2020 Webinar Series - Energy Foundations

Current status of energy foundation research and implications for design

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Outline

1) Introduction
2) Preoccupations for designers
3) Overview of research
4) Insights from research
5) Implications for design of energy foundations

1. INTRODUCTION

pre-Lisbon

- Chief Geotechnical Engineer at Cementation Skanska
- Coordinated Lambeth College Energy Pile test with Tony Amis
- Worked with GI Energy and Cambridge University to understand test, and co-authored several seminal papers based on this.

Técnico

- 8 Final year projects
- 1 PhD in progress
- 1 Post-Doc
- Project DEEPCOOL financed by FCT, 240k€, 2018 – 2021
- 12 articles & 2 book chapters to-date
- COST Action participant

2. PREOCCUPATIONS for DESIGNERS

1) **GEO**technical safety

Can the pile suffer bearing capacity failure?

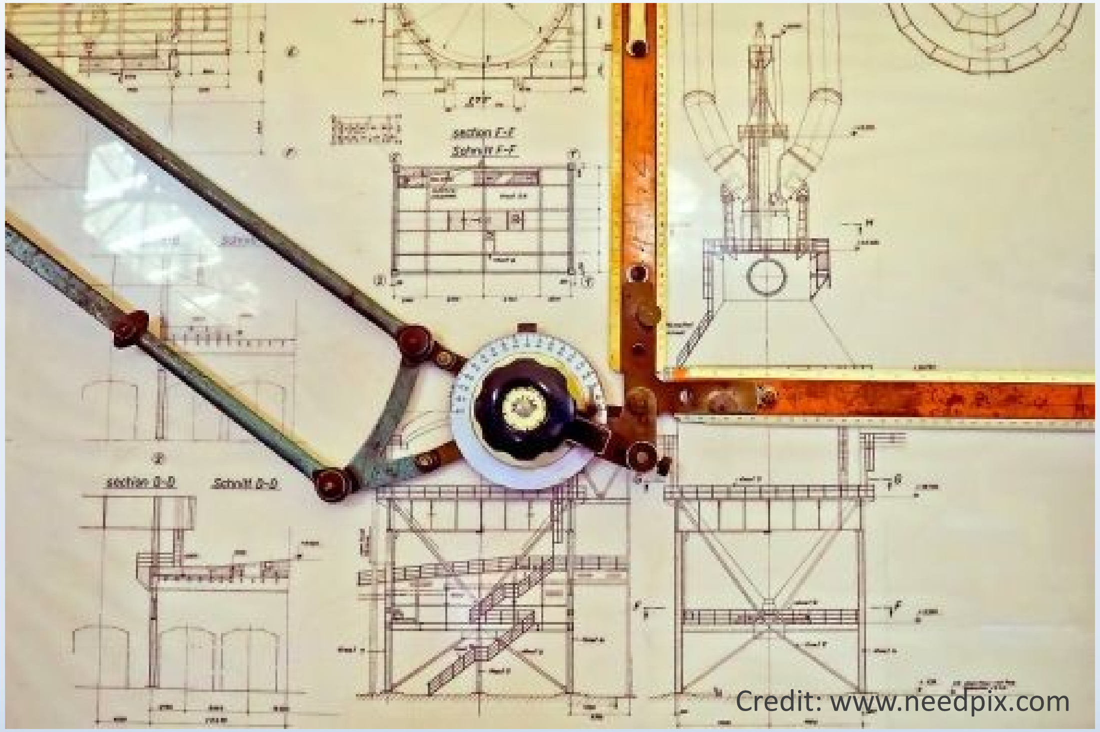
2) **STR**uctural safety

Can the pile suffer overstress or cracking due to restraint of thermal strain?

3) **SERVICEABILITY**

Could the pile move too much?

What heating & cooling can be expected?



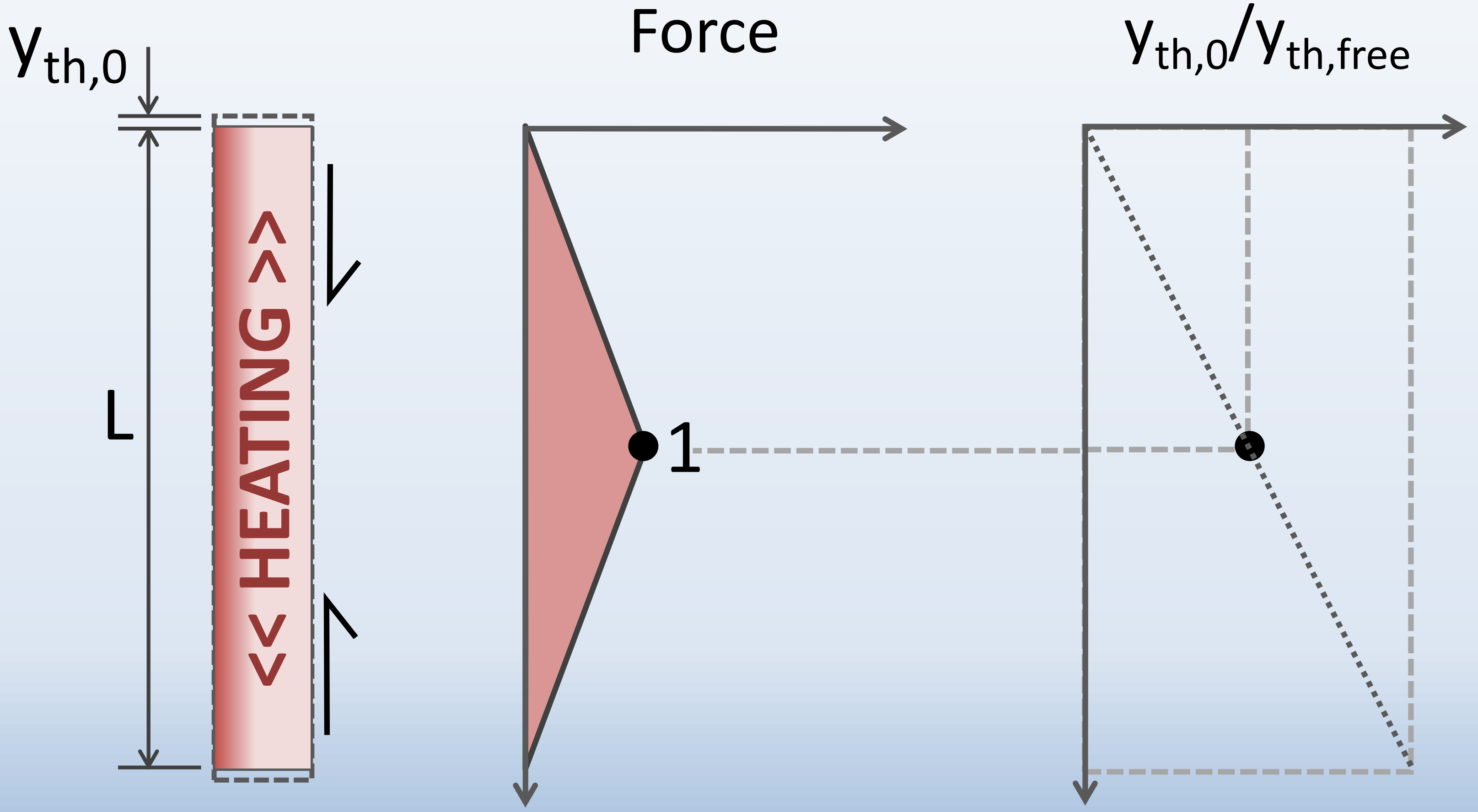
Credit: www.needpix.com

3. RESEARCH OVERVIEW

- Field tests on piles in several European countries, USA, China, Japan, Australia & Brazil.
- Operational monitoring still rare.
- Model tests from a number of institutions – China, USA, France (Tecnico soon!).
- Numerous efforts at numerical modelling of thermally-activated single piles and pile groups.

4. RESEARCH INSIGHTS

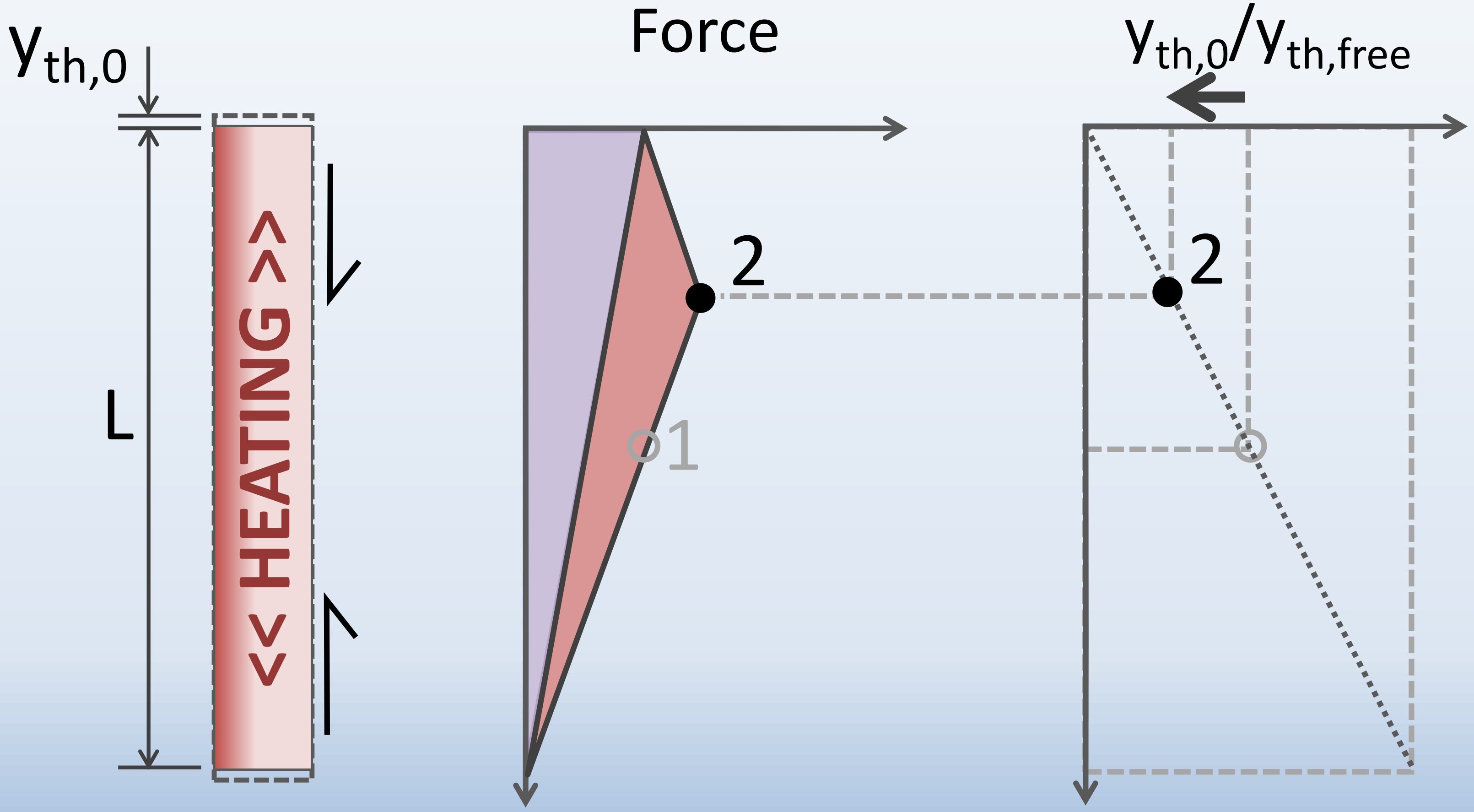
Model for pile response to thermal load: heating



1. No external load, pile expands about a neutral point (NP);

4. RESEARCH INSIGHTS

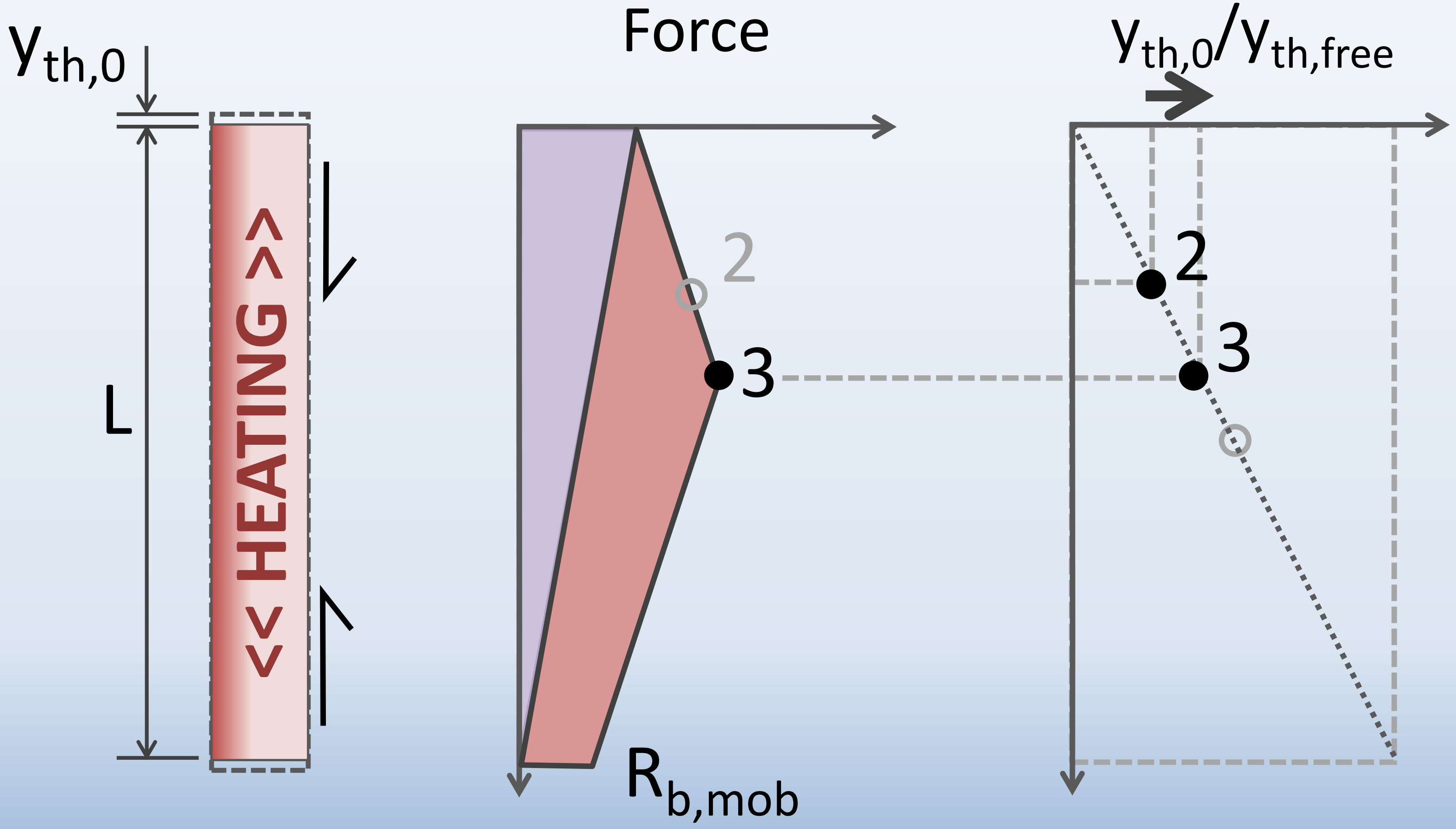
Model for pile response to thermal load: heating



1. No external load, pile expands about a neutral point (NP);
2. External load moves NP up, reducing pile head displacement;

4. RESEARCH INSIGHTS

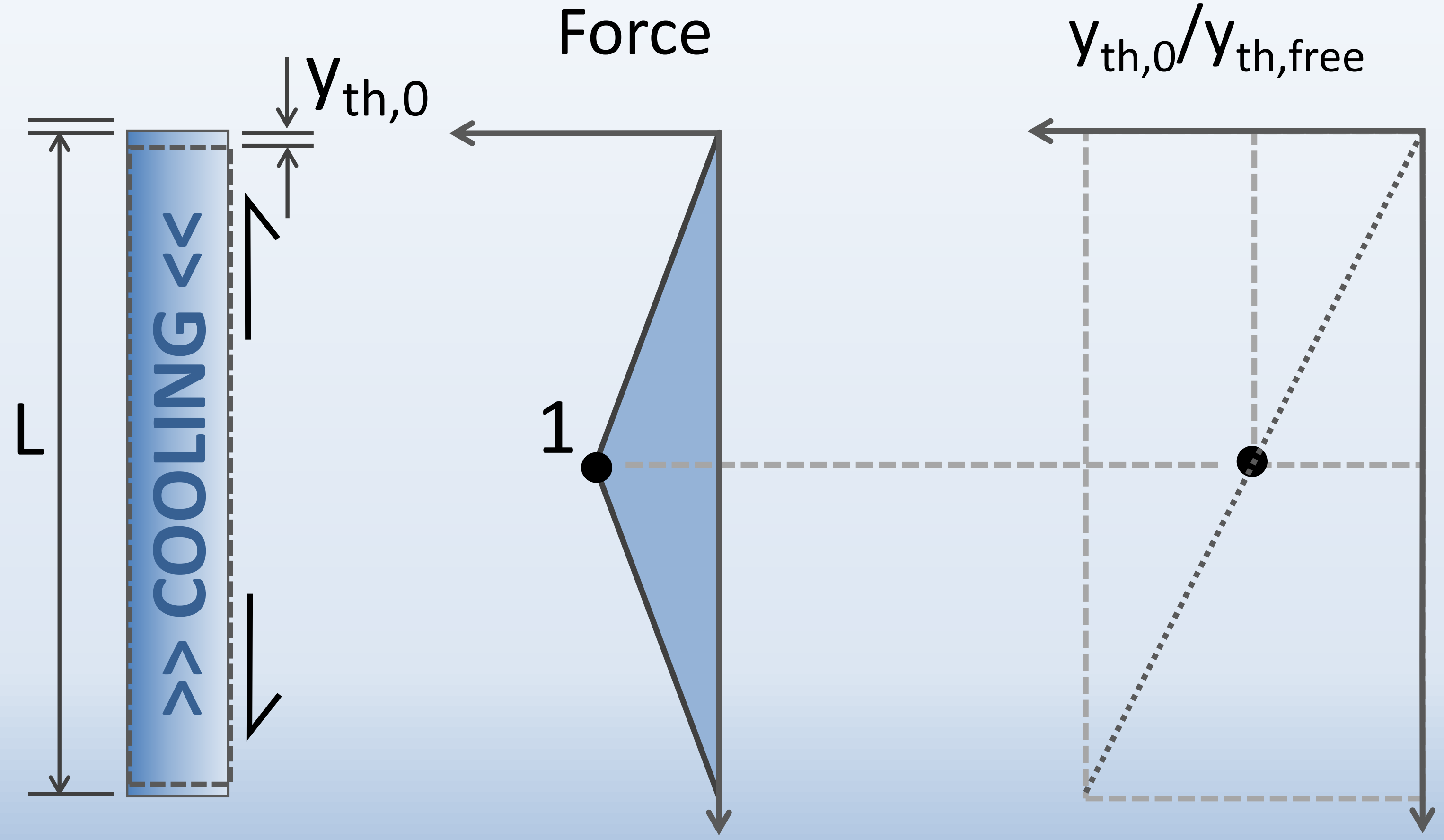
Model for pile response to thermal load: heating



1. No external load, pile expands about a neutral point (NP);
2. External load moves NP up, reducing pile head displacement;
3. If base mobilised, NP does not move up as far;

4. RESEARCH INSIGHTS

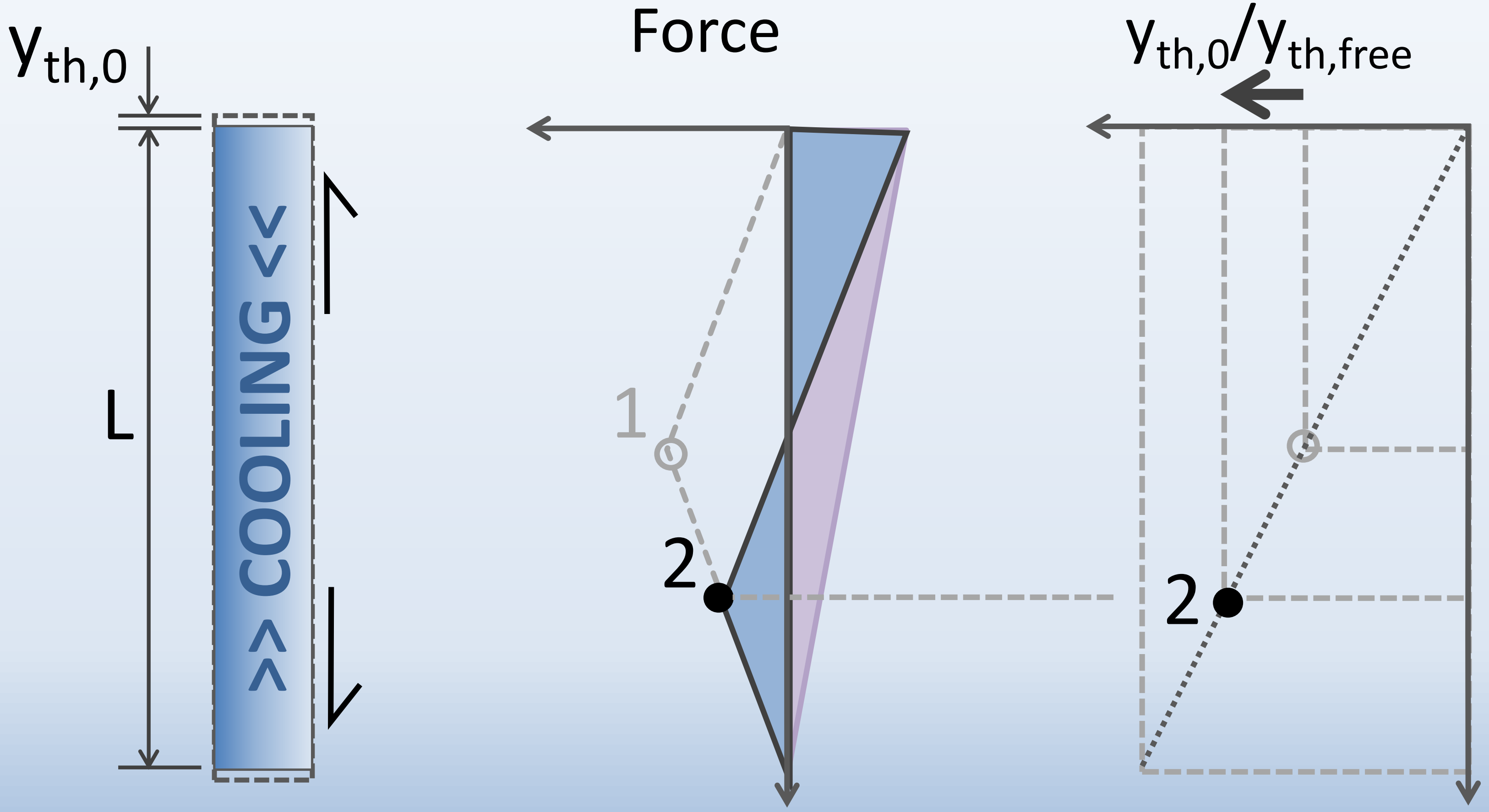
Model for pile response to thermal load: cooling



1. No external load, pile expands about NP but effect reversed cf. heating;

4. RESEARCH INSIGHTS

Model for pile response to thermal load: heating

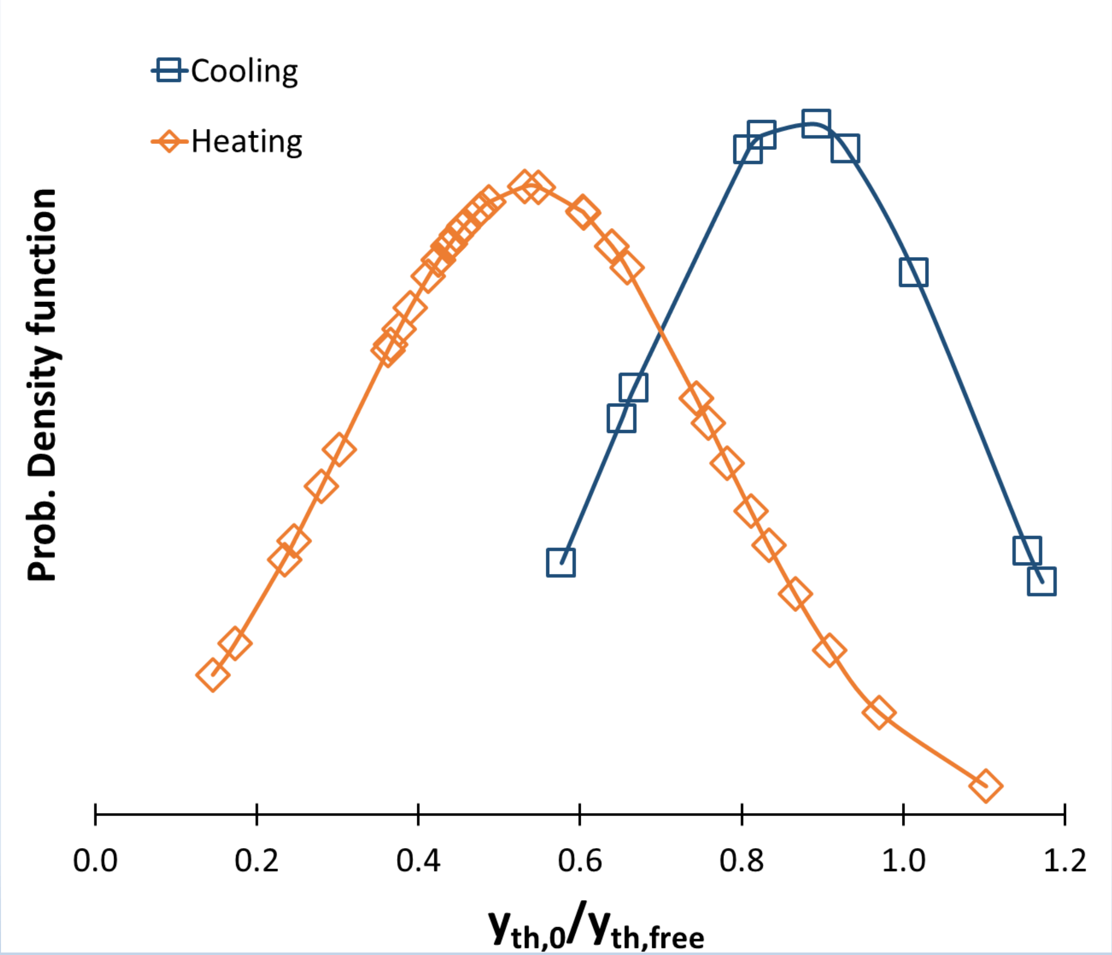


1. No external load, pile expands about NP but effect reversed cf. heating;
2. External load moves NP down, increasing pile head displacement;
3. If base mobilised, NP does not move as far down (unless in tension);

4. RESEARCH INSIGHTS

Pile thermal displacement response

- Collated results from various studies are consistent with descriptive model.
- Cooling – thermal displacements at pile head with mean $y_{th,0}/y_{th,free} \approx 0.9$;
- Heating – thermal displacements reduced with mean $y_{th,0}/y_{th,free} \approx 0.5$;
- Cooling might be biased by no. tests in sand with low FS-shaft (later).
- Unbalanced load has background effect.



$$y_{th,free} = \alpha.\Delta T.L$$

4. RESEARCH INSIGHTS

Pile thermal displacement response

- Cool
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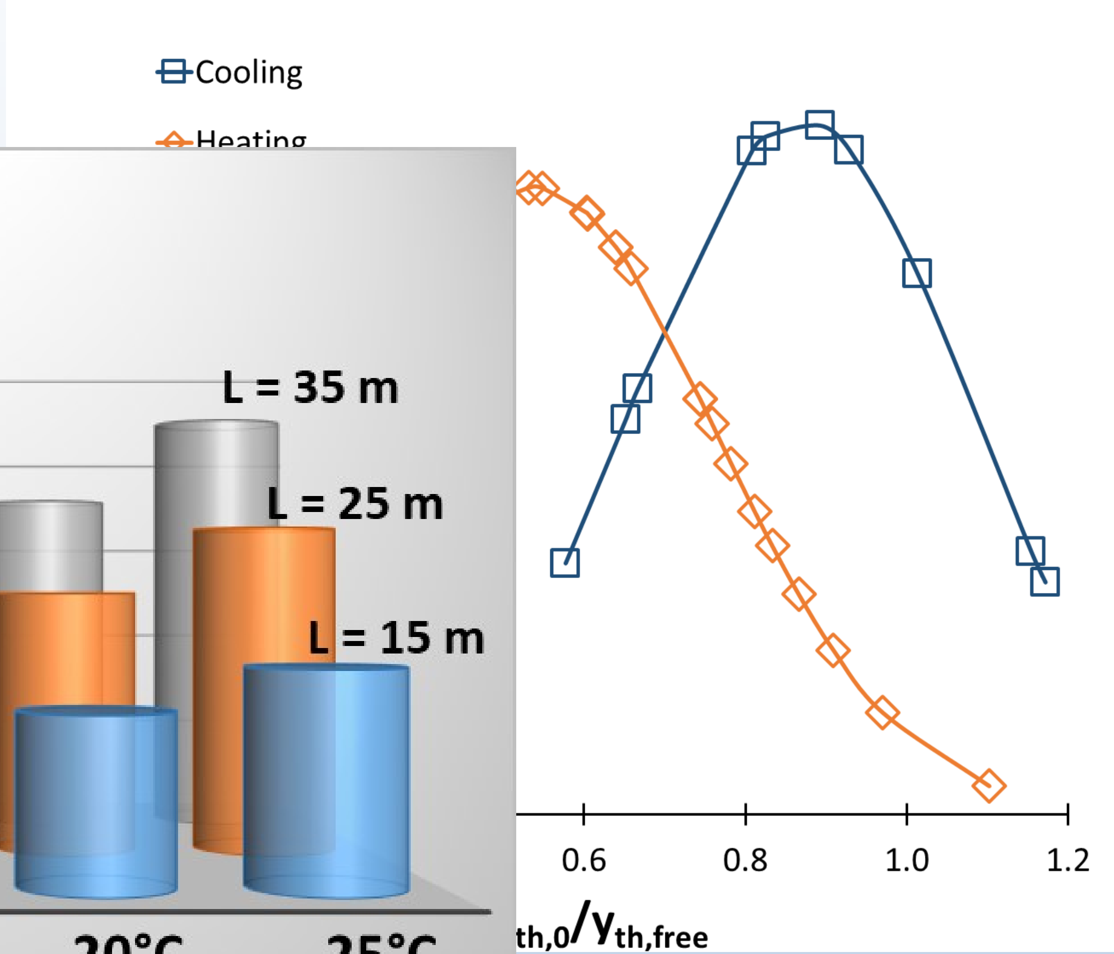
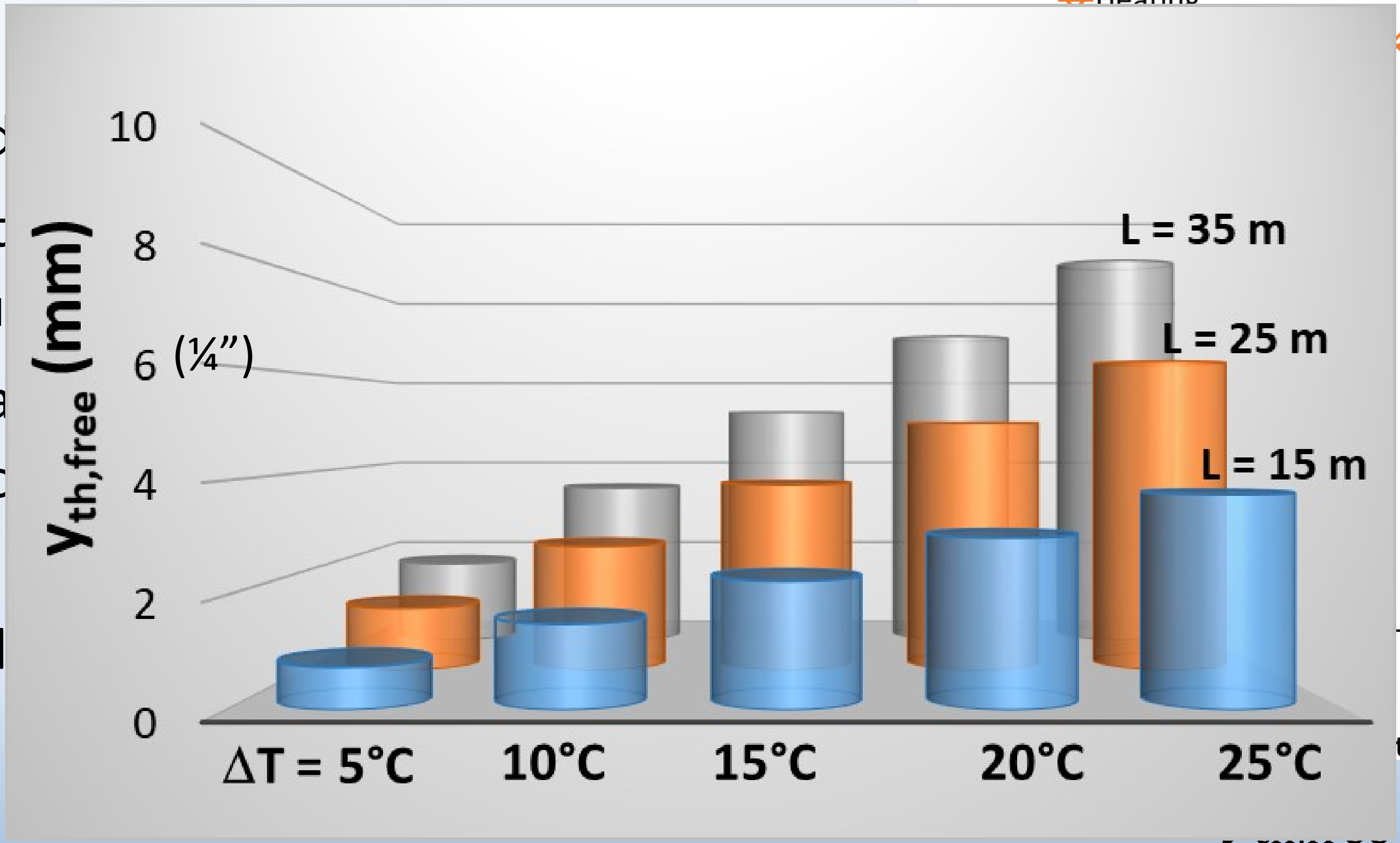
- Cool
  sand



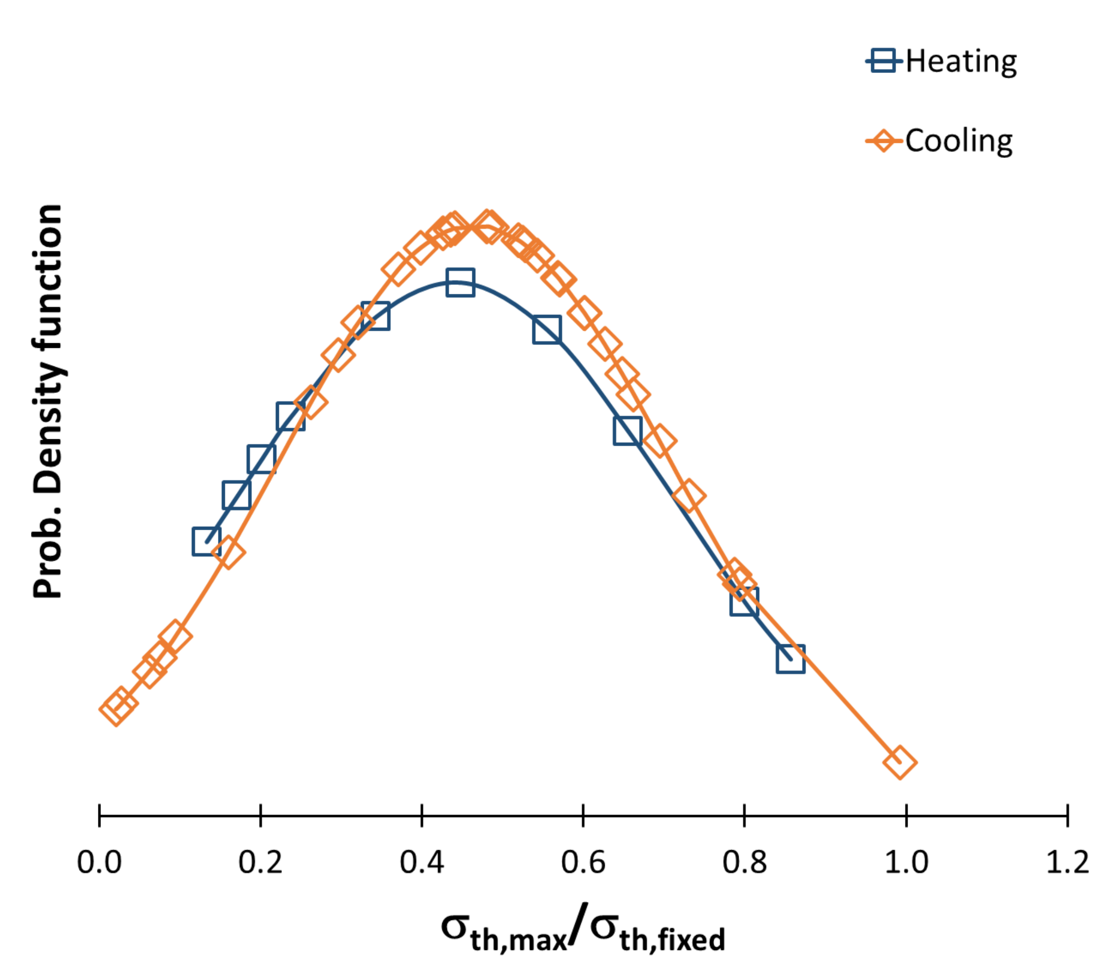


$= \alpha . \Delta T . L$

4. RESEARCH INSIGHTS

Pile thermal stress response

- Remarkably little variation between heating and cooling, with mean $\sigma_{th,max}/\sigma_{th,fixed} \approx 0.5$;
- Difficult to validate against descriptive model as depends on restraint conditions on shaft and base.



$$\sigma_{th,fixed} = \alpha.\Delta T.E$$

4. RESEARCH INSIGHTS

Pile thermal stress response

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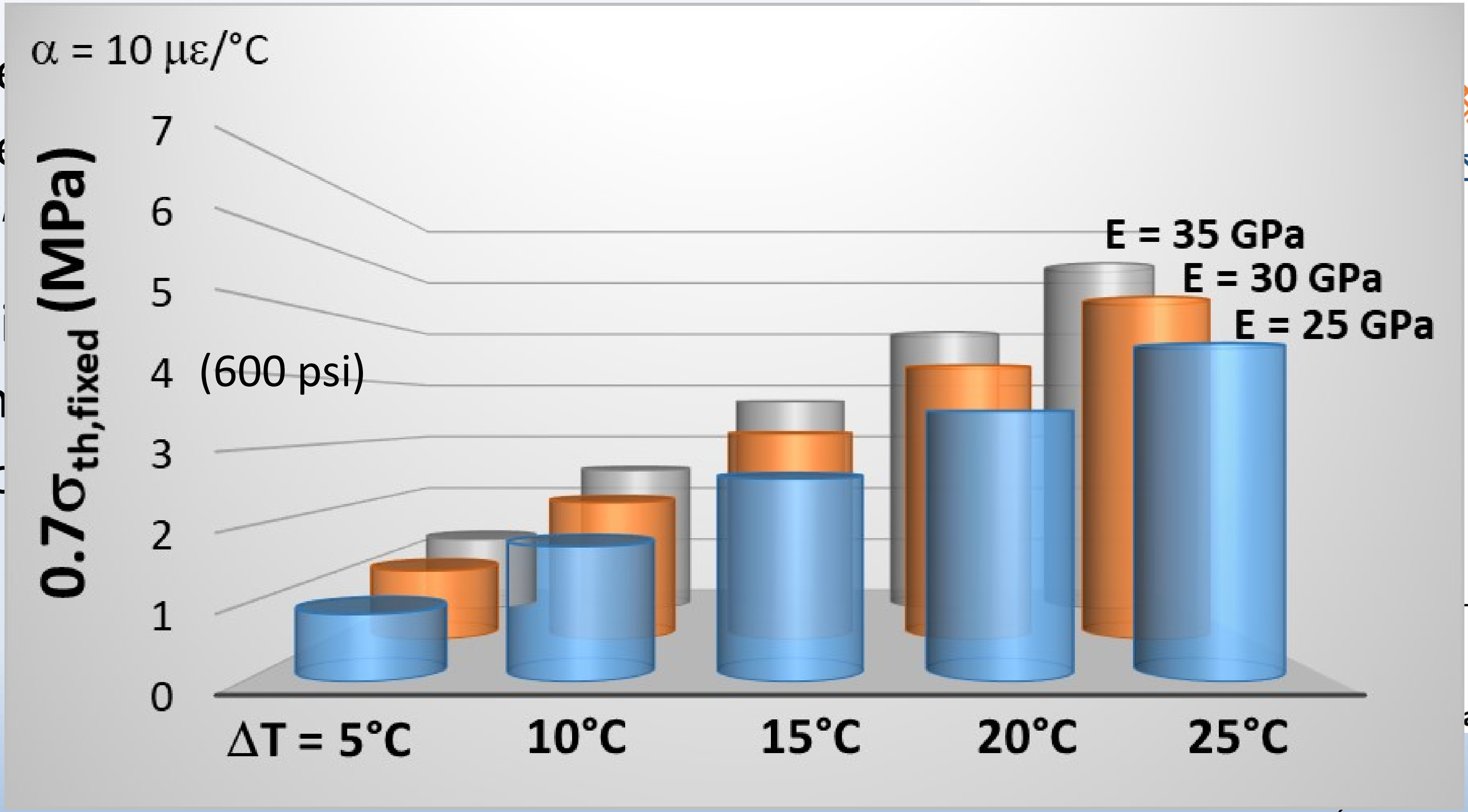
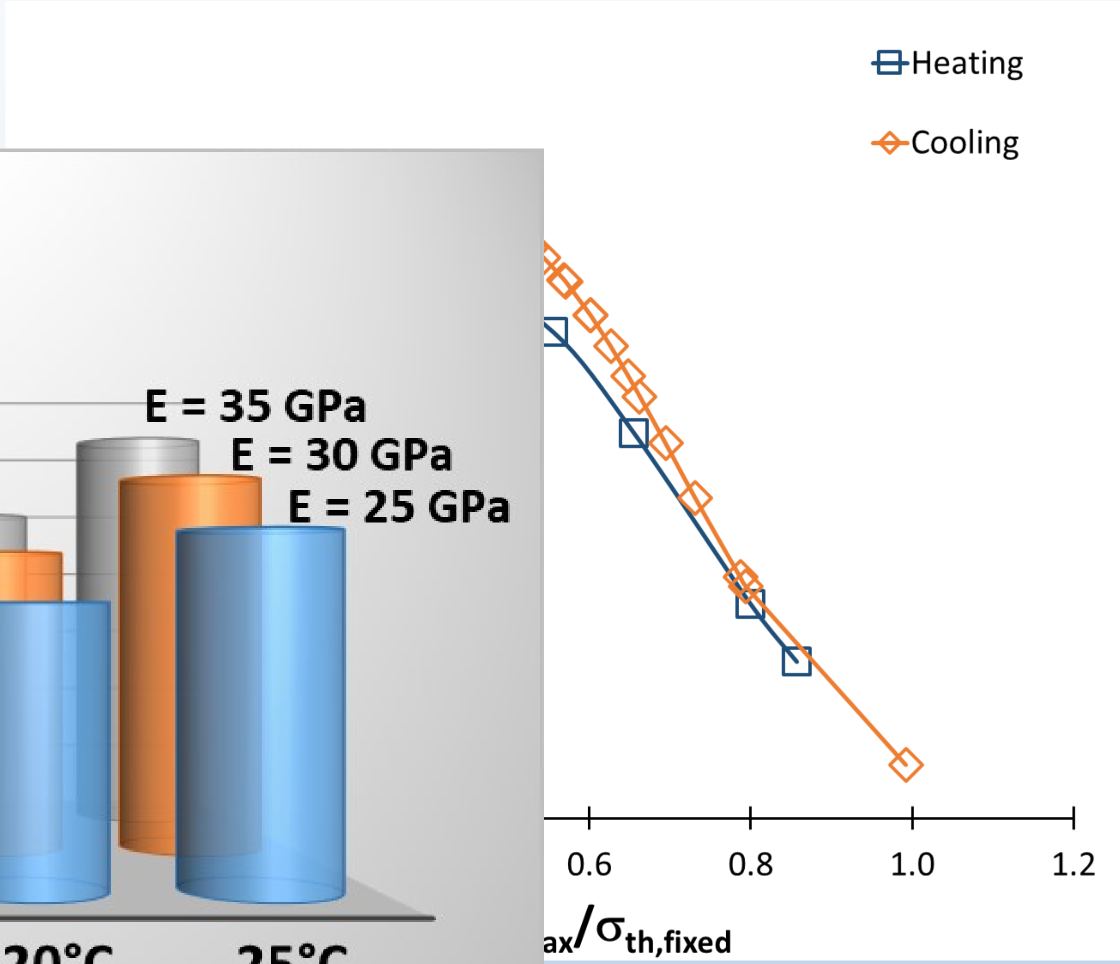
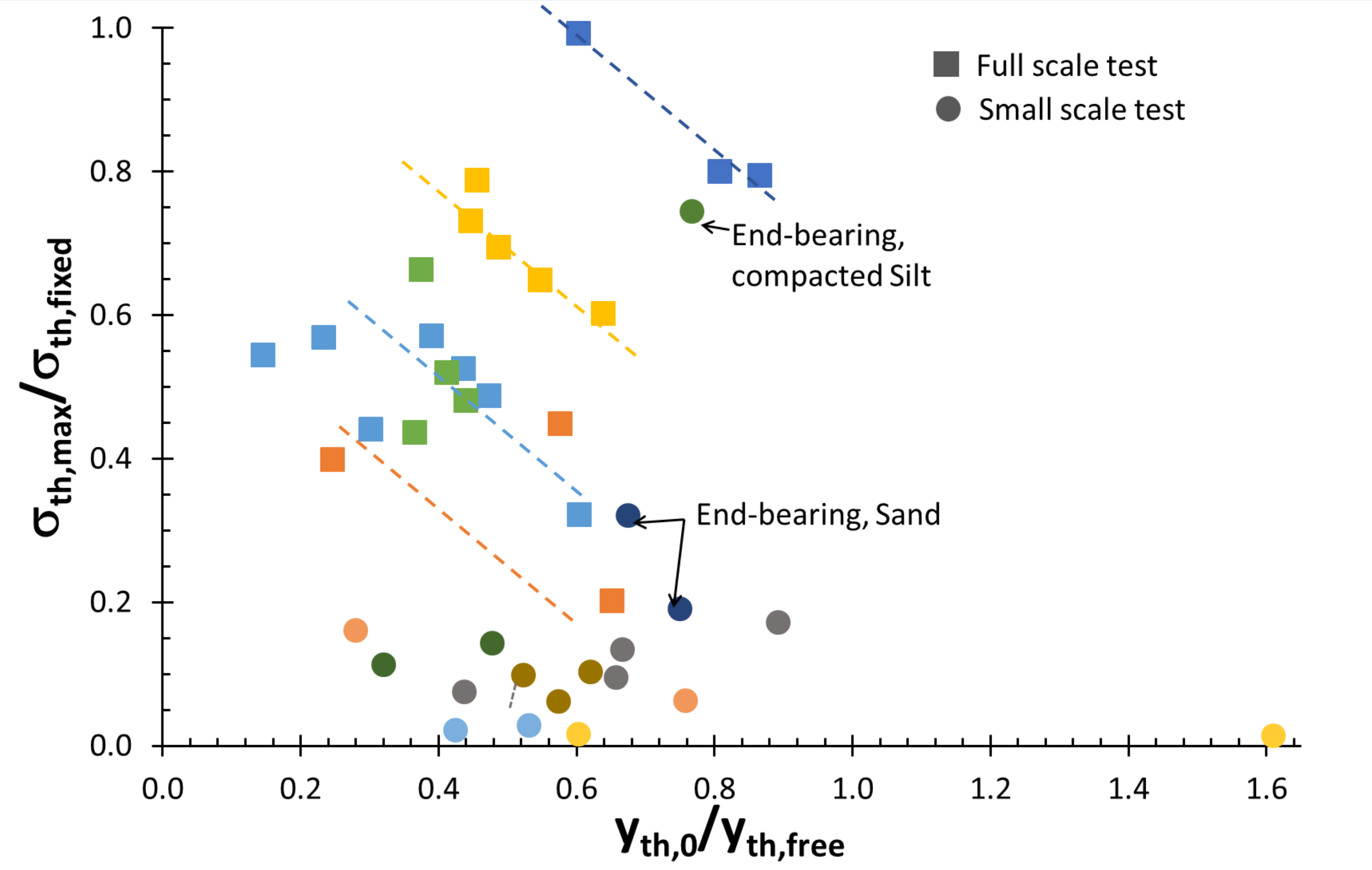




$= \alpha . \Delta T . E$

4. RESEARCH INSIGHTS

Pile thermal stress-displacement response

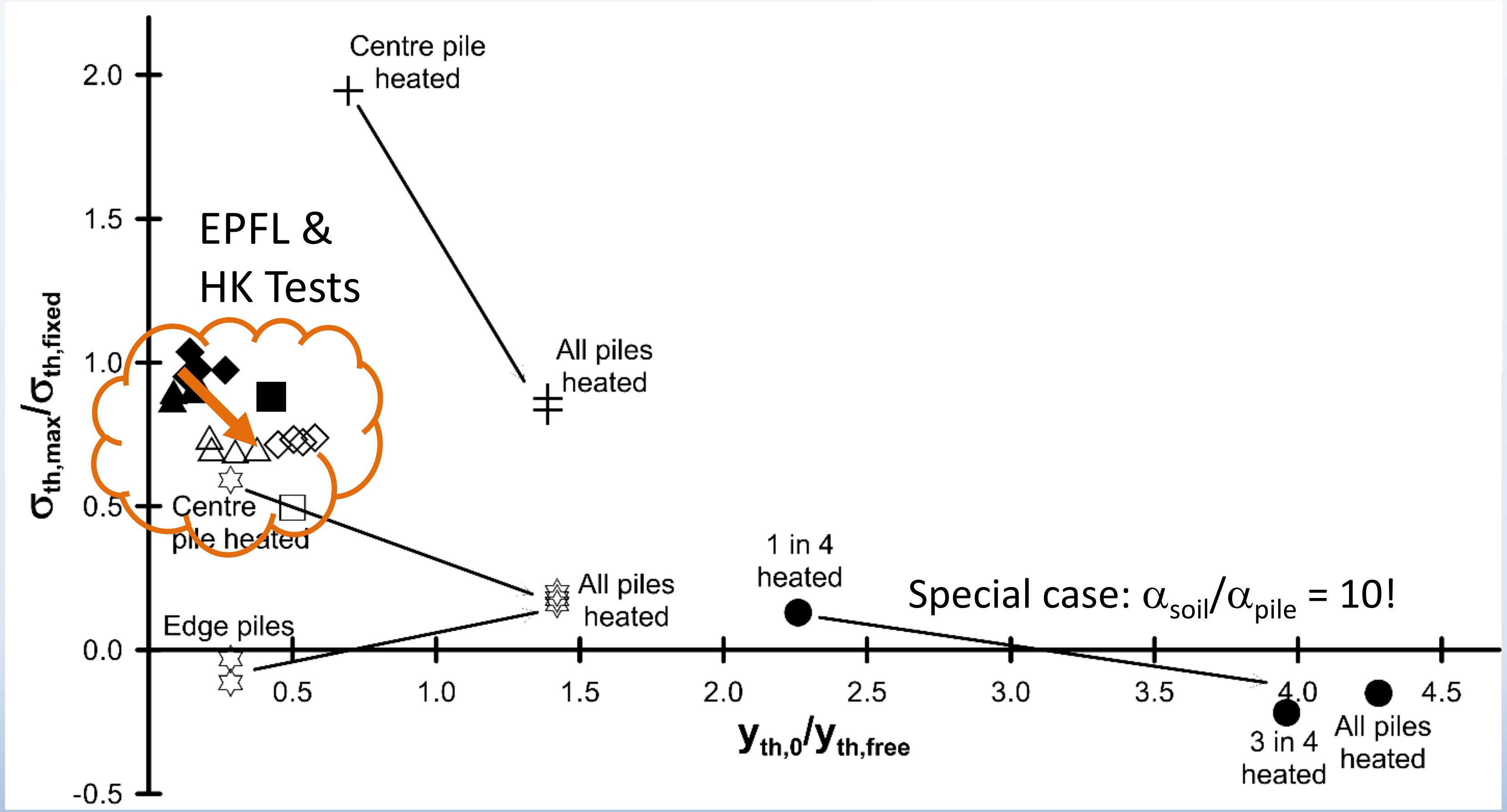


- Thermal stress and pile head displacement are complementary:

  displacement ↓ ⇨ stress ↑
  & vice versa.

4. RESEARCH INSIGHTS

Pile groups

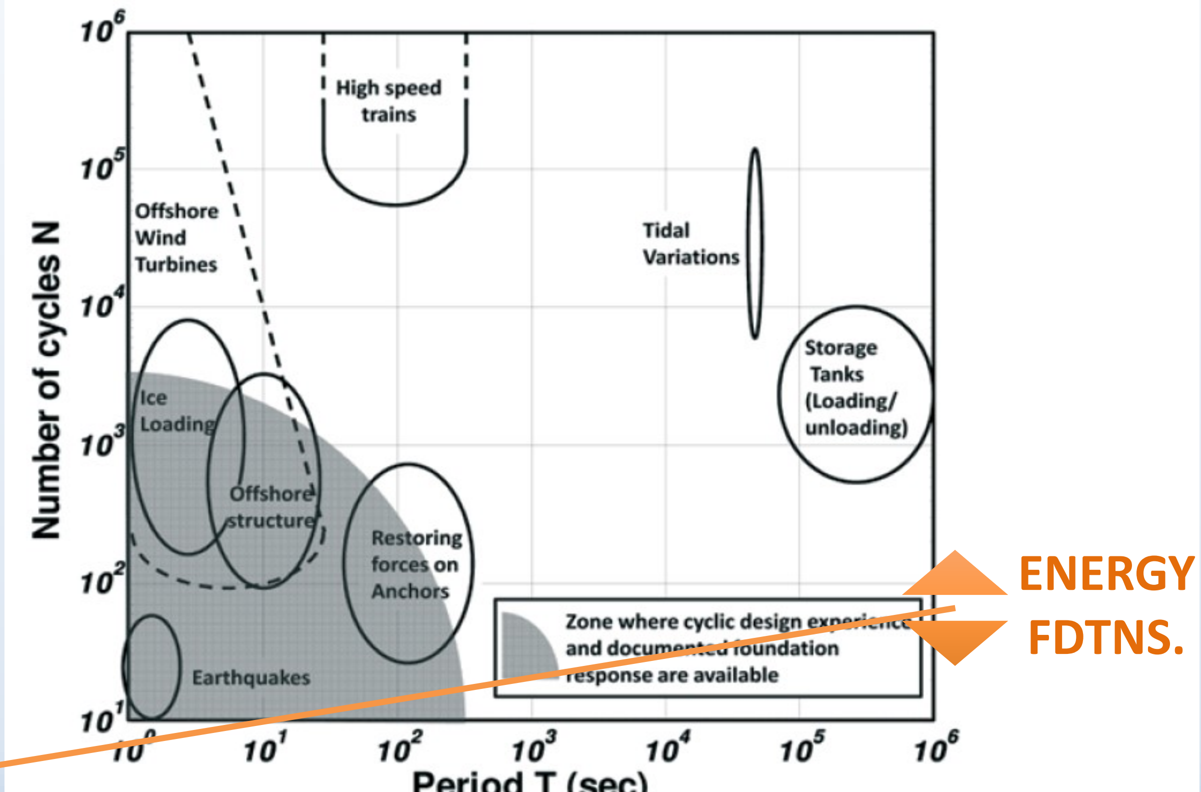


- Field tests limited to special conditions but show reduced stress and larger displacement as more piles heated.
- Numerical analysis suggests the same.
- BUT use continuous heating, not cyclic.

4. RESEARCH INSIGHTS

Pile geotechnical resistance

- For geotechnical failure, pile plunges, so all shaft resistance has to become "positive", thermal effects $\rightarrow$ 0.
- Resistance of soil & interfaces does not appear to be compromised by temperature effects.
- Cyclic degradation has not been demonstrated (lower no. & frequency of imposed cycles cf. offshore)

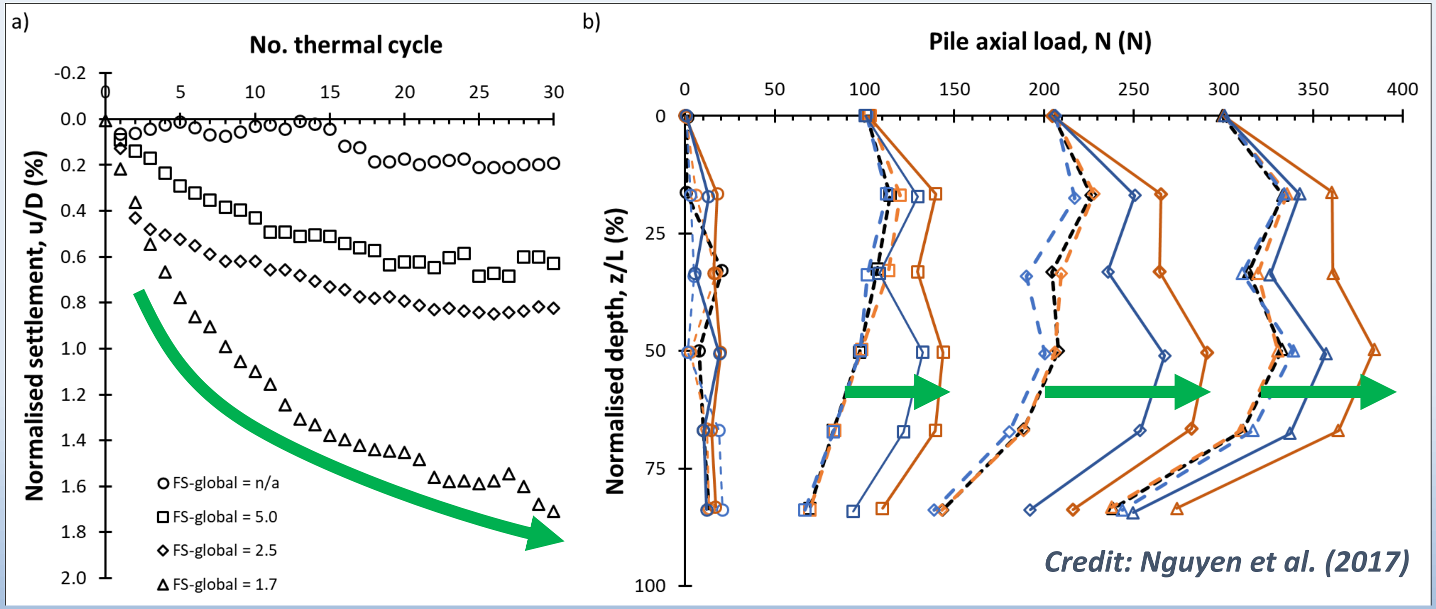


Credit: Andersen et al. (2013)

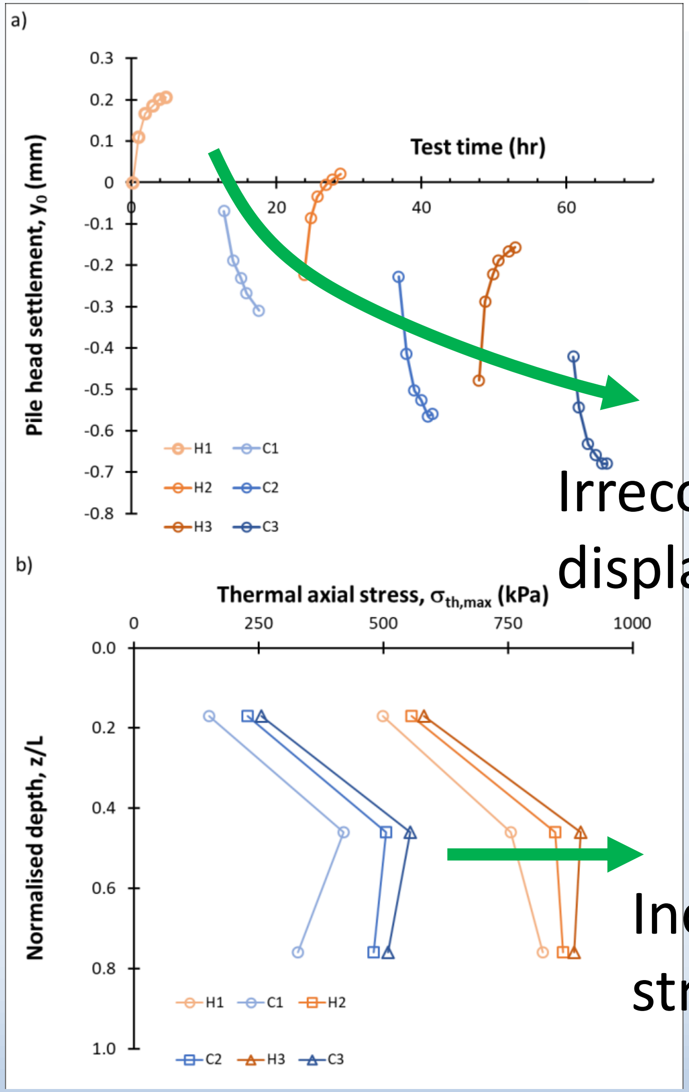
4. RESEARCH INSIGHTS

Cyclic thermal loading – isolated piles

- Full scale unclear but interesting behaviours in small scale tests.
- Ratcheting during thermal cycles but seems to stabilise – Why? Is it always stable? Importance?



Credit: Nguyen et al. (2017)



Irrecoverable displacement

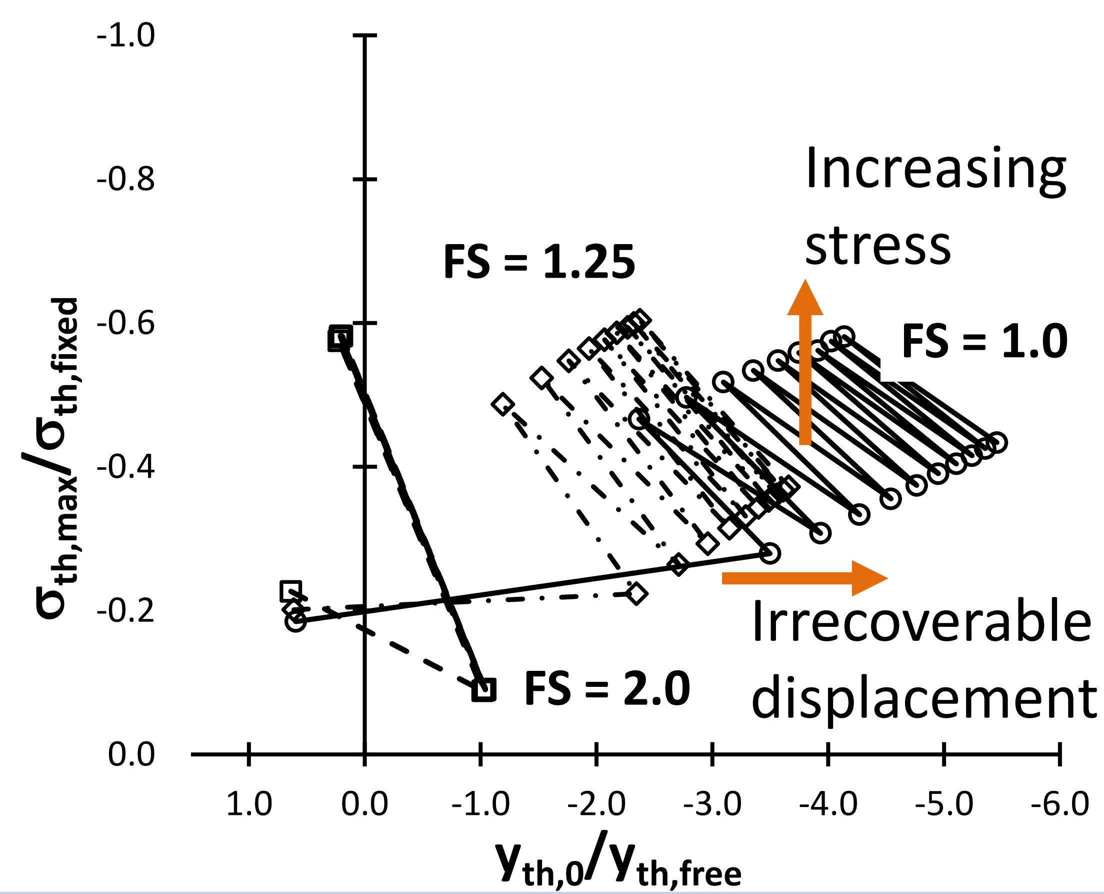
Increasing stress

Credit: Wang et al. (2017)

4. RESEARCH INSIGHTS

Cyclic thermal loading – isolated piles

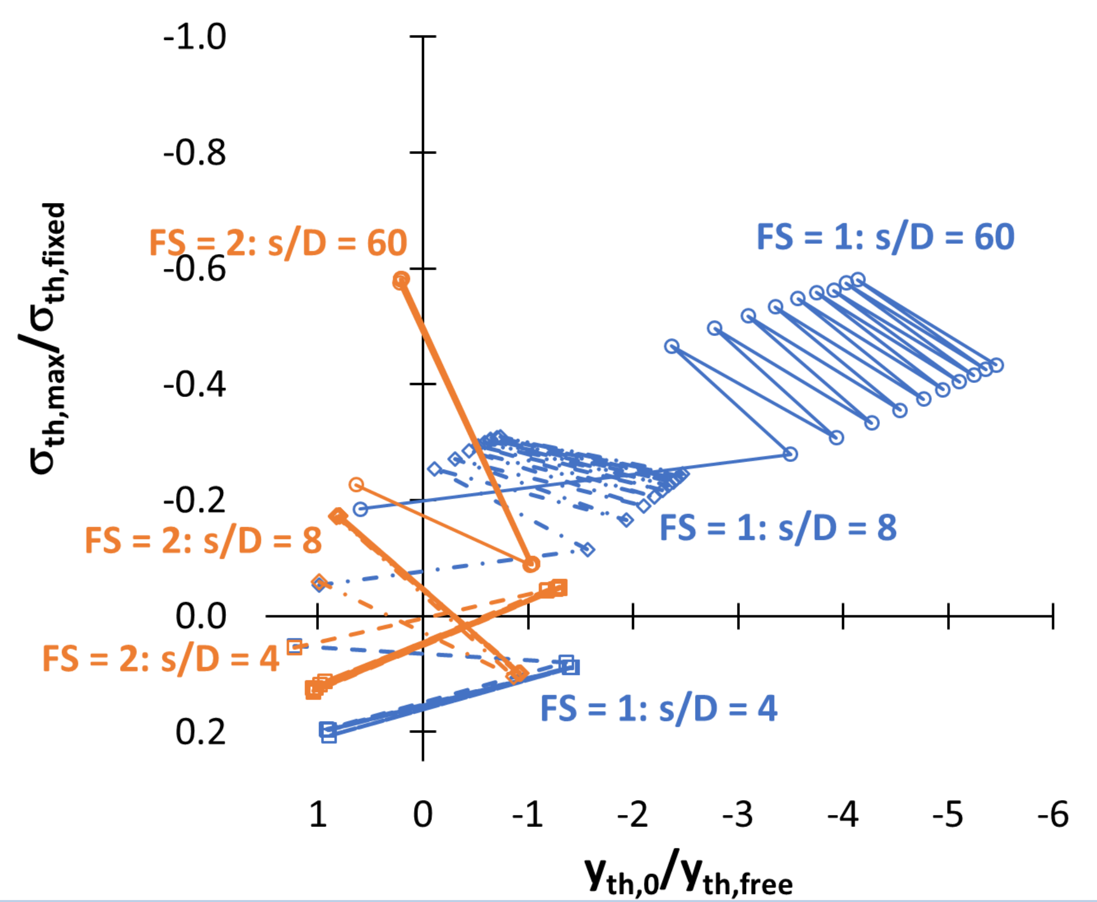
- Why?
  - Reaction to thermal strains cannot be mobilised on shaft when FS-shaft is low, during cooling need to mobilise base reaction to maintain force equilibrium, and pile settles.
- Does it stabilise?
  - Yes, it seems to settle down after several cycles.
- Is it important?
  - Depends… over 10 cycles, thermal ratcheting equates to about 10% (FS = 2) to 50% (FS = 1) of initial settlement.



4. RESEARCH INSIGHTS

Cyclic thermal loading – pile groups

- Why?
  - As pile spacing reduces, pile interaction under mechanical load suppresses mobilisation of shaft friction (in effect FS-shaft increases).
- Does it stabilise?
  - Yes, seems to settle down; low-FS needs to be extended over longer operational period.
- Is it important?
  - Counterintuitively, reduced pile spacing helps.
  - Edge & corner piles closer to isolated in terms mobilised shaft resistance (to be checked).



5. IMPLICATIONS for DESIGNERS

SAFETY

- **GEOtechnical safety**
  - Thermal loads do not seem to affect geotechnical resistance;
  - No evidence of cyclic degradation of shaft resistance.
- **STRtuctural safety**
  - Thermal stresses only likely to be an issue if pile already highly stressed and/or at large ΔT.

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- **GEOtechnical safety**
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SERVICEABILITY

- Thermal displacements an issue for long piles with large ΔT, and under cyclic loading
- Thermal ratcheting more important for piles at large spacing and low FS-shaft.
- Down-drag in NC clays.
- Unbalanced thermal loads lead to additional displacement as ground heats/cools.

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Thanks!

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7. REFERENCES

Recent contributions:

[1] Bourne-Webb P.J., Bodas Freitas T.M., Freitas Assunção R.M. (2019) A review of pile-soil interactions in isolated, thermally-activated piles, Computers and Geotechnics **108**(April):61-74

[2] Bourne-Webb P.J., Bodas Freitas T.M. (2018) Thermally-activated piles and pile groups under monotonic and cyclic thermal loading – A review, Renewable Energy **147**, Part 2 (March): 2572-258

Lambeth College test pile papers:

[3] Amis T., Bourne-Webb P., Davidson C., Amatya B., Soga K. (2008) An investigation into the effects of heating and cooling energy piles whilst under working load at Lambeth College, Clapham Common, UK. Proc. of the 33rd Annual and 11th Intl. Conf. of the Deep Foundations Institute, New York

[4] Bourne-Webb P.J., Amatya B., Soga K., Amis A., Davidson C., Payne P. (2009) Energy pile test at Lambeth College, London: geotechnical and thermo-dynamic aspects of pile response to heat cycles, Géotechnique **59**(3):237-248

[5] Amatya B.L., Soga K., Bourne-Webb P.J., Amis T., Laloui L. (2012). Thermo-mechanical behaviour of energy piles, Géotechnique, 62(6): 503-519

[6] Bourne-Webb, P.J., Amatya B., Soga K., (2013). A framework for understanding energy pile behaviour, ICE Proc. Geotechnical Engineering, **166**(GE2): 170-177

[7] Bourne-Webb P.J. (2020) The role of concrete creep under sustained loading, during thermo-mechanical testing of energy piles, Computers and Geotechnics **118**(Feb.):103309