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Thermal Behaviour of Piles used as Heat Exchangers

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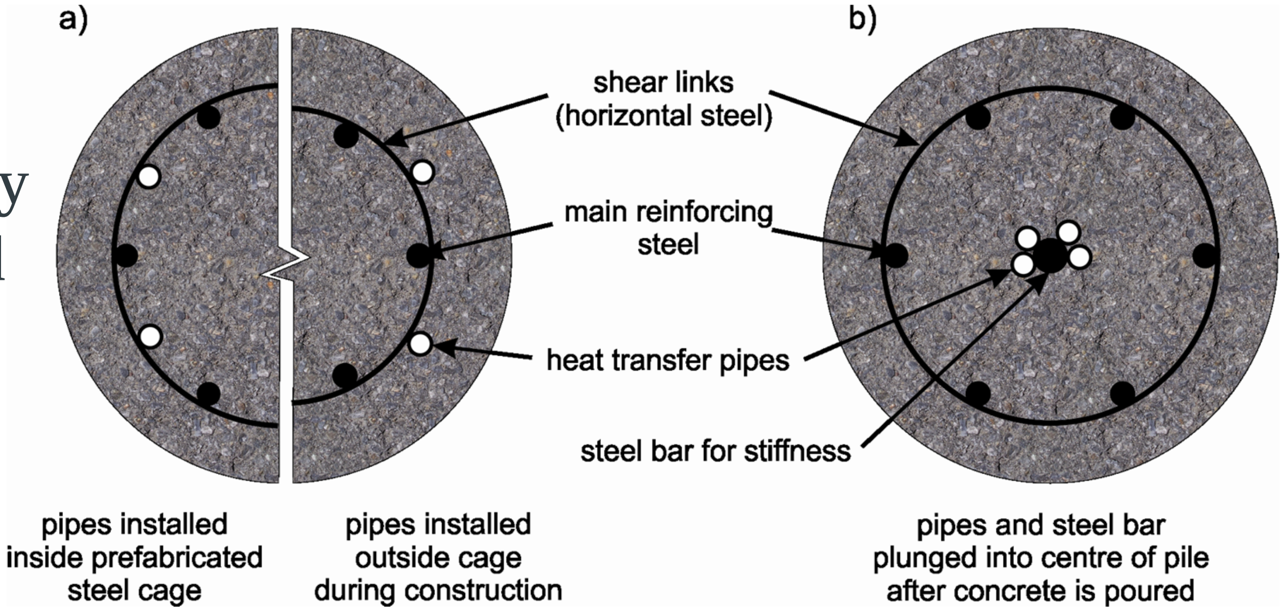
Contents

Scope

- Bored foundation piles with concrete cast in situ
- Piles, not walls or piled walls
- Thermal behaviour, not thermo-mechanical

Rotary Bored Piles



Contiguous Flight Auger (CFA) Piles

Differences to BHs

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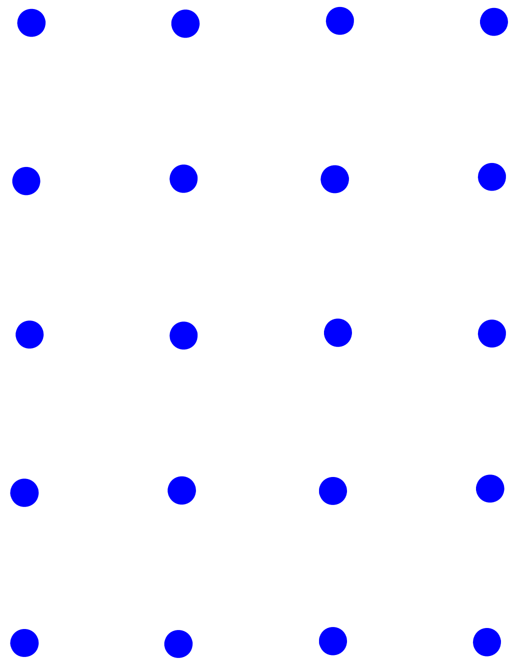
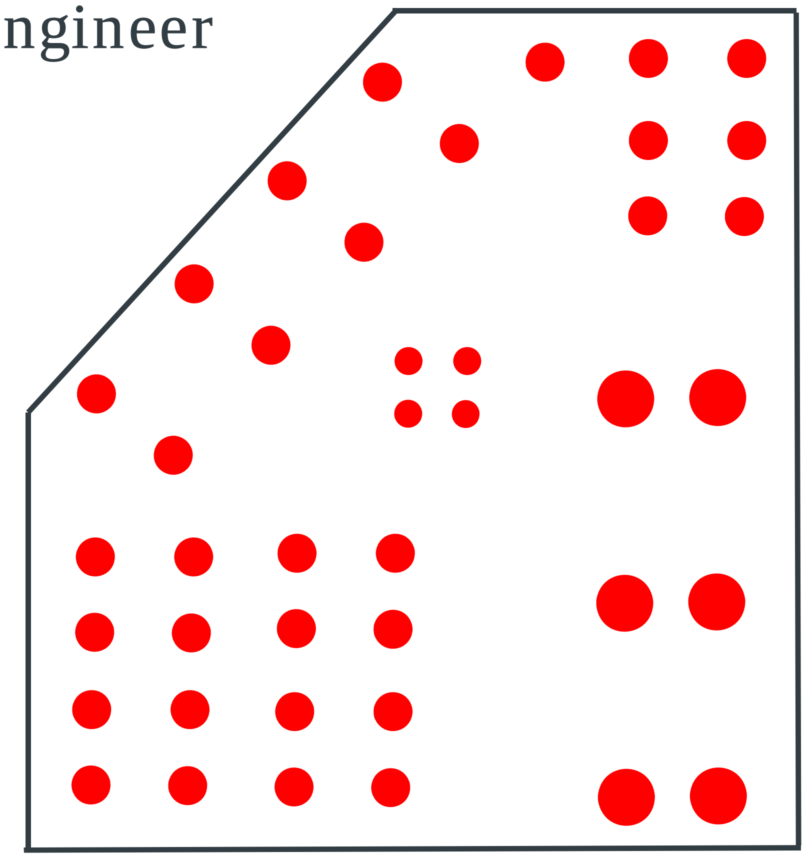
Pile Layout

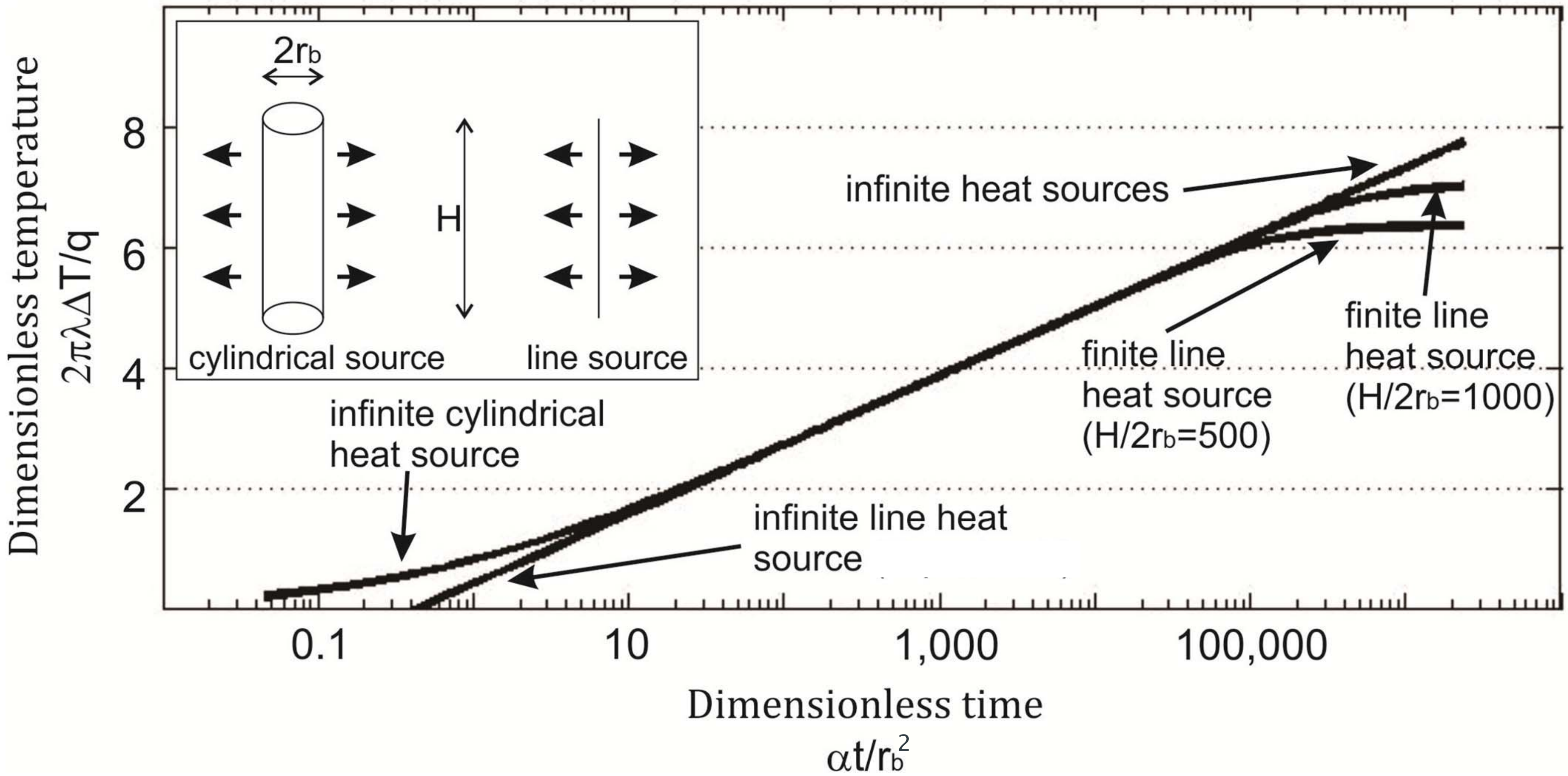
- Often irregular in terms of length, diameter & spacing
- Determined by structural engineer



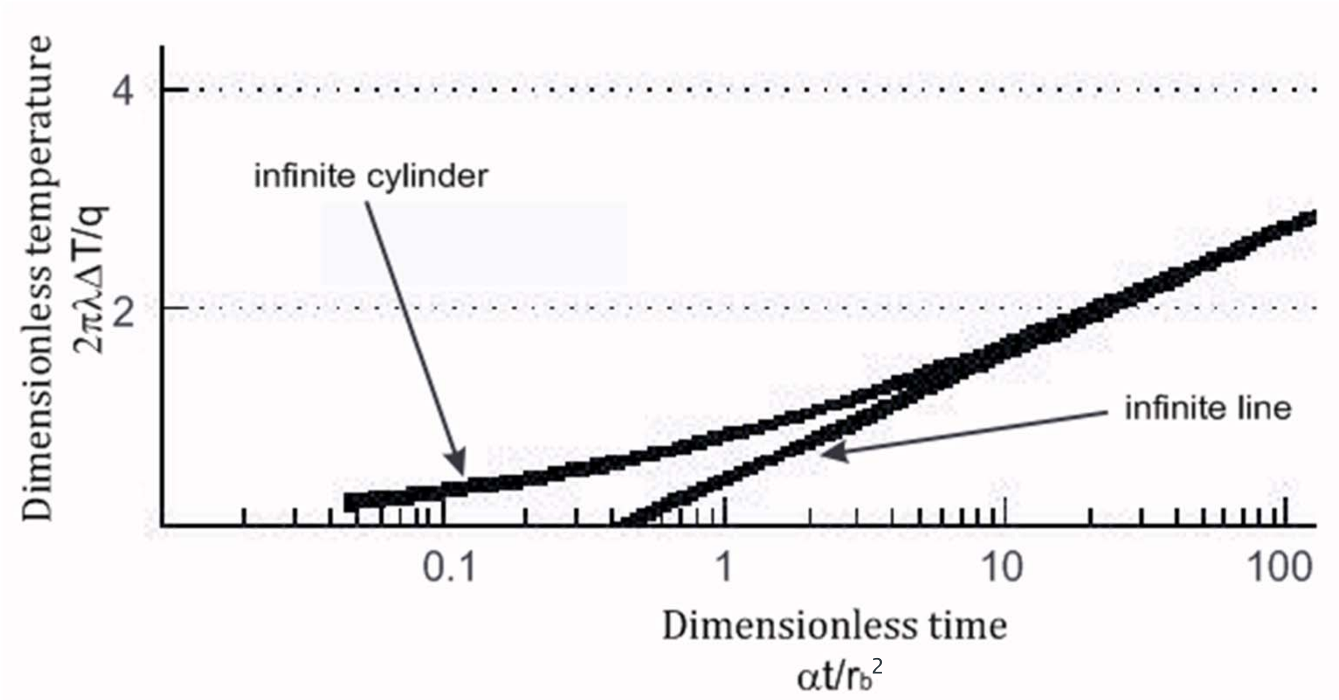


Geometry:

Line and Cylindrical Sources, Ground Response



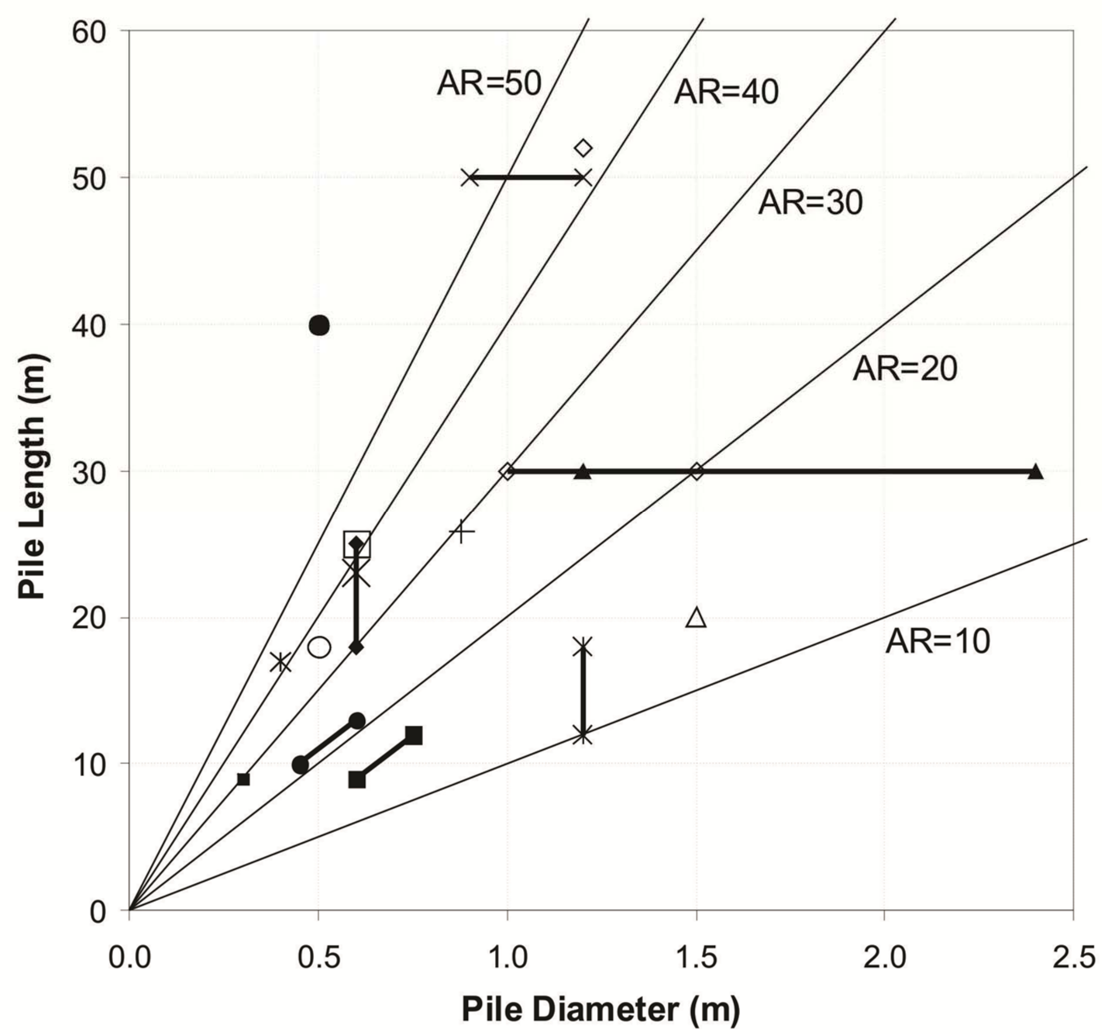
Geometry : Pile Diameter



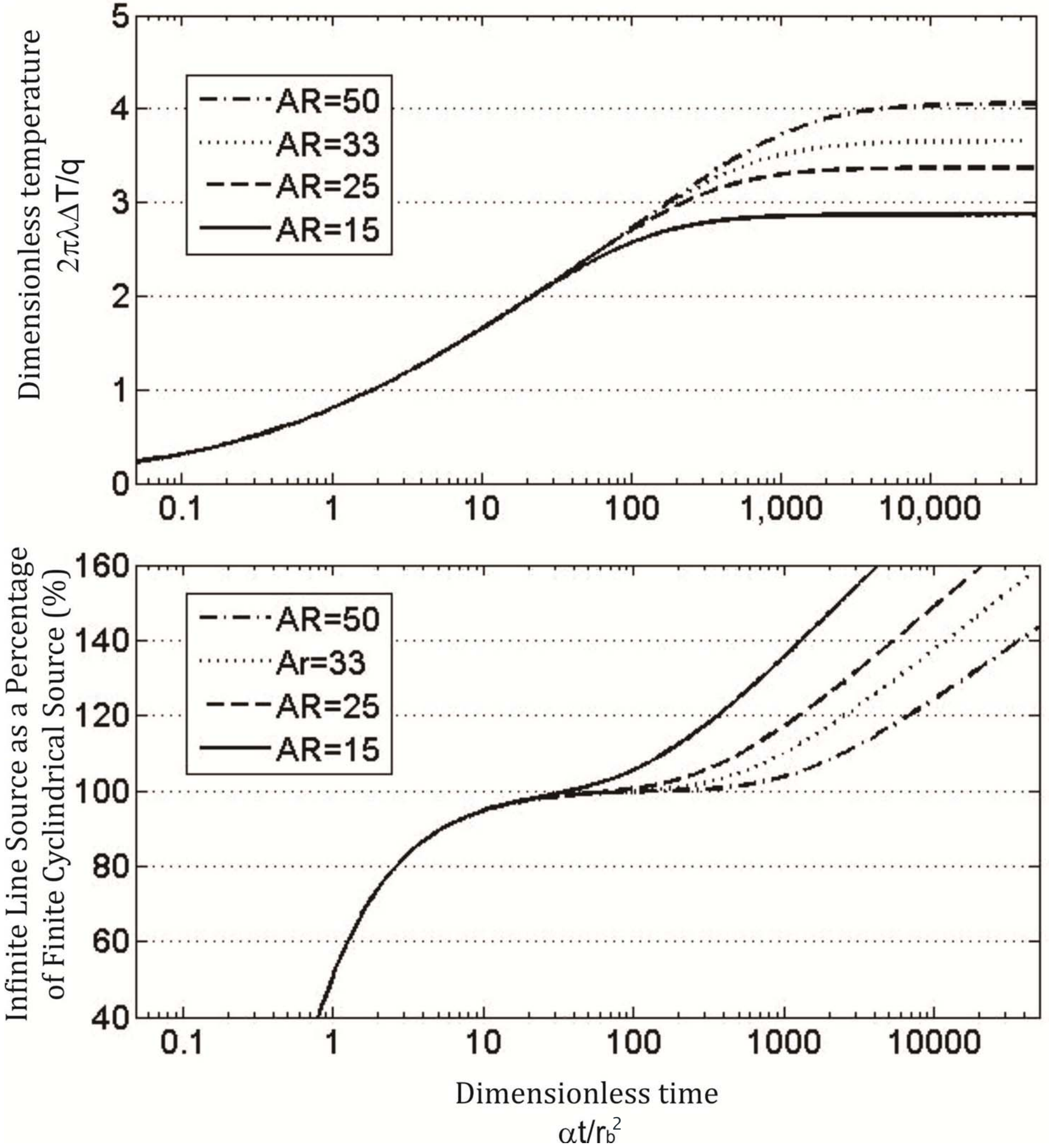
	r=0.1m	r=0.3m	r=0.6m
5% error Fo=10	28 hours	10 days	42 days
10% error Fo=5	14 hours	5 days	21 days
25% error Fo=2	6 hours	2 days	8 days

Pile Geometry : Aspect Ratio

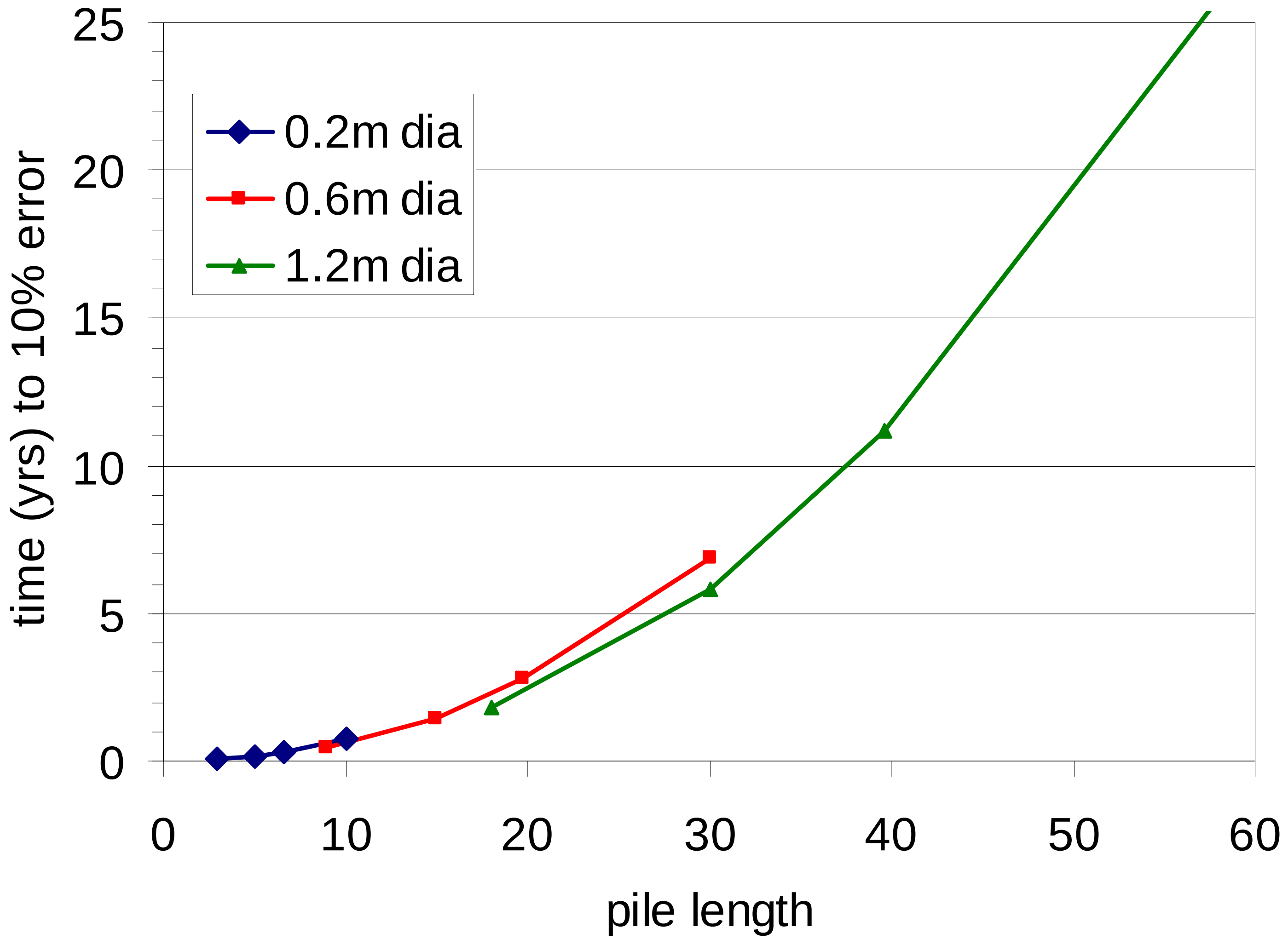
- Aspect ratio = length/diameter
- Borehole AR = 500 to 2,000
- Pile AR = 10 to 50

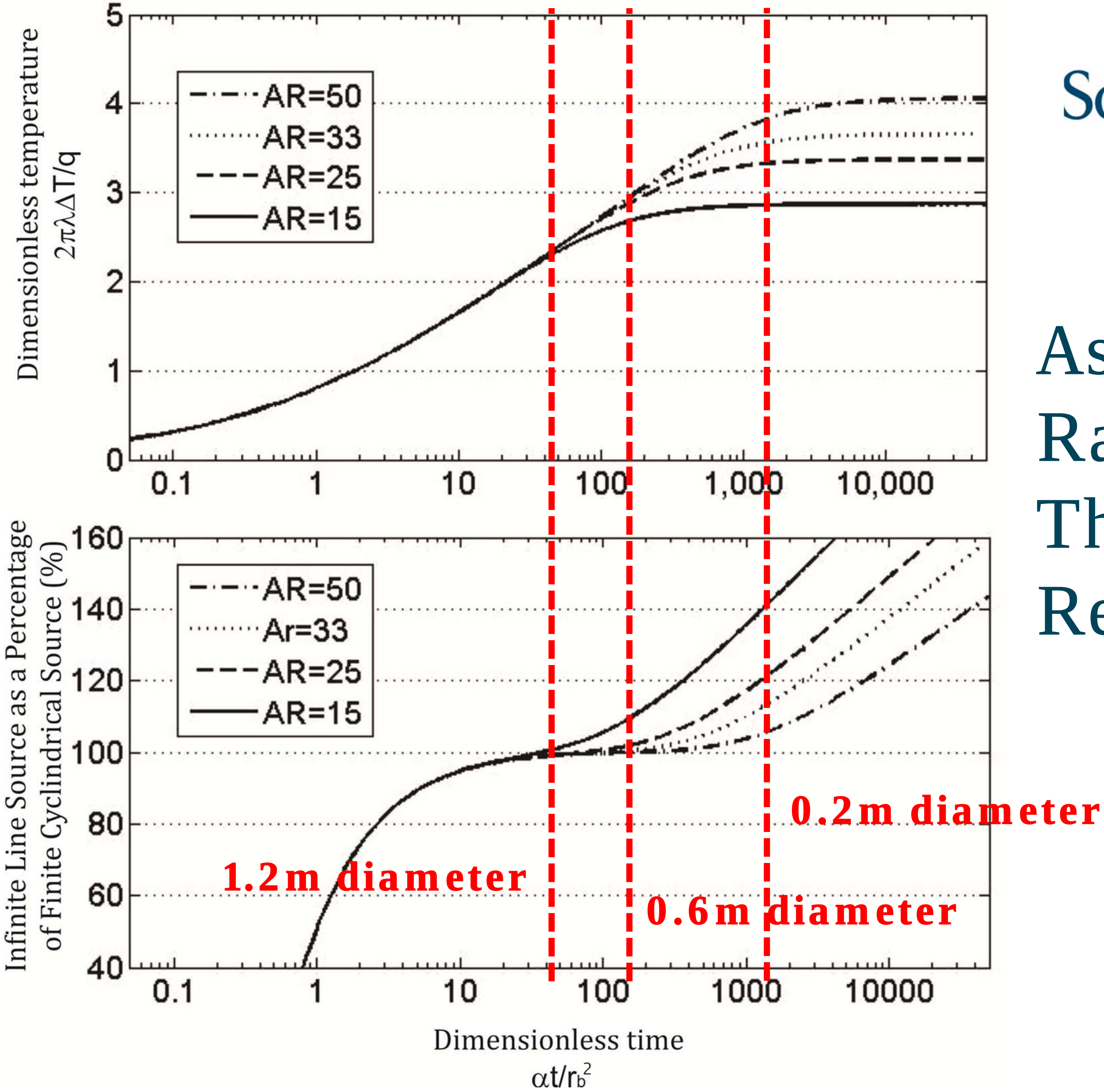


Aspect Ratio: Thermal Response



Pile Geometry – Pile Length



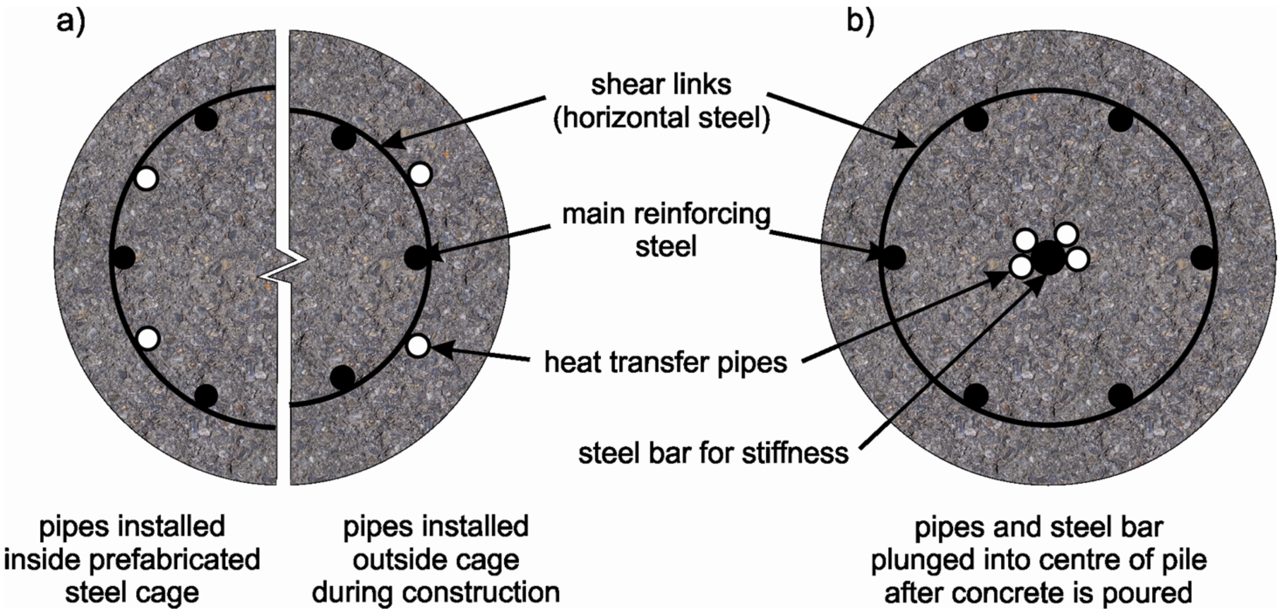


Aspect Ratio: Thermal Response

Pipe Arrangements

- More pipes
- More widely spaced
- Larger cover

- Lower Resistance
- Higher resistance?
- Higher Resistance



Pile Thermal Resistance

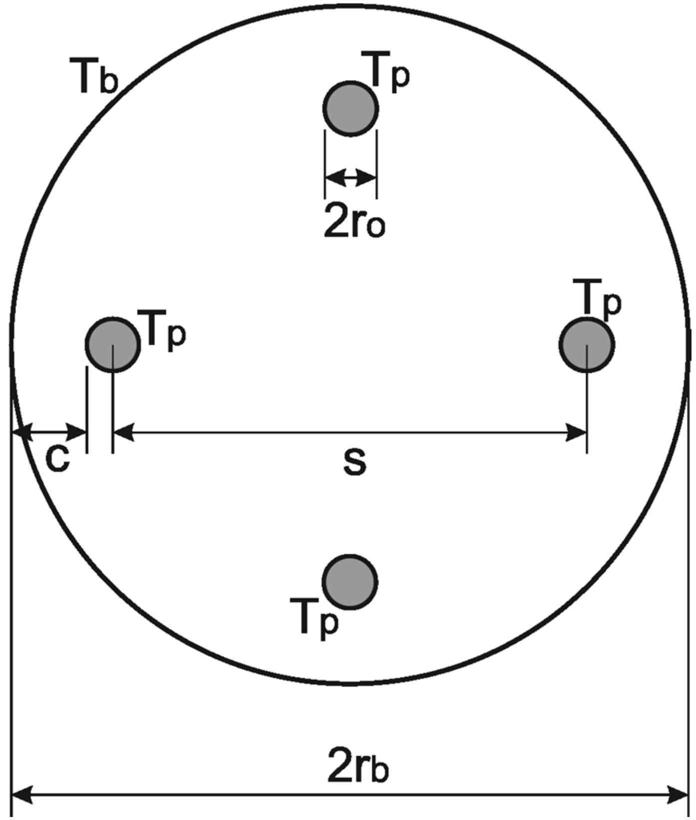
$$R_b = R_{pconv} + R_{pcond} + R_c$$

- R_{pconv} & R_{pcond} relatively “easy” to calculate
- R_c – complex multipole method or numerical modelling
- Depends on pipe arrangements and thermal conductivity of concrete
- Possibility to determine in situ ??

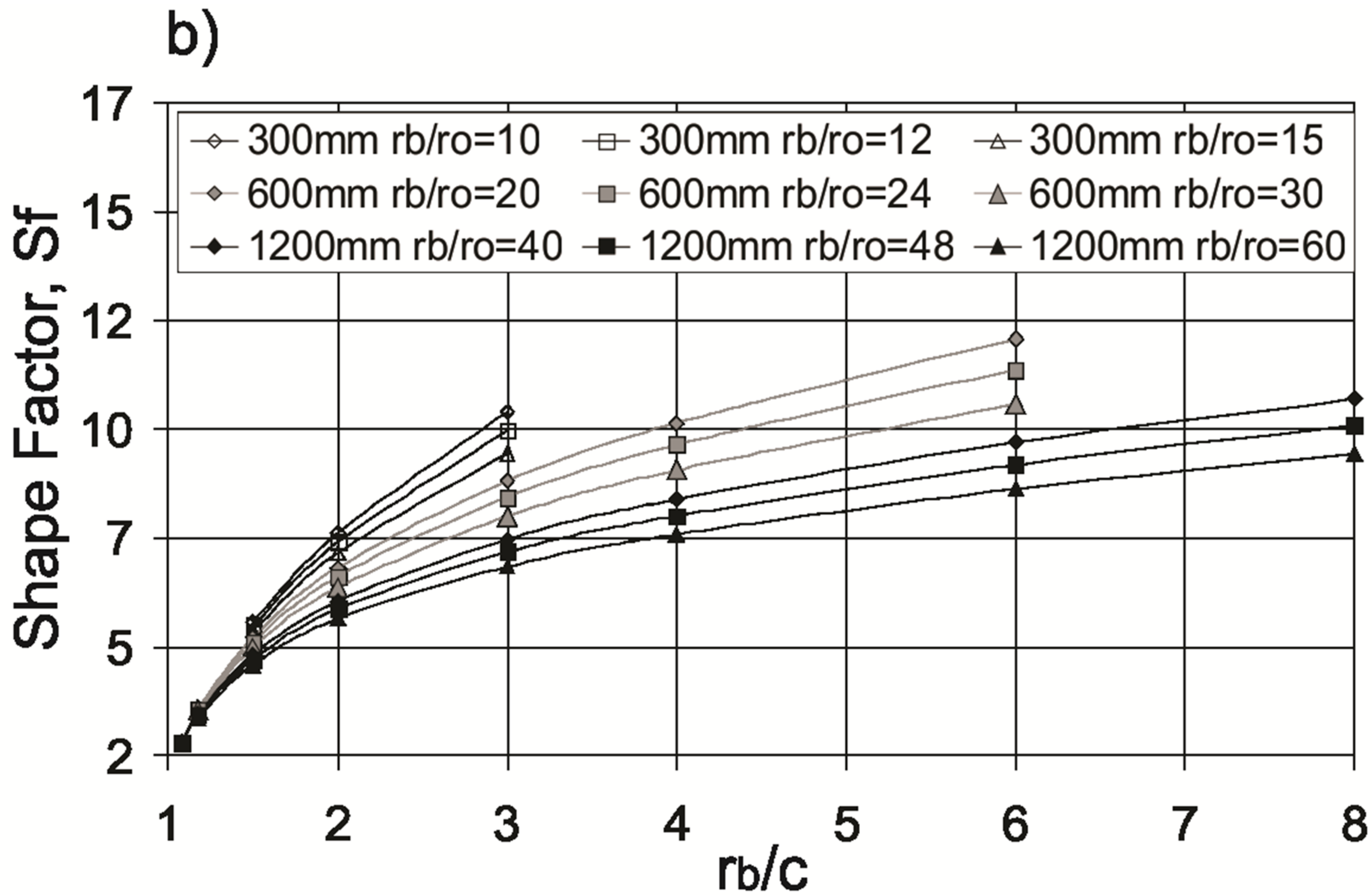
Numerical Modelling for R_c

$$R = \frac{1}{S_f \lambda}$$

- Aim to determine shape factor so that R_c can be calculated
- Steady state vs transient
- Lower resistance if:
  - More pipes
  - Pipes closer to edge
- For central pipes number & arrangement matters less
- Still need to know $\lambda_{concrete}$



Design Chart for R_c with four pipes



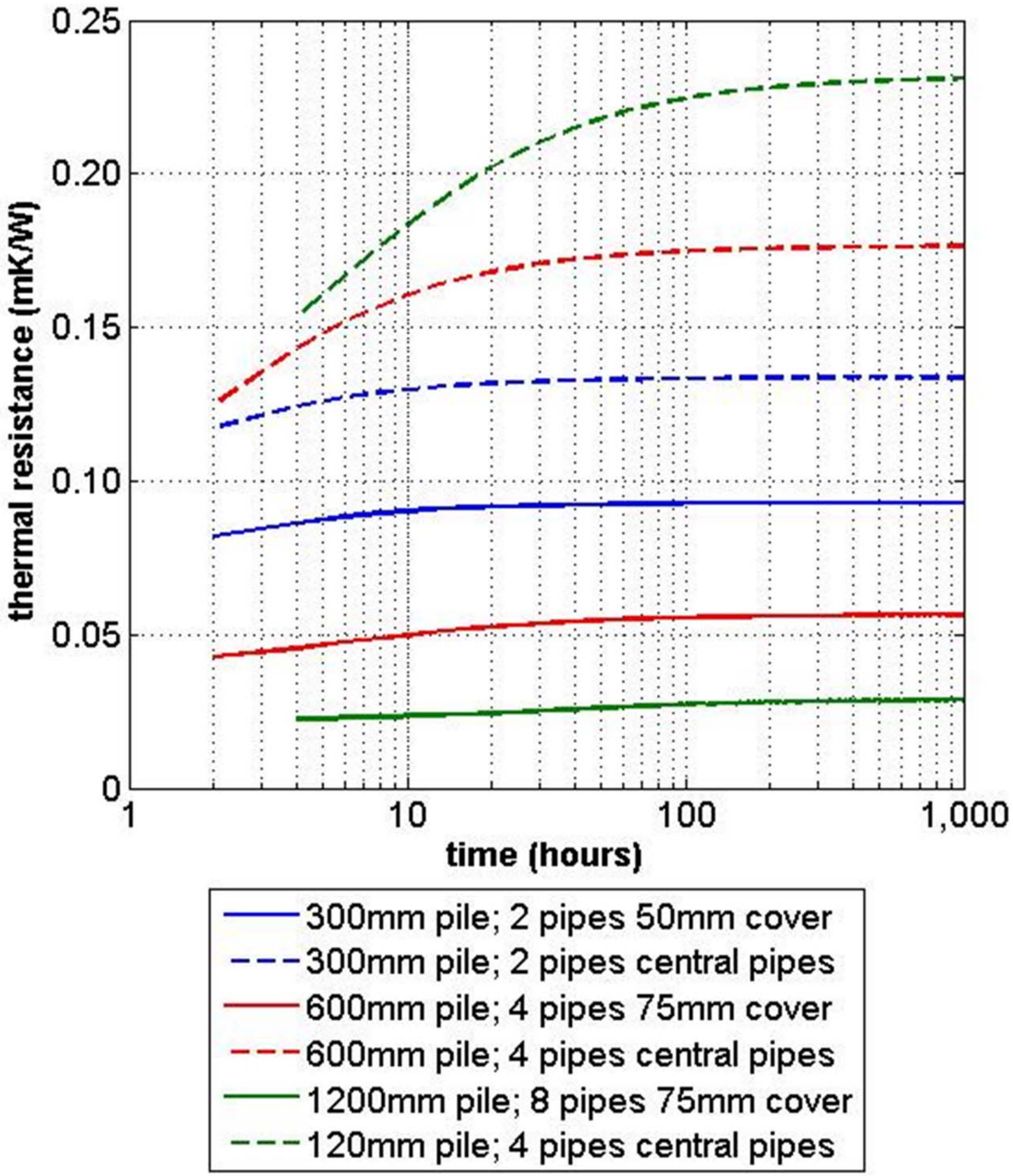
Pile Thermal Resistance -Values

$$R_b = R_{pconv} + R_{pcond} + R_c$$

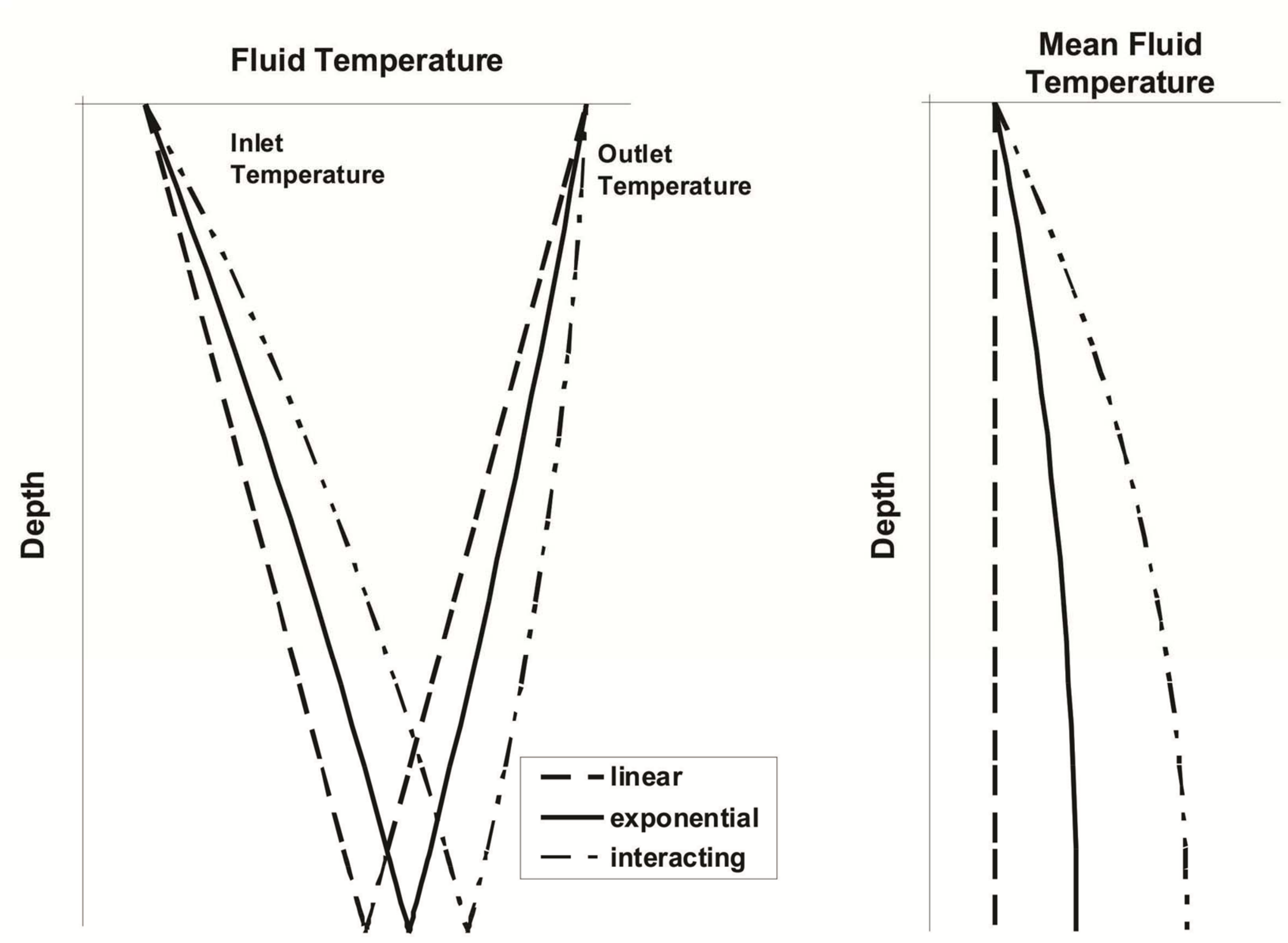
Pile Dia mm	Pipes	Rp_{conv}	Rp_{cond}	Rc $\lambda=1.25$	Rc $\lambda=2.5$	Rb $\lambda=1.25$	Rb $\lambda=2.5$
300	2 central	0.05	0.04	0.214	0.107	0.304	0.197
300	2 edge	0.05	0.04	0.148	0.074	0.238	0.164
600	4 central	0.02	0.02	0.282	0.141	0.322	0.181
600	4 edge	0.02	0.02	0.090	0.045	0.130	0.085
1200	4 central	0.02	0.02	0.372	0.186	0.412	0.226
1200	8 edge	0.01	0.01	0.046	0.023	0.066	0.043

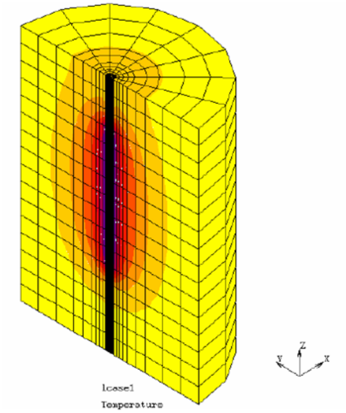
Pile Resistance: Time for Steady State

- 300mm diameter pile: < 1 day
- 600mm diameter pile: up to 2 days
- 1200mm diameter pile: up to 5 days
- Is steady state resistance approach appropriate?



3D: Pipe Interactions





3D: Pipe Interactions (modelling)

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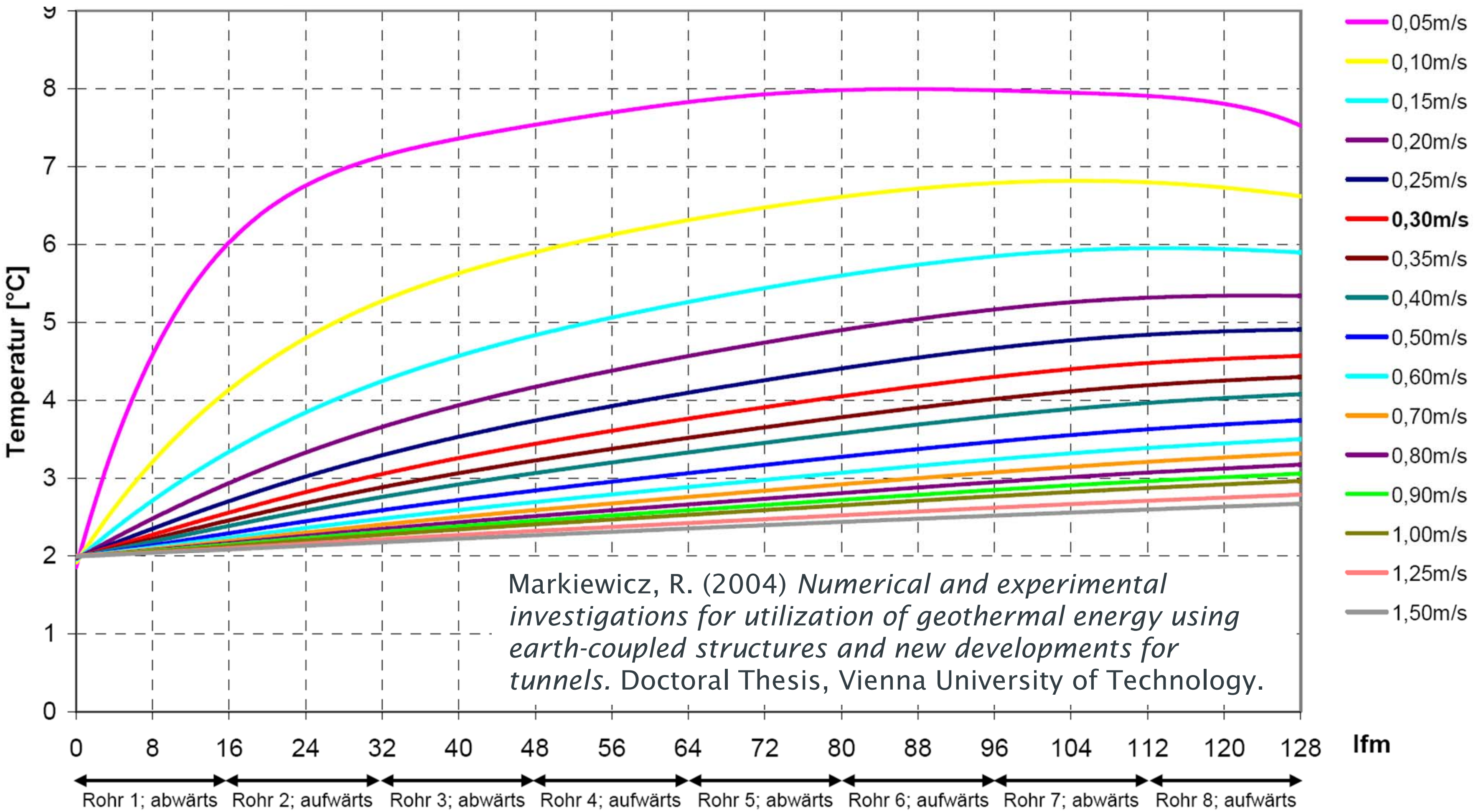
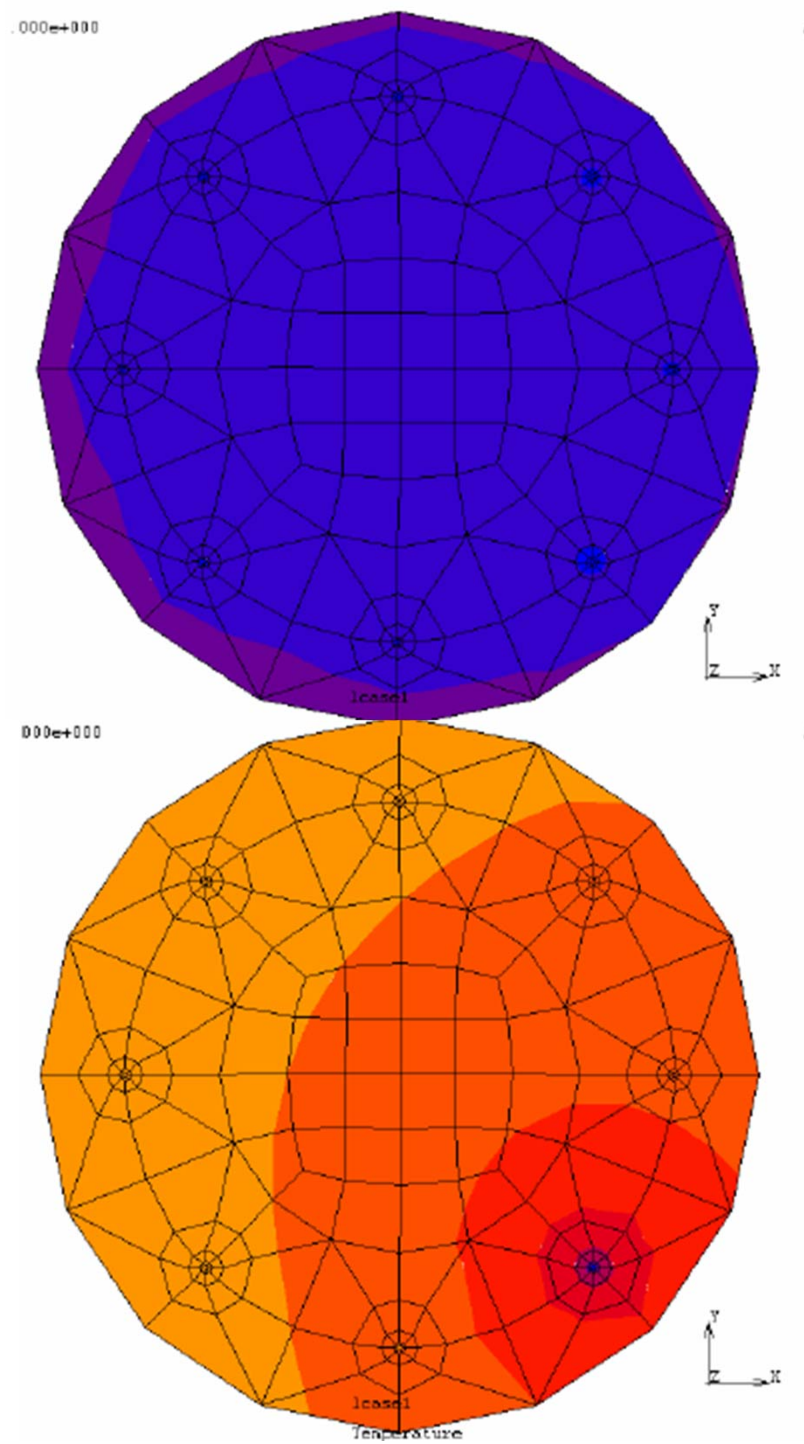


Markiewicz, R. (2004) *Numerical and experimental investigations for utilization of geothermal energy using earth-coupled structures and new developments for tunnels.* Doctoral Thesis, Vienna University of Technology.

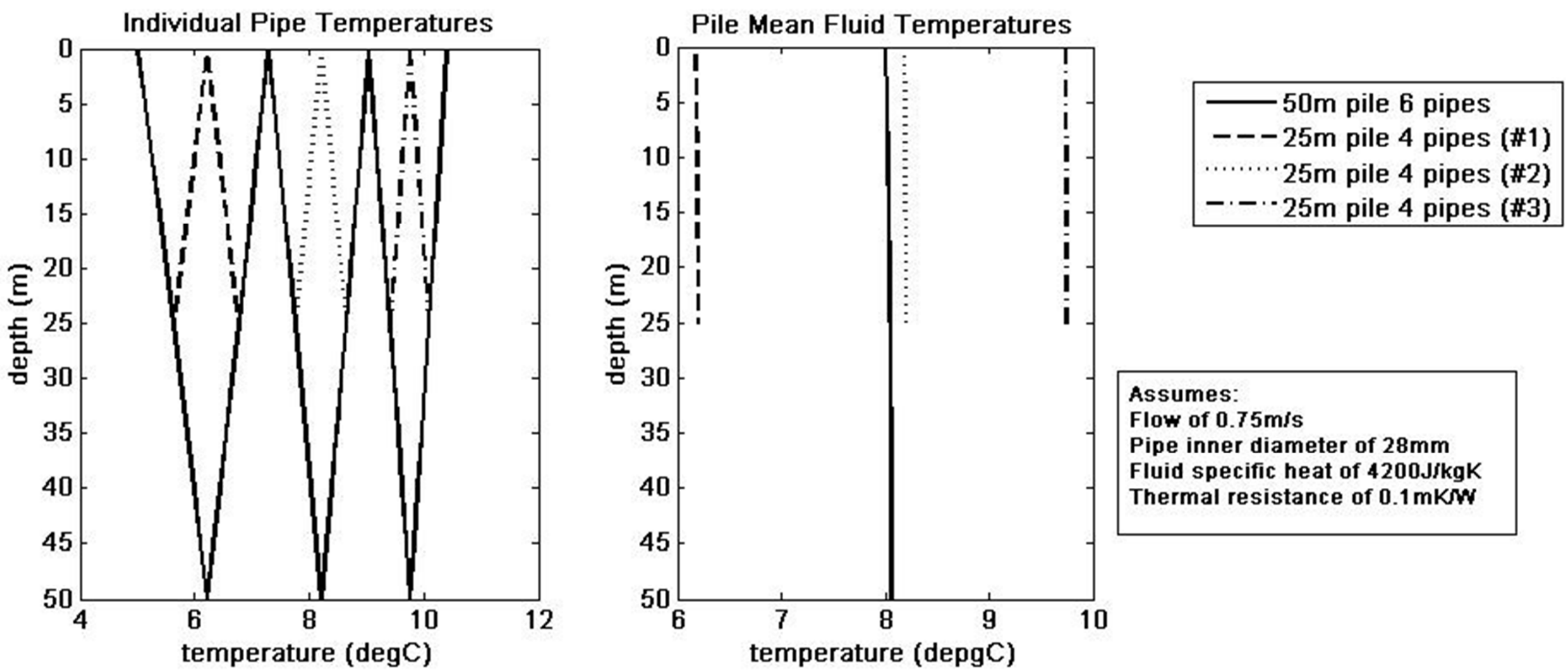
3D: Pipe Interactions (thermal resistance)

Flow Rate	Thermal Resistance
1 m/s	0.05 mK/W
0.5 m/s	0.07 mK/W
0.25 m/s	0.09 mK/W
0.1 m/s	0.15 mK/W



Pile Connections

- 1 No. 50m deep pile with 3 up and down loops
- 3 No. 25m deep piles with 2 up and down loops each



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Thermal Response Testing

Thermal Response Testing

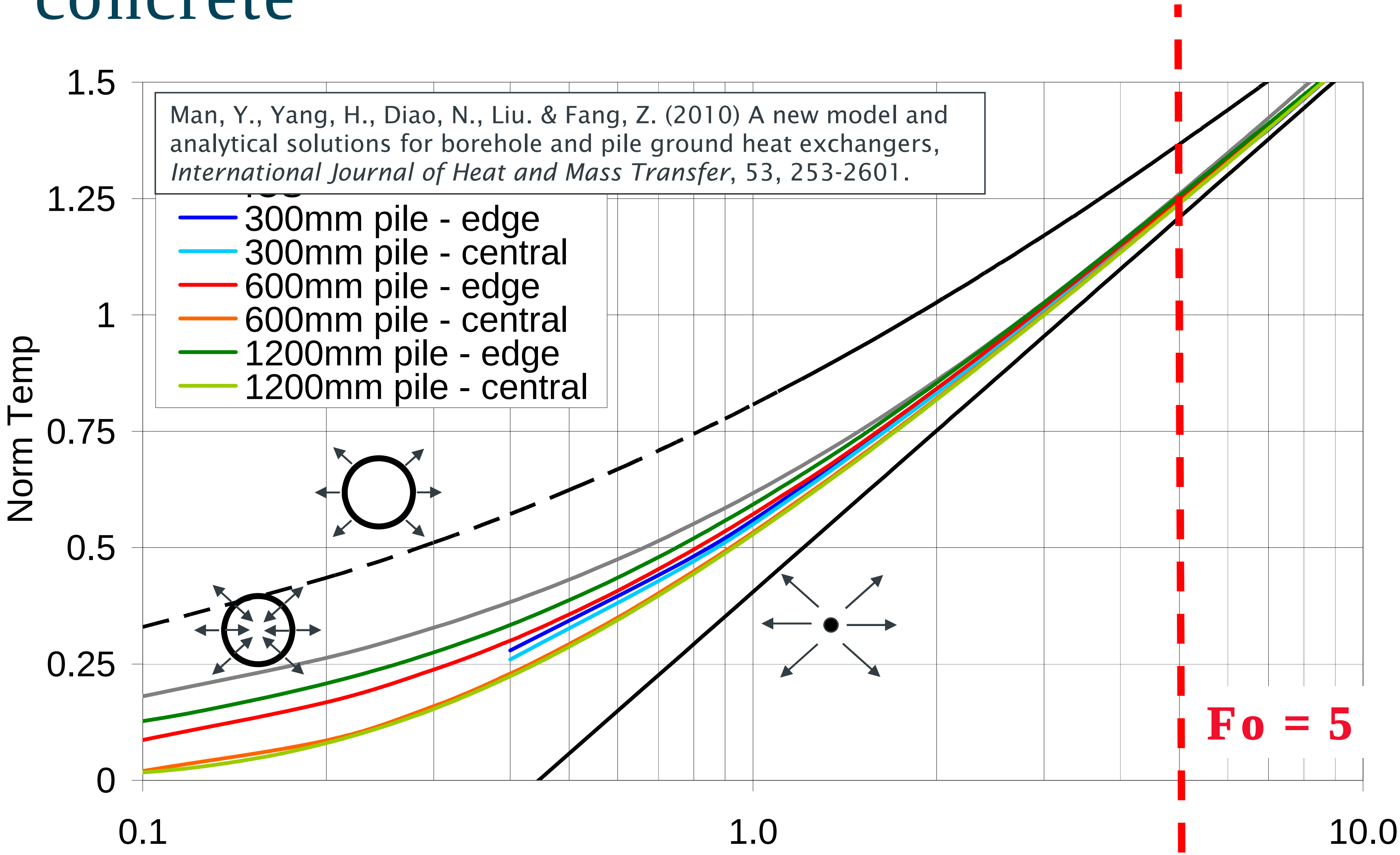
- Data discarded prior to Fo=5:

$$t_{\min} = 5\frac{r_b^2}{\alpha}$$

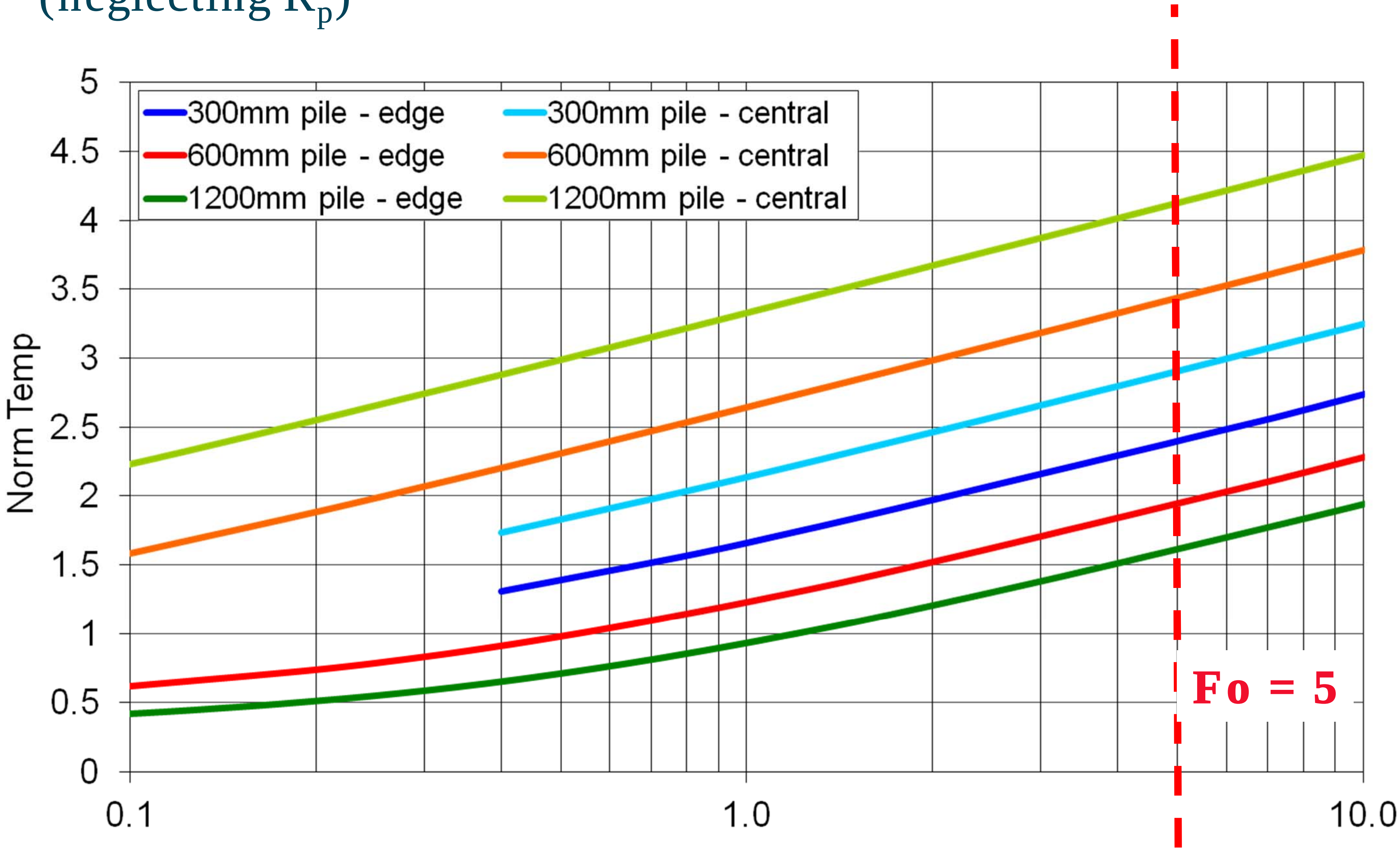
- 300mm dia pile ~ 1.3 days
- 600mm dia pile ~ 5 days
- 1200mm dia pile ~ 21 days

- Standard TRT timescale = 60 hrs = 2.5 days

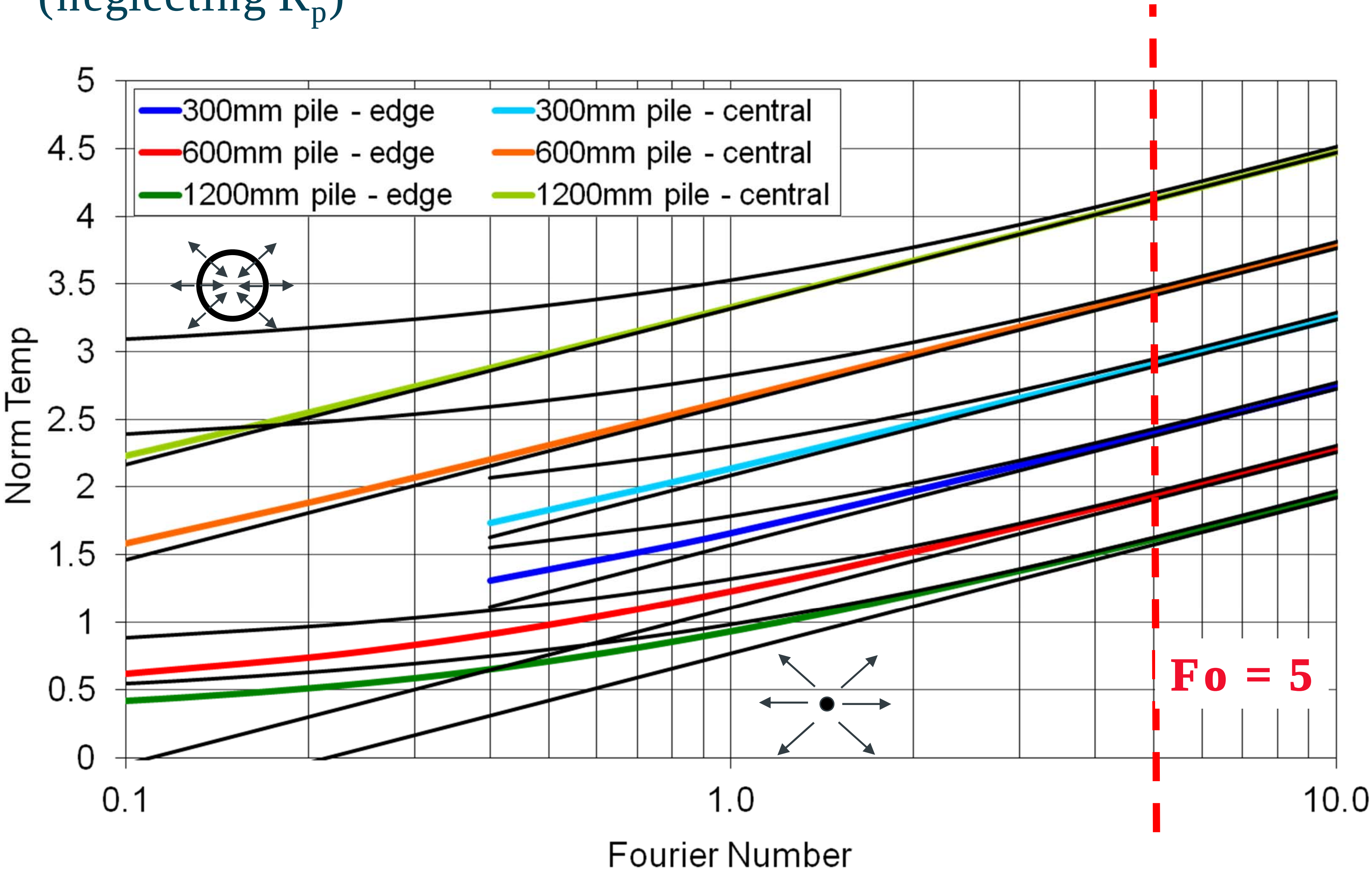
Temperature at edge of concrete



Temperature at pipes
(neglecting R_p)



Temperature at pipes
(neglecting R_p)



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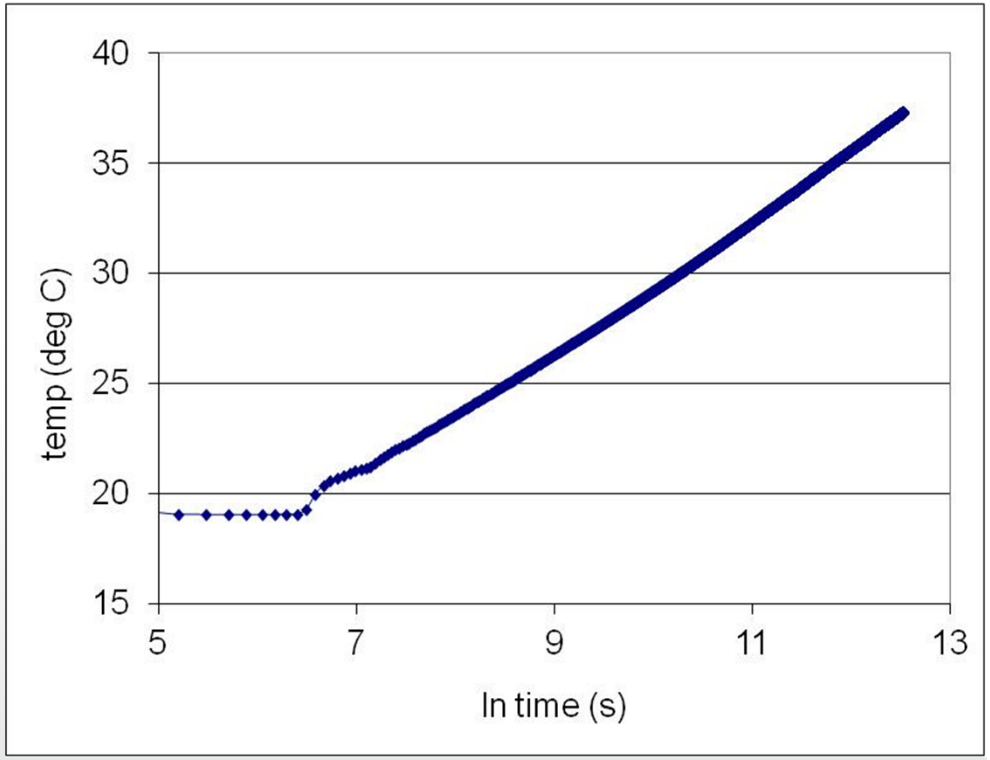
In reality?

- Few TRTs on piles done so far.
- Recent test by GIL of large diameter pile with central loops gave good results
- Warning: measuring concrete properties not soil
- Warning: can not determine Rb in this case



Fieldwork

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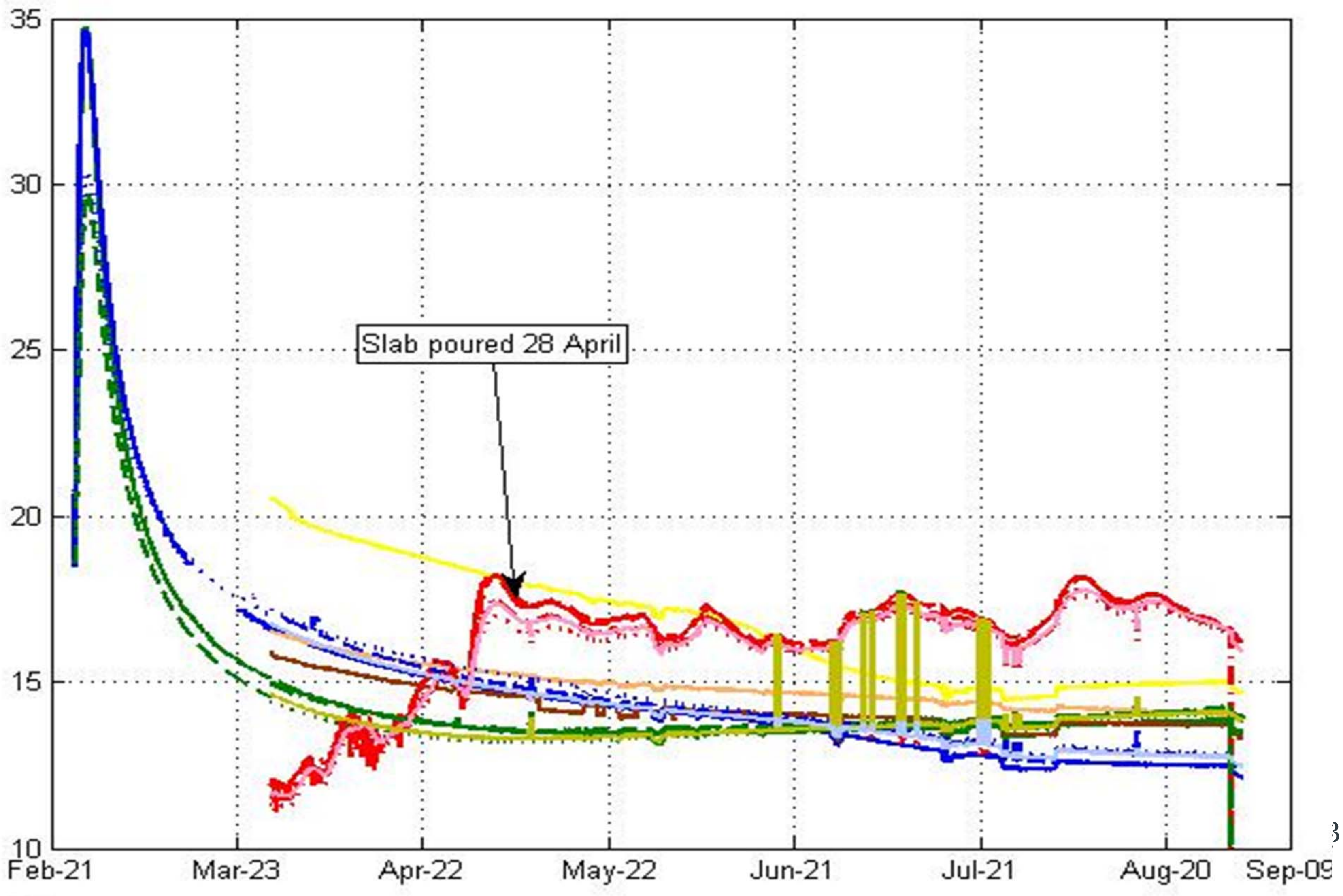
Field Monitoring

- Need to quantify real behaviour
- Instrumentation of a site in East London
- Always looking for more site opportunities

Initial Data



Conclusions

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Conclusions & Recommendations

- Care with respect to irregular pile layouts.
- Important to consider larger diameter of piles, especially for small time-step behaviour. A solid cylinder model may be most appropriate.
- Short piles mean an appropriate surface boundary condition is important.
- Probably larger thermal resistance, but also higher range of values.
- A transient model of concrete and ground may be most appropriate for large diameter piles
- Connecting piles together can lead to temperature and heat flux variations in the pile group.

Conclusions & Recommendations

- Thermal Response Testing:
  - Small diameter piles, standard test ok
  - Large diameter CFA piles, measure concrete properties, but NOT Rb
  - Large diameter piles with pipes at edge, not appropriate (without long timescales)
  - Tests on boreholes during site investigation
- Most design currently conservative due to some of these uncertainties:
  - Scope for improving efficiency in the future