# ELABORATION OF CHARTS BASED ON GEOMETRY VARIATIONS FOR THE DESIGN OF THERMO-ACTIVE PILES

Mila Smiljanovska [1], Hussein Mroueh [2], Julien Habert [3], and Josif Josifovski [4]

[1] Civil Engineering Institute Macedonia, Skopje, North Macedonia
[2] Laboratory of Civil Engineering and geo-Environment, University of Lille, France
[3] Cerema, France
[4] Faculty of Civil Engineering, “Ss. Cyril and Methodius” University, Skopje, North Macedonia

EGU General Assembly 2020



EGU2020-584

EGU General Assembly 2020

# THERMO-ACTIVE FOUNDATIONS

- The thermo-active foundations represent an innovative “green” technology in the field of Civil Engineering and geo-Environment
  - base slabs, piles, diaphragm walls, retaining walls, tunnels…
- Offer structural improvement and provide long-term eco-friendly solutions
- Advantages:
  - ecological (continuous and sustainable energy resource, reducing the dependency on fossil and nuclear fuels)
  - economical (saves up to two-thirds comparing to the conventional sources, reduced energy imports and a possible combination with other energy systems)
  - aesthetic (more comfortable and functional solutions by removing heating and cooling objects)

*Figure 1. Thermo-active foundation*

# GEOTHERMAL PILES

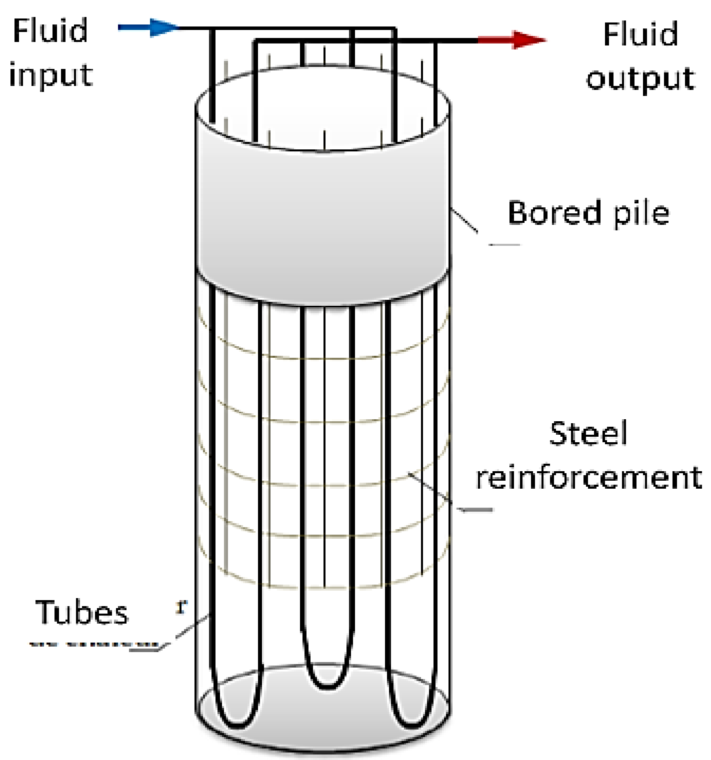


*Figure 2. Description of a geothermal pile (Brandl, 2006)*

- Analysis of geothermal piles based on methods developed for borehole heat exchanger systems
- Reinforced concrete dual-function elements
  - geothermal closed loops connected to the reinforcement bars, filled with fluid with a turbulent flow
- Energetic potential is increased with depth hence associated with deep foundations where the ground temperature is more constant (10-15m for majority of Europe) with no seasonal variations
- Heat transfer is primarily done by conduction
- Thermal exchange efficient due to the favourable thermal properties of the reinforced concrete

# GEOTHERMAL PILES

- Thermal load is applied following the mechanical load as an additional axial load
- Simplifying the thermal load as equally distributed along the element
- Time dependant analysis, hence cyclic loading analysis is needed

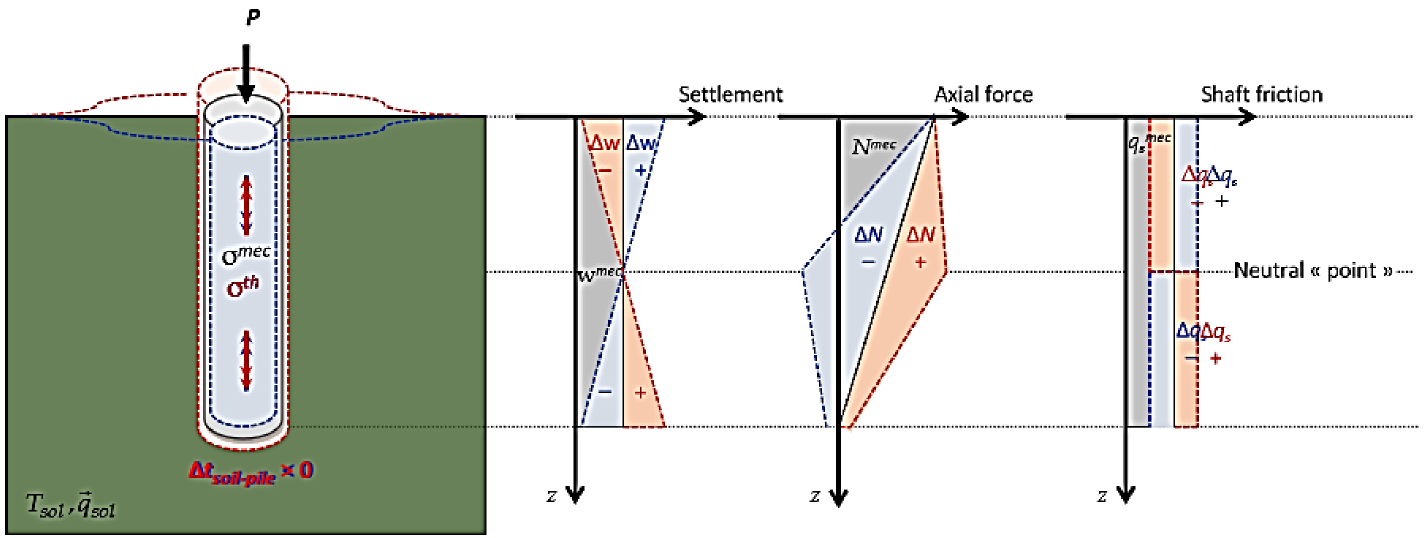


*Figure 3. Behaviour of a pile exposed to thermo-mechanical loading*

# THERMO-MECHANICAL ANALYSIS OF A SINGLE PILE

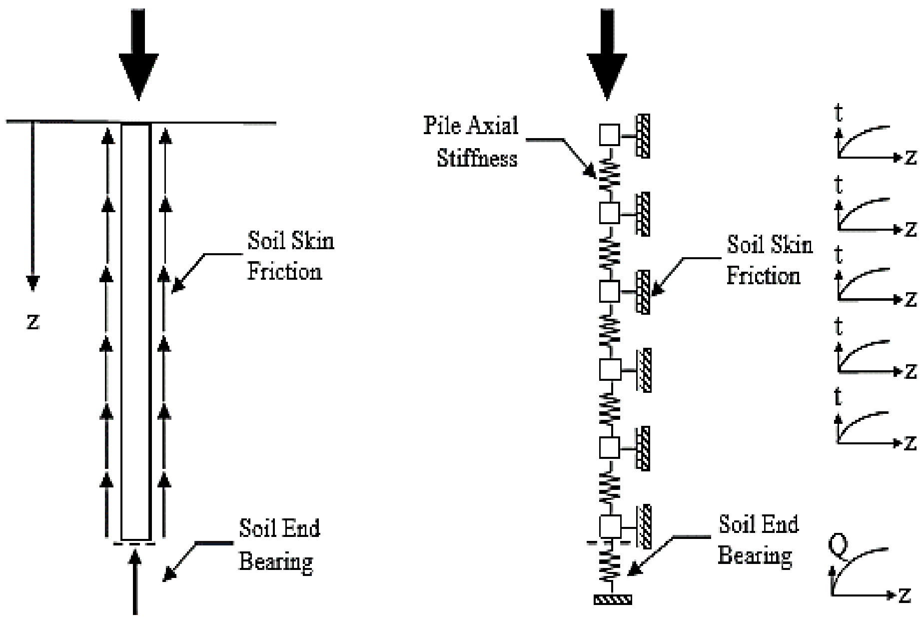


*Figure 4. 1) Load transfer mechanisms in axially loaded piles 2) Spring mass model (Rocscience, 2018)*

- Numerical method (boundary element method)
- The soil surrounding the element is represented with a rheological mode – spring (Winkler concept)
- Load transfer approach (t-z curves) – Frank and Zhao theory
  - one dimensional problem
  - the liaison between the element and the surrounding soil is considered as elastoplastic
- Total deformation of the pile

$$\varepsilon = \varepsilon^{mec} + \varepsilon^{th}$$

- Additional thermal stress in the pile

$$\sigma = E\left(\varepsilon - \varepsilon^{th}\right) = E(\varepsilon - \alpha_T \Delta T)$$

EGU General Assembly 2020

# THERMO-MECHANICAL ANALYSIS OF A SINGLE PILE

- Numerical model based on a full-scale model from an experimental project in Dunkirk
    - loaded with a mechanical load V=1050kN
- Restrained pile, assuming there is no movement of the pile head and an infinite axial stiffness $k_h$
- Two steps analysis
    - first step – mechanical (bearing) analysis
    - second step – thermal analysis (+15°C for heating, and -15°C for cooling)

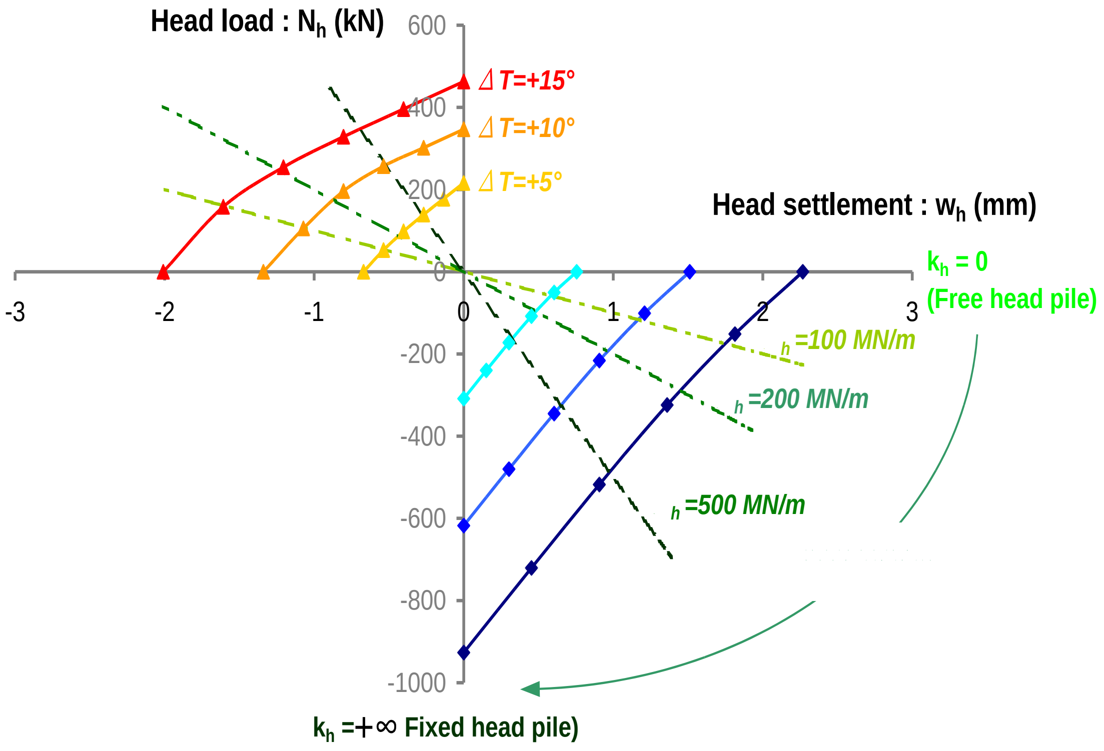


*Figure 5. Typical diagram of axial force variation and head displacement for different head rigidity (Burlon et al, 2013)*

# THERMO-MECHANICAL ANALYSIS OF A SINGLE PILE

- Analysis performed on a pile located in sandy soil
  - due to the very low thermal gradient of the sandy soil, only the concrete element is exposed to additional thermal volumetric deformation
- Charts with normalised values
  - $w_h/(\alpha\Delta T)_p L$ - axial displacement at the head of the pile
  - $z\Delta N_{max}/L$ - depth of the maximal absolute variation
  - $\Delta N_h/(\alpha\Delta T)_p ES$ – axial force at the pile head
  - $\Delta N_{max}/(\alpha\Delta T)_p ES$ – maximal absolute variation of the axial force at the pile head

| i | e (m) | Type of soil | Em (MPa) | $q_s$ (kPa) | $q_b$ (kPa) |
|---|---|---|---|---|---|
| 1 | 2.7 | silt | 4 | 30 | - |
| 2 | 3.8 | sand | 8 | 70 | - |
| 3 | 2 | sand | 17 | 100 | - |
| 4 | 3.5 | sand | 30 | 110 | 4620 |

*Figure 6. Table of soil properties*

- i – number of layer
- e – thickness of layer
- $E_m$ – Menard's modulus
- $q_S$ – unit shaft friction
- $q_B$ – ultimate stress of the base
- $E_c$ = 20000MPa

# THERMO-MECHANICAL ANALYSIS OF A SINGLE PILE

EGU General Assembly 2020

- Geometry variation analysis
  - Case study 1: analysing a pile with smaller length variations (3m) and variations of the diameter of the pile, while keeping the same value of the mechanical load and almost the same overall resistance of the element

| case | D (m) | L (m) | V (kN) | R (kPa) | V/R (%) |
|---|---|---|---|---|---|
| 1 | 0.7 | 9 | 1050 | 3102 | ≈35 |
| 2 | 0.6 | 12 | 1050 | 3063 | ≈35 |
| 3 | 0.52 | 15 | 1050 | 3043 | ≈35 |

*Figure 7. Table of geometry variations (case study 1)*

- D – diameter of the element
- L – length of the element
- V – mechanical load
- R – overall resistance of the element

# THERMO-MECHANICAL ANALYSIS OF A SINGLE PILE

- Case study 1:

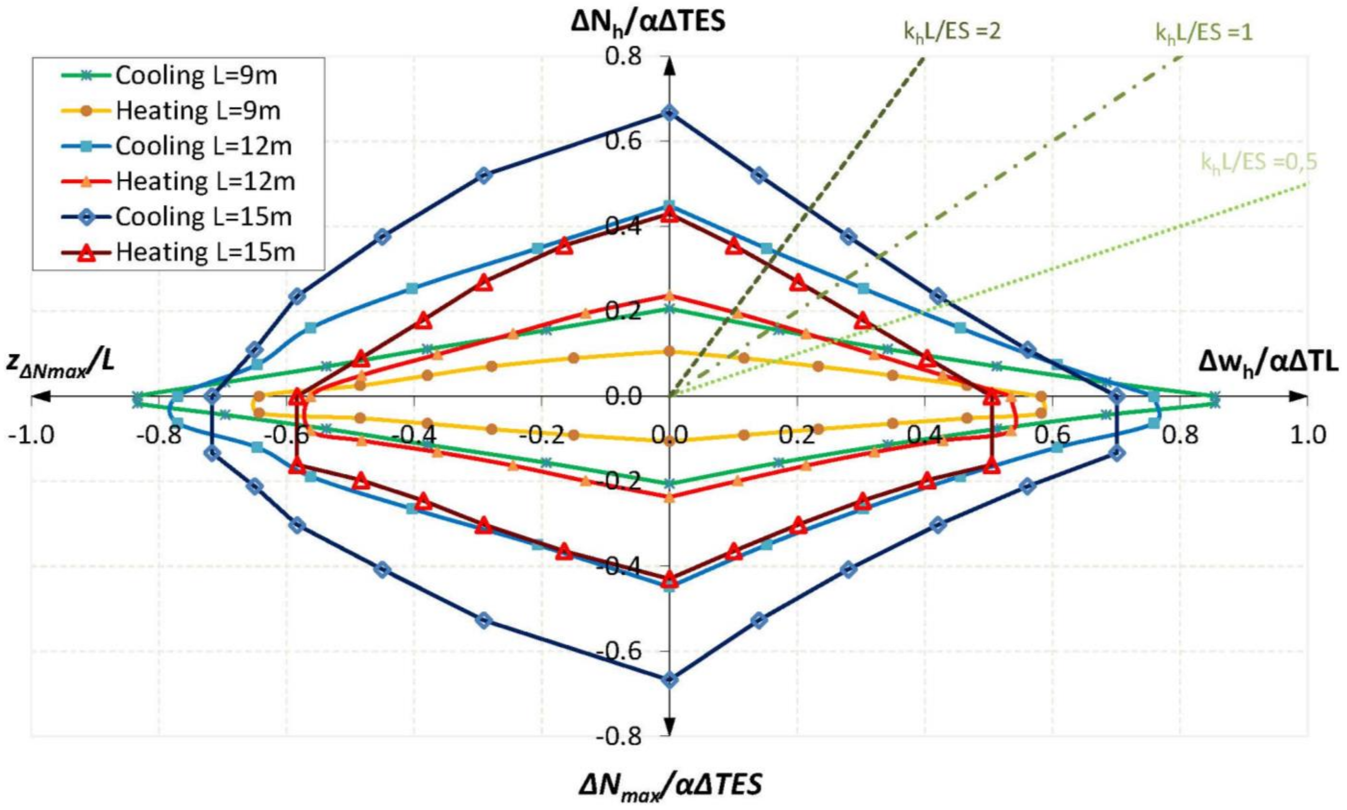


*Figure 8. Normalised chart of the axial force and head displacement due to thermo-mechanical loading (case study 1)*

# THERMO-MECHANICAL ANALYSIS OF A SINGLE PILE

- Geometry variation analysis
  - Case study 2: analysing a pile with larger length variations (9m), while keeping the same diameter and the same value of the mechanical load

| case | D (m) | L (m) | V (kN) | R (kPa) |
|---|---|---|---|---|
| 1 | 0.7 | 12 | 1500 | 3828 |
| 2 | 0.7 | 21 | 1500 | 6005 |
| 3 | 0.7 | 30 | 1500 | 8182 |

*Figure 9. Table of geometry variations (case study 2)*

- D – diameter of the element
- L – length of the element
- V – mechanical load
- R – overall resistance of the element

EGU General Assembly 2020

# THERMO-MECHANICAL ANALYSIS OF A SINGLE PILE

- Case study 2:

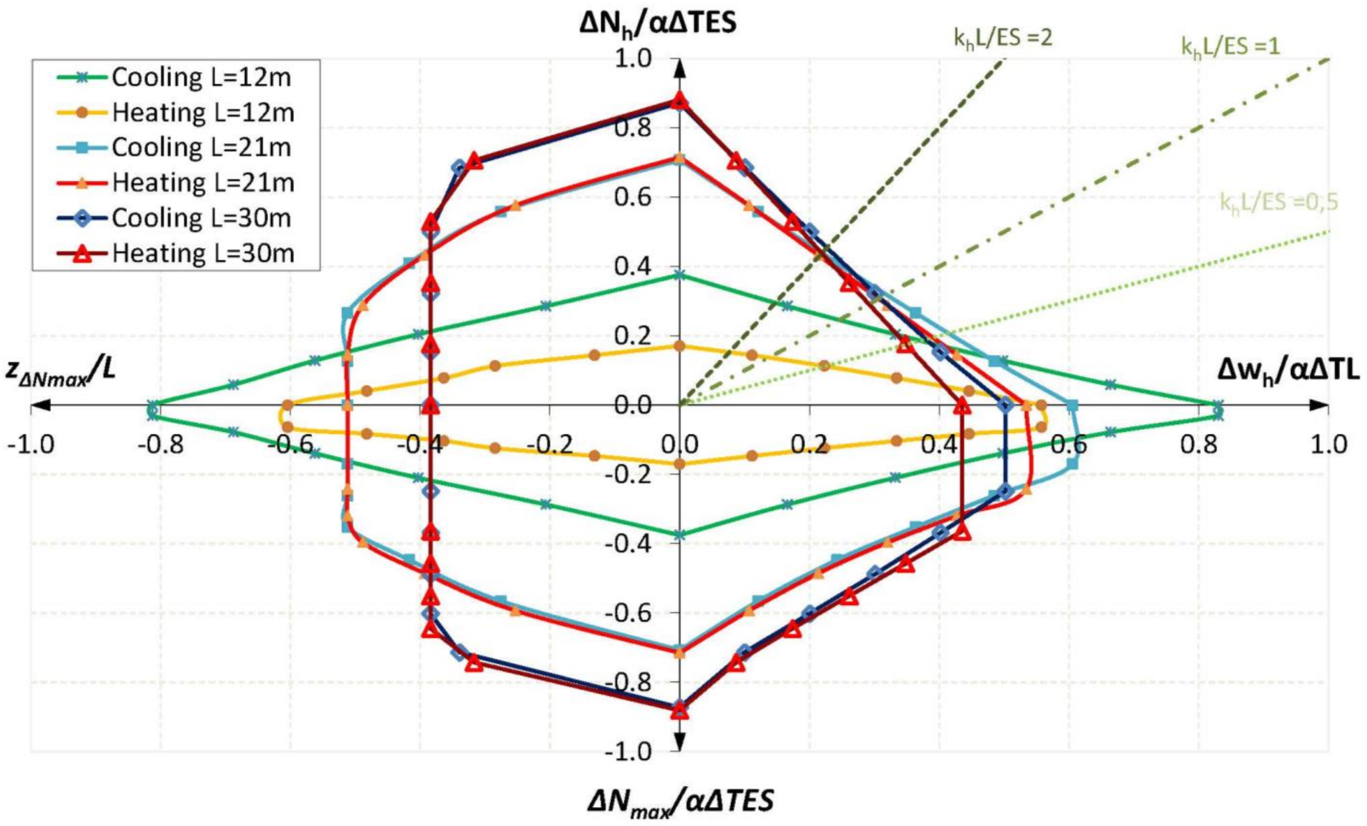


*Figure 8. Normalised chart of the axial force and head displacement due to thermo-mechanical loading (case study 2)*

# CONCLUSIONS

- The process of cooling has a larger effect on the displacement of the pile than the process of heating, due to the lack of restrictions from the surrounding soil
- On the charts it might be noticed that by increasing the length of the pile the value of the normalised axial force always increases, and the value of the normalised displacement at the head of the pile always decreases, for both case studies with and without diameter variation
- Normalised axial forces are generally affected by the process of heating, while the normalised displacements at the head of the pile are affected by the process of cooling
- For shorter piles more attention should be directed toward the SLS requirements, while for longer piles more attention should be directed toward the ULS requirements
- In case study 2 it might be noticed that for longer piles the processes of cooling and heating have almost the same effect on the normalised axial force generated in the pile