology · GOOIMEER · Università degli Studi di Milano

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Energy quay wall

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

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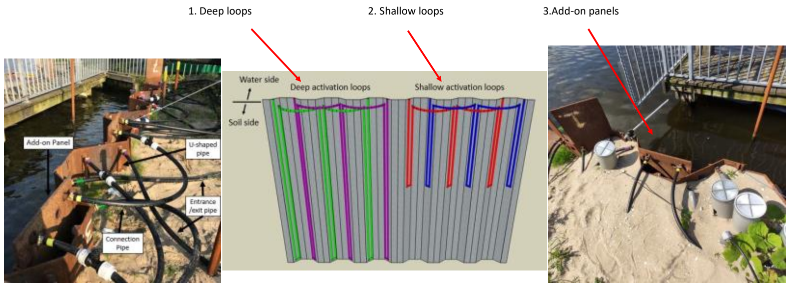
Energy quay wall – field test



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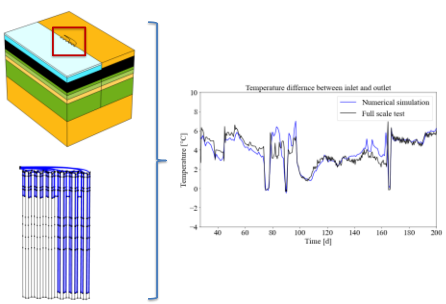
Energy quay wall – field test



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

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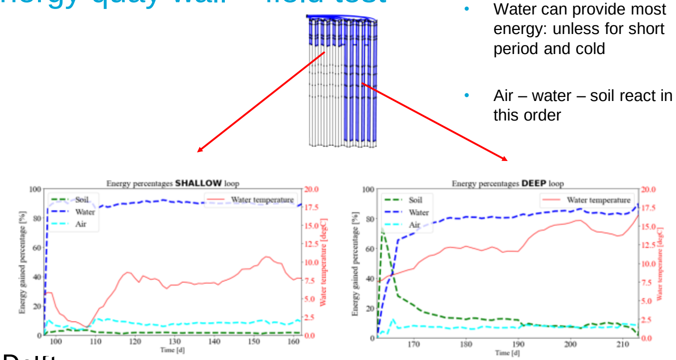
Energy quay wall – field test

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



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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.

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