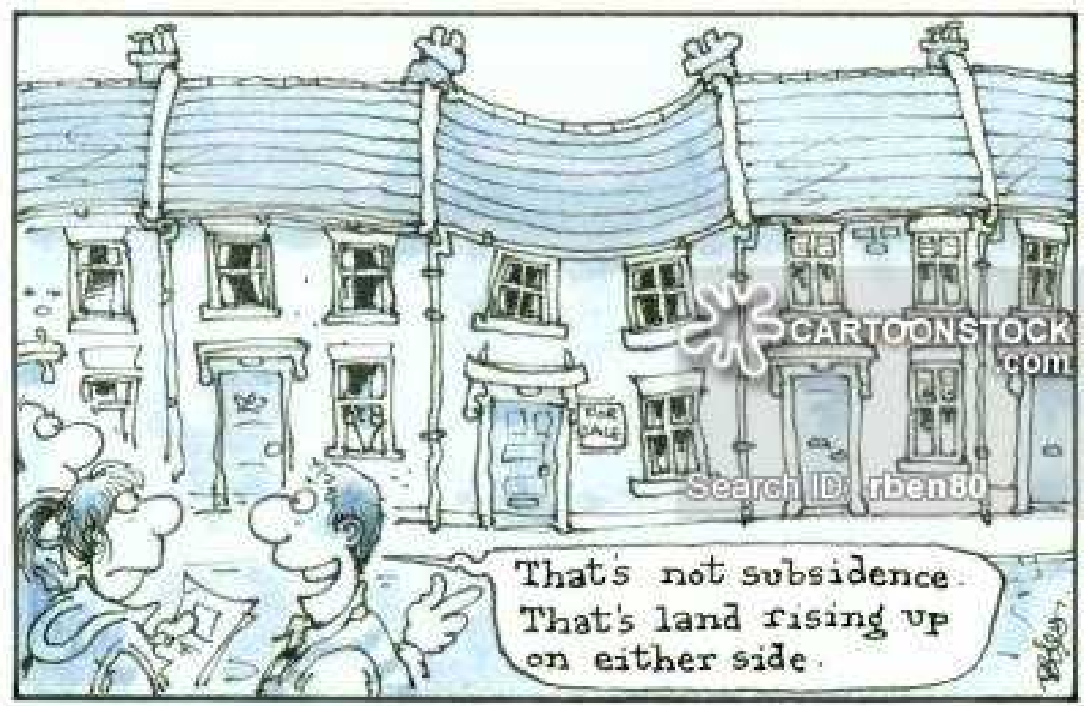
“Piles in settling soil conditions”

Dr. Mandy Korff



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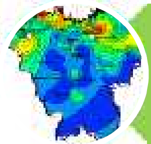
Topics for today’s seminar


Introduction


Subsidence


Soil – Pile Interaction


Case Amsterdam

? Conclusions & Discussion

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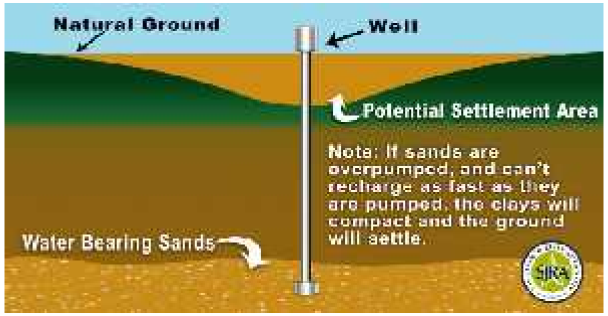
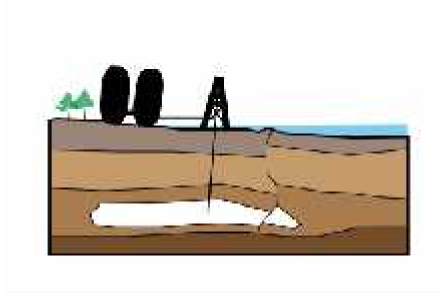
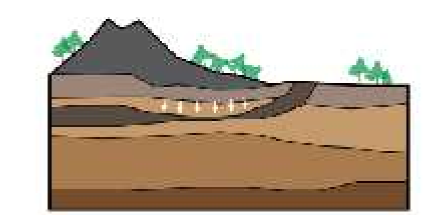
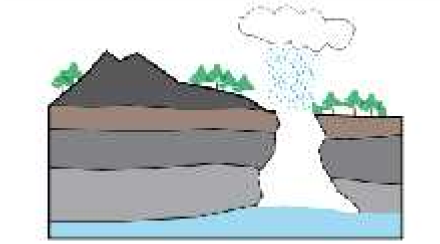
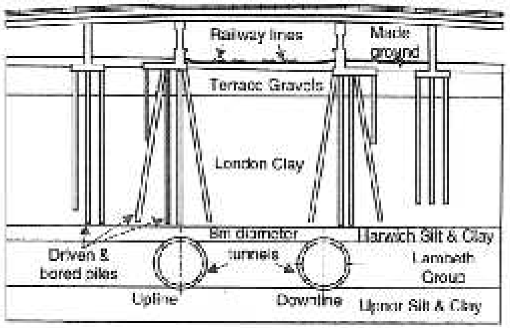
Land subsidence influencing structures / piles



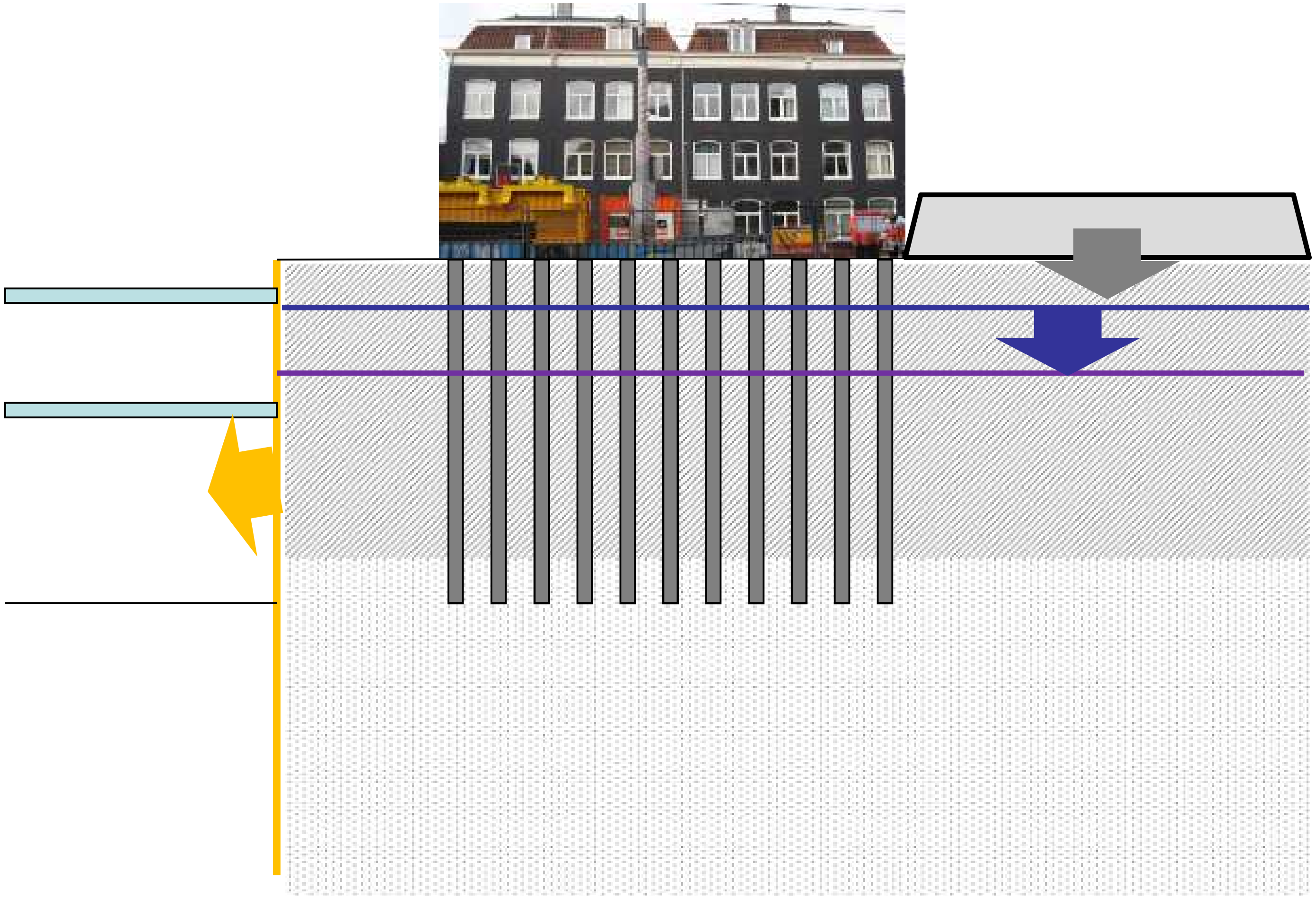








Land subsidence influencing structures / piles



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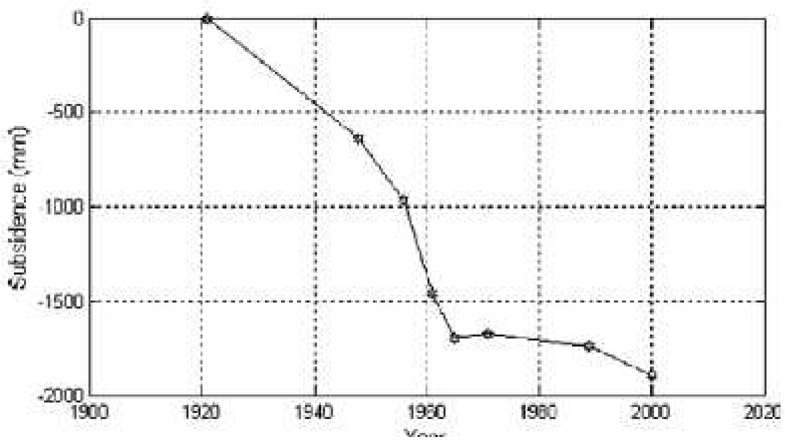
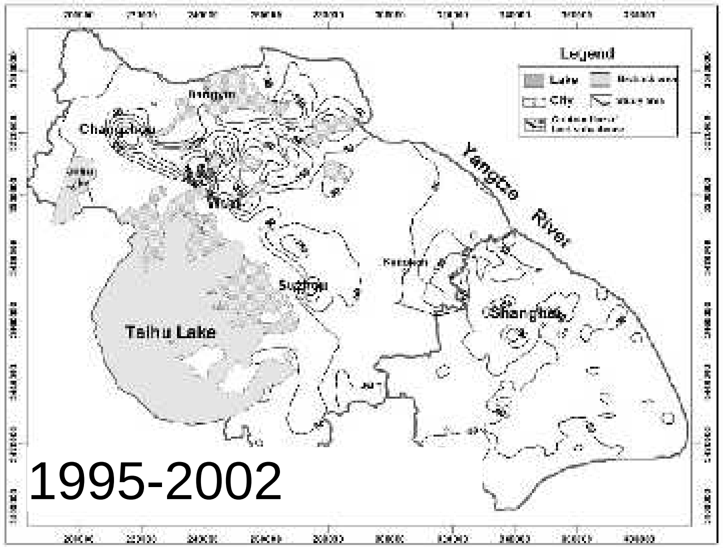
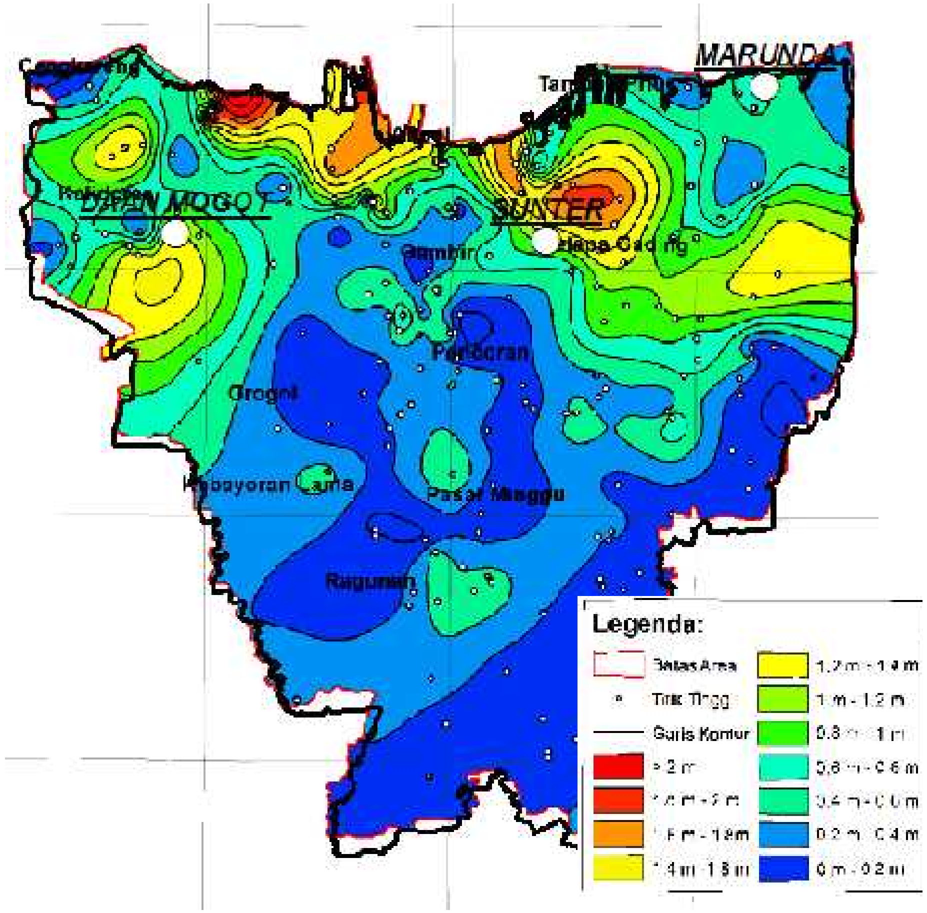
Examples of land subsidence in large cities – groundwater extraction



- Shanghai – 2.7 m (1921-2001), max 110 mm/year



1995-2002



Jakarta
2000-2014

Settlement of piles / piled buildings - example

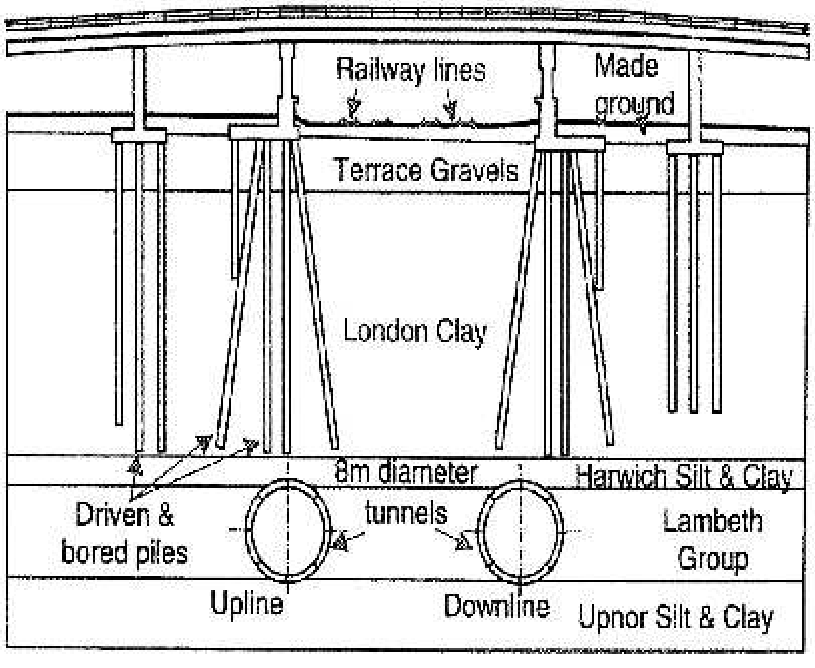
Amsterdam Singelgracht

‘natural’ behaviour (in polder system)

Building settlement 0-2 mm/year

Interaction soil - pile foundations

Previous work by Esvir Jacobzs a.o. for tunnels

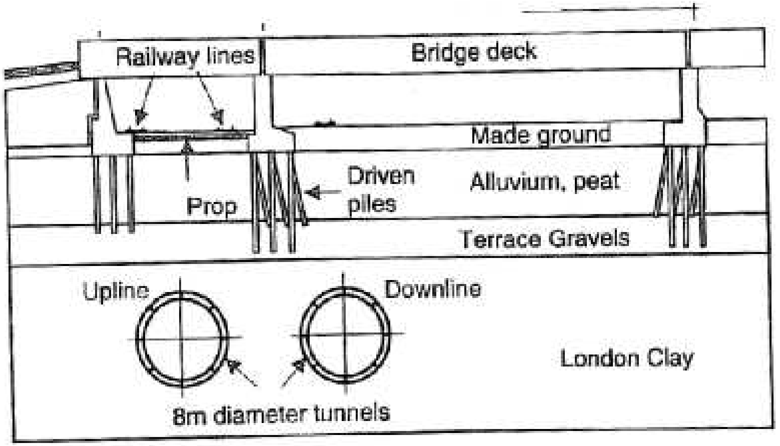


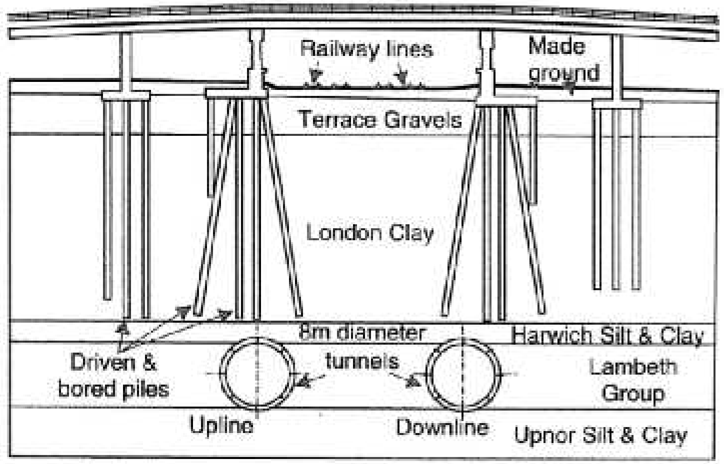
Simplified approach:

- **End bearing piles settle same as green field pile tip level**
- **Floating piles settle same as green field surface level**

Piles influenced by tunneling

For example by Jacobosz (Jacobsz et al 2005)





Renwick Road bridge (left) and Ripple Road Flyover (right)

End bearing piles: reduction in the pile base load (due to stress relief) will result in the mobilisation of positive shaft friction.

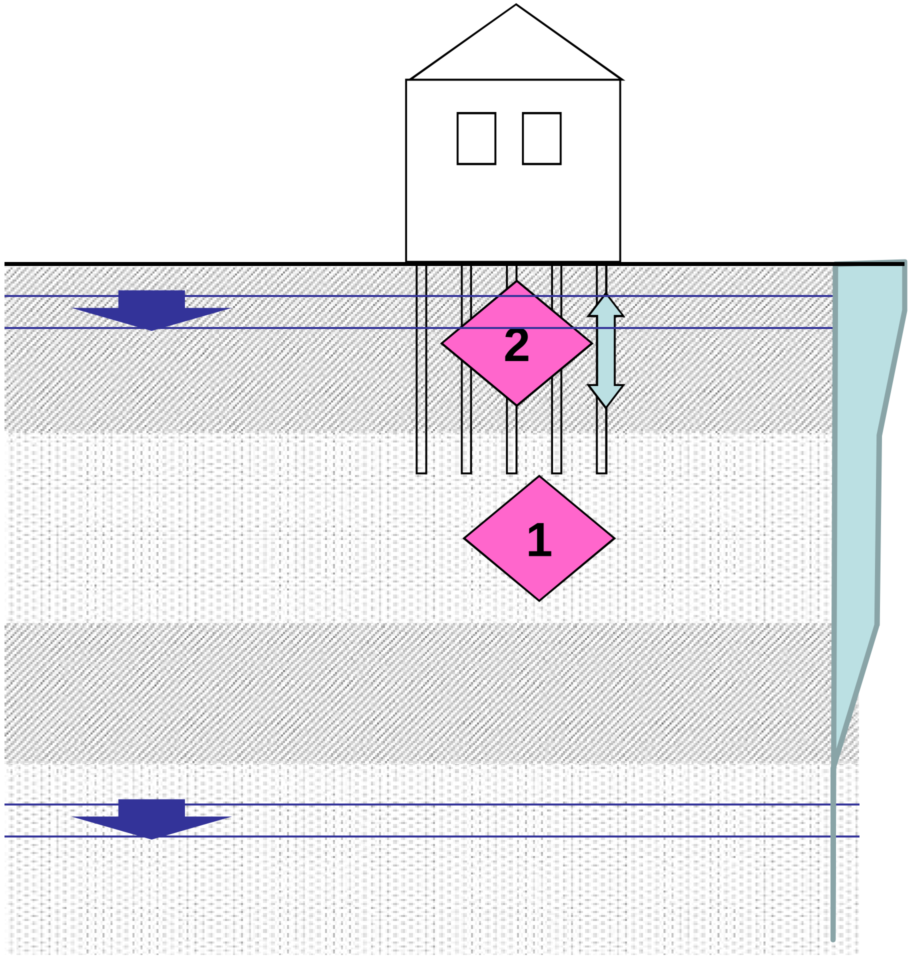
The soil and pile will settle the same amount at the neutral point.

Friction piles above tunnels will move with the ground movements, which may differ from the green field situation (load transfer).

Effect ground water lowering - piles

The buildings in the influence zone of the ground water lowering may experience several phenomena:

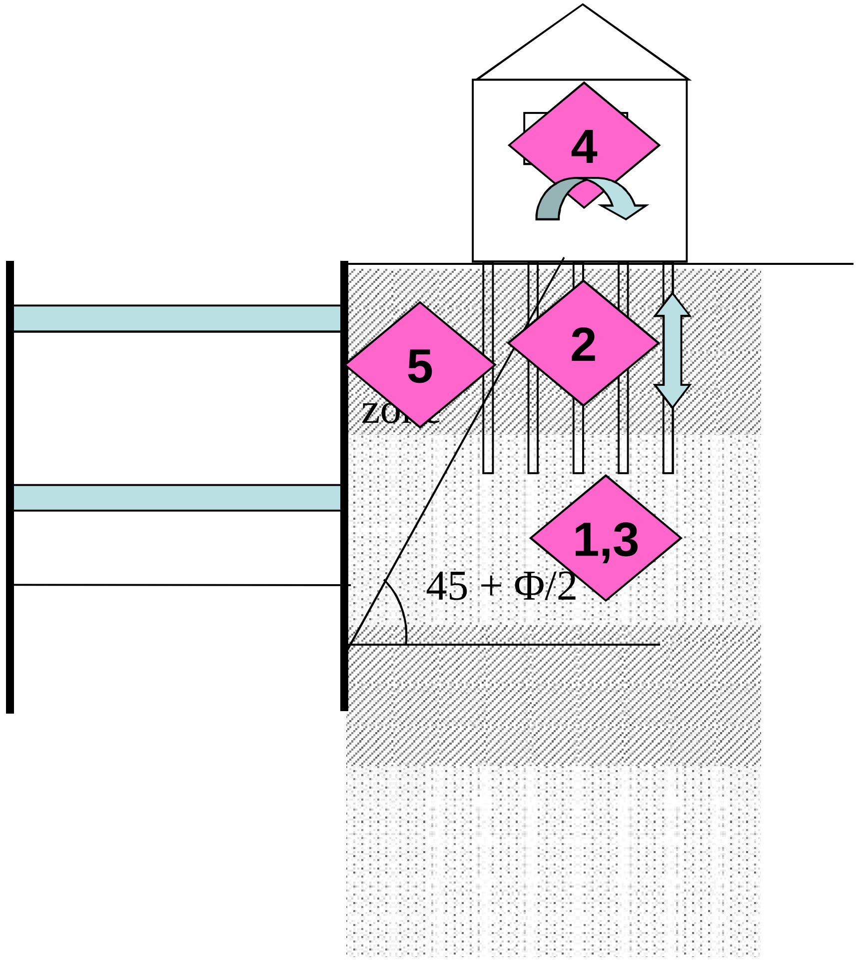
1. settlement of the pile tip due to soil deformations below the base of the pile
2. development of negative skin friction due to relative movements of the soil and the pile shaft



Effect deep excavations - piles

The buildings in the influence zone of the excavation may experience several phenomena:

1. settlement of the pile tip due to soil deformations below the base of the pile
2. development of negative (or positive) skin friction due to relative movements of the soil and the pile shaft
3. reduction of pile capacity due to lower stress levels
4. redistribution of pile load over the piles under the building slab, the building wall or a foundation cap or beam
5. horizontal deformations of the piles (causing bending of the pile).



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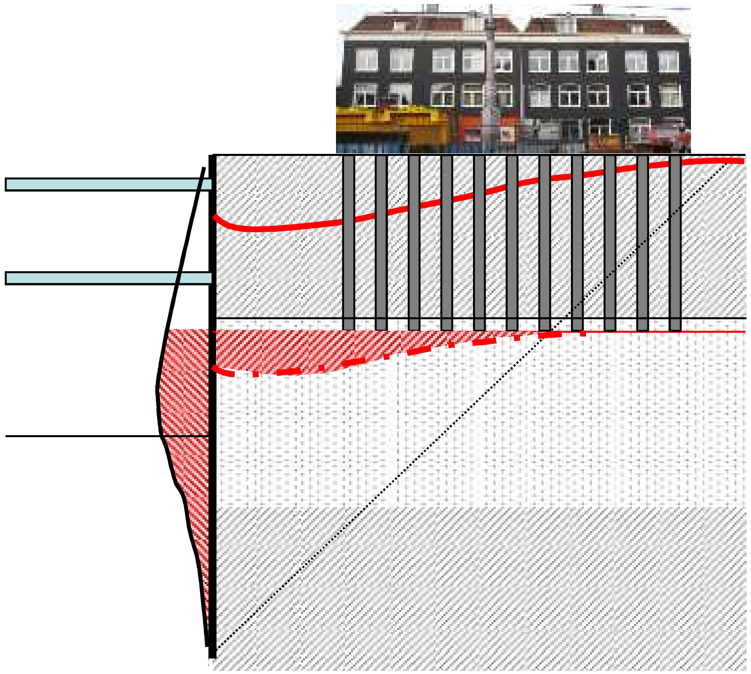
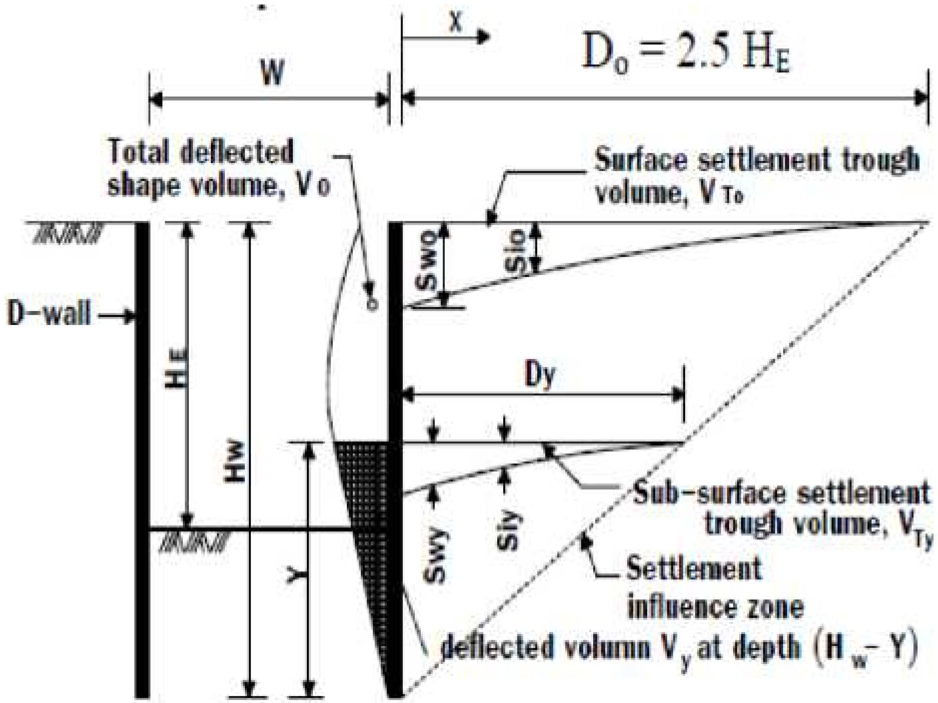
1 Settlement of the pile tip due to soil deformations below the base of the pile

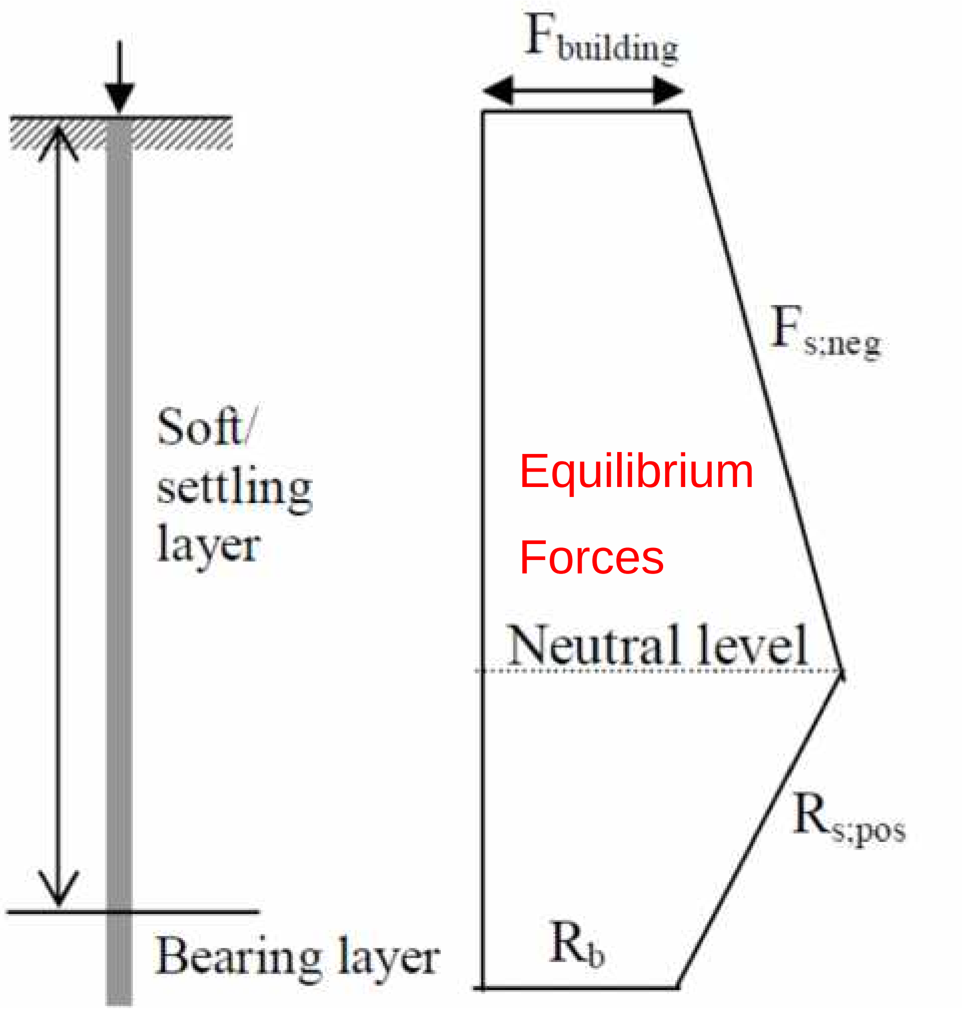


Determine with FEM

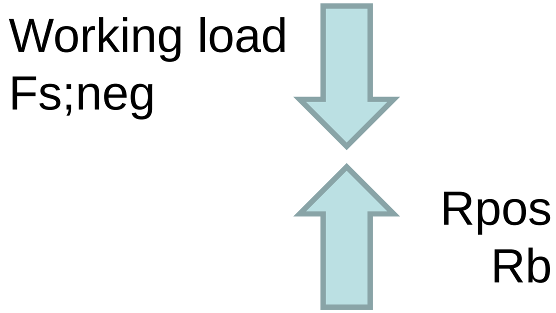
or Aye et al (2006):



2 Combination negative skin friction and soil deformation



Balance:



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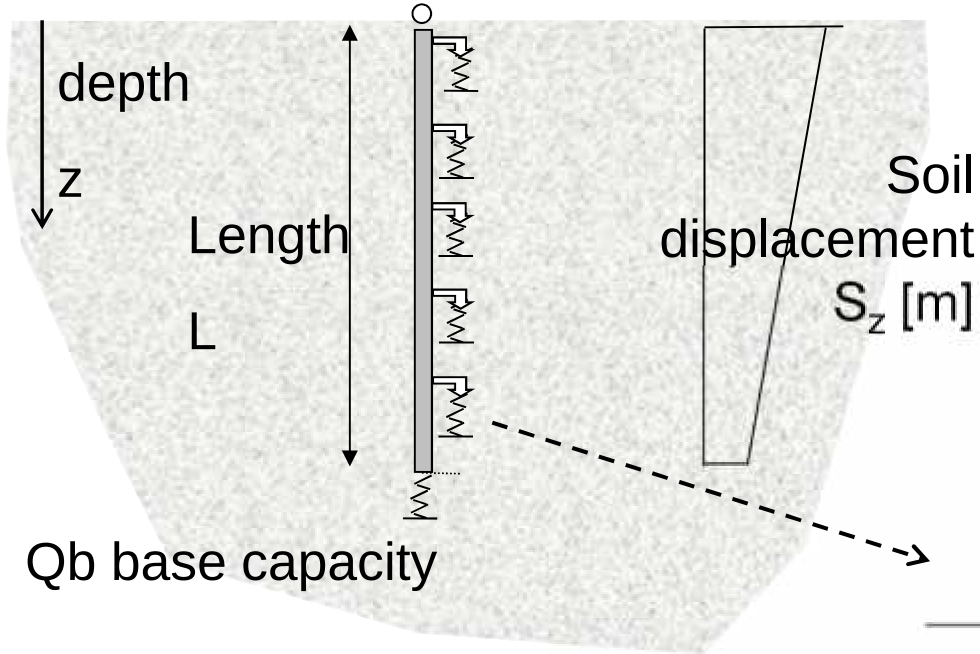
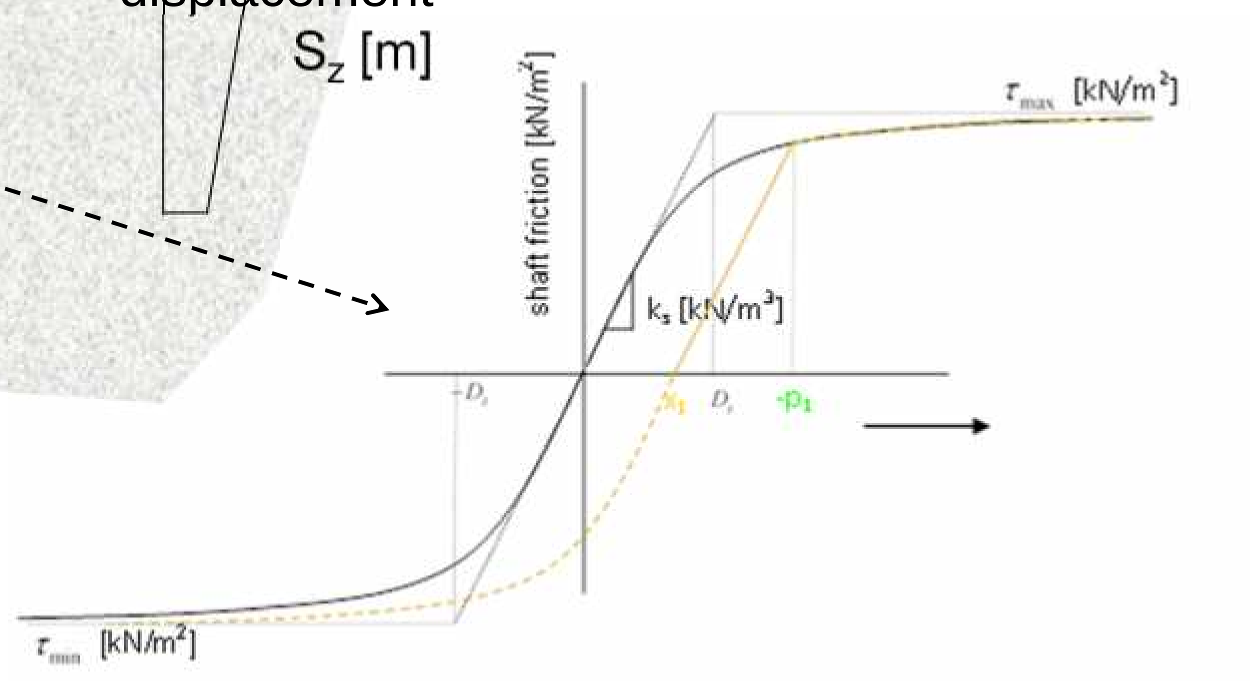
3 Combination negative skin friction and soil deformation

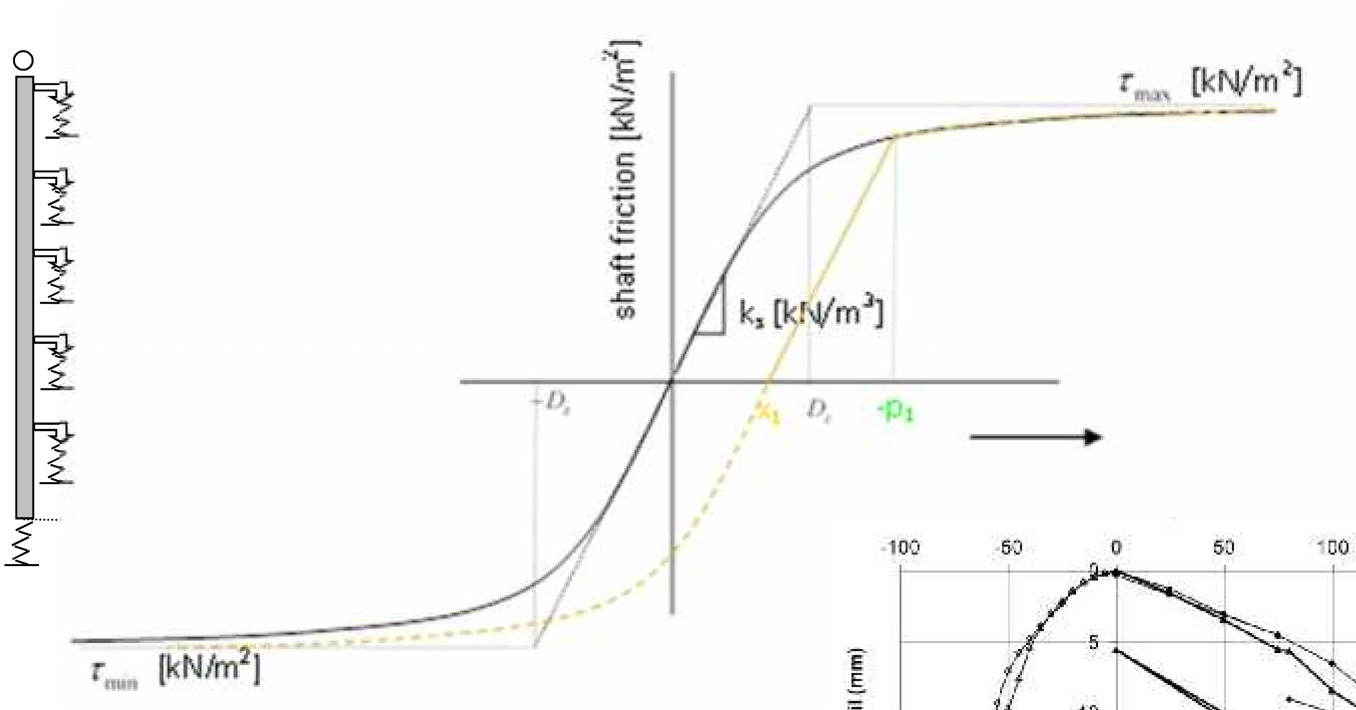
working load W [kN]

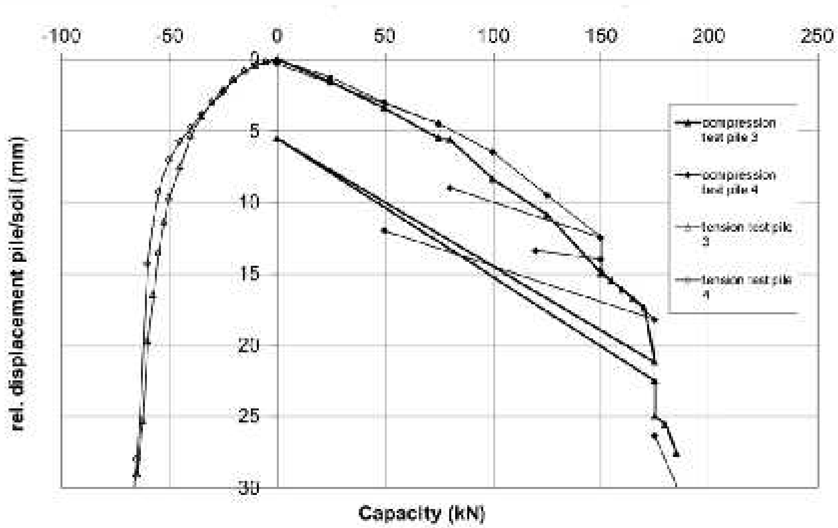
$$W = \int_0^{L_p} \tau \cdot \pi \cdot D dz + A \cdot q_b$$





3 Combination negative skin friction and soil deformation





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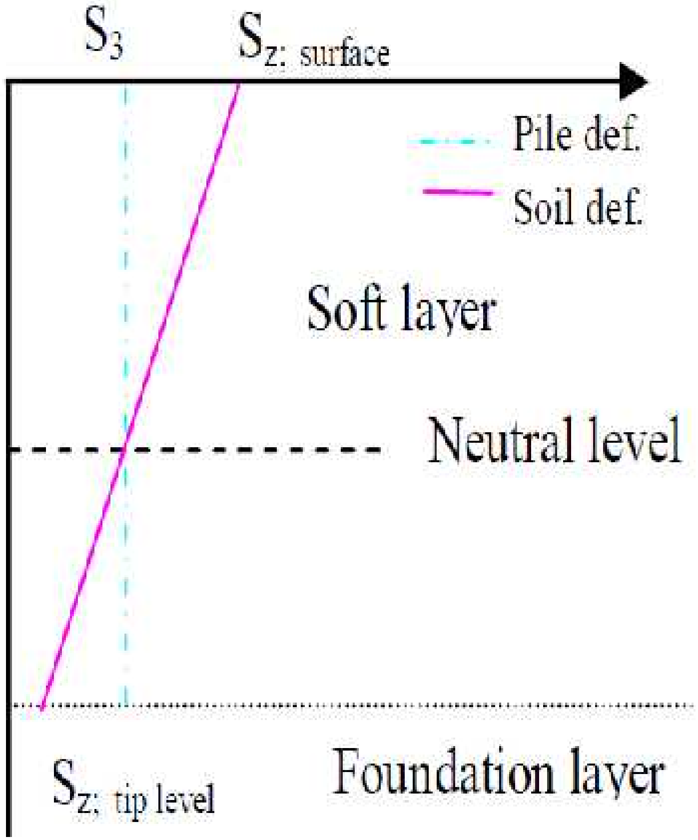
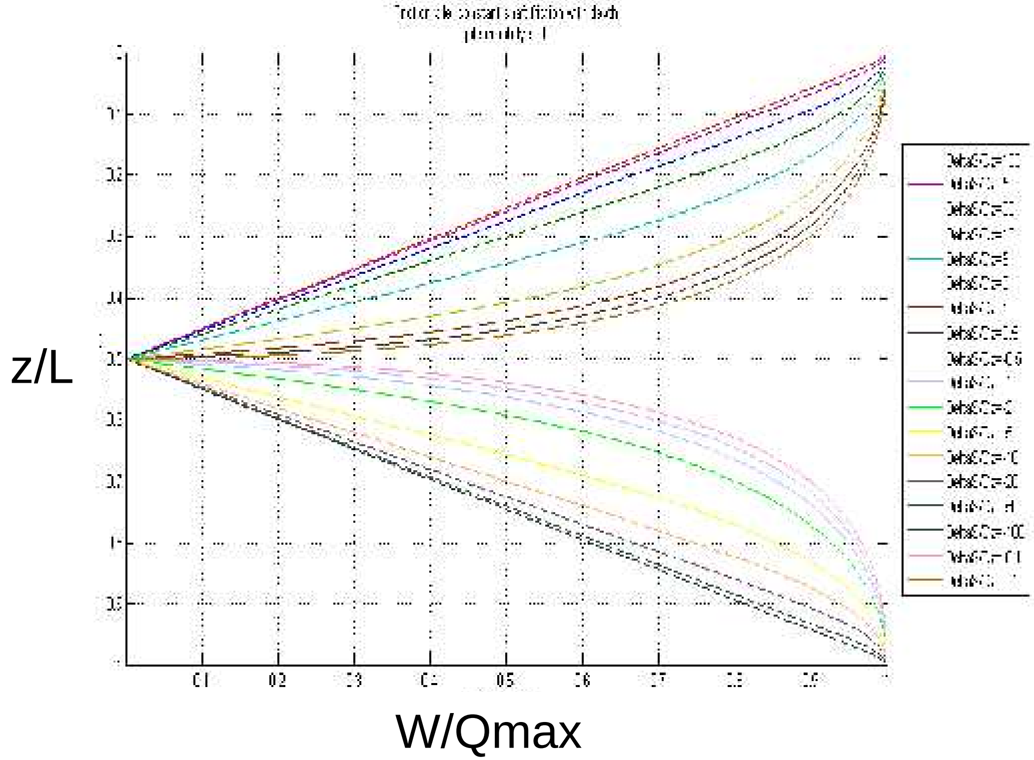
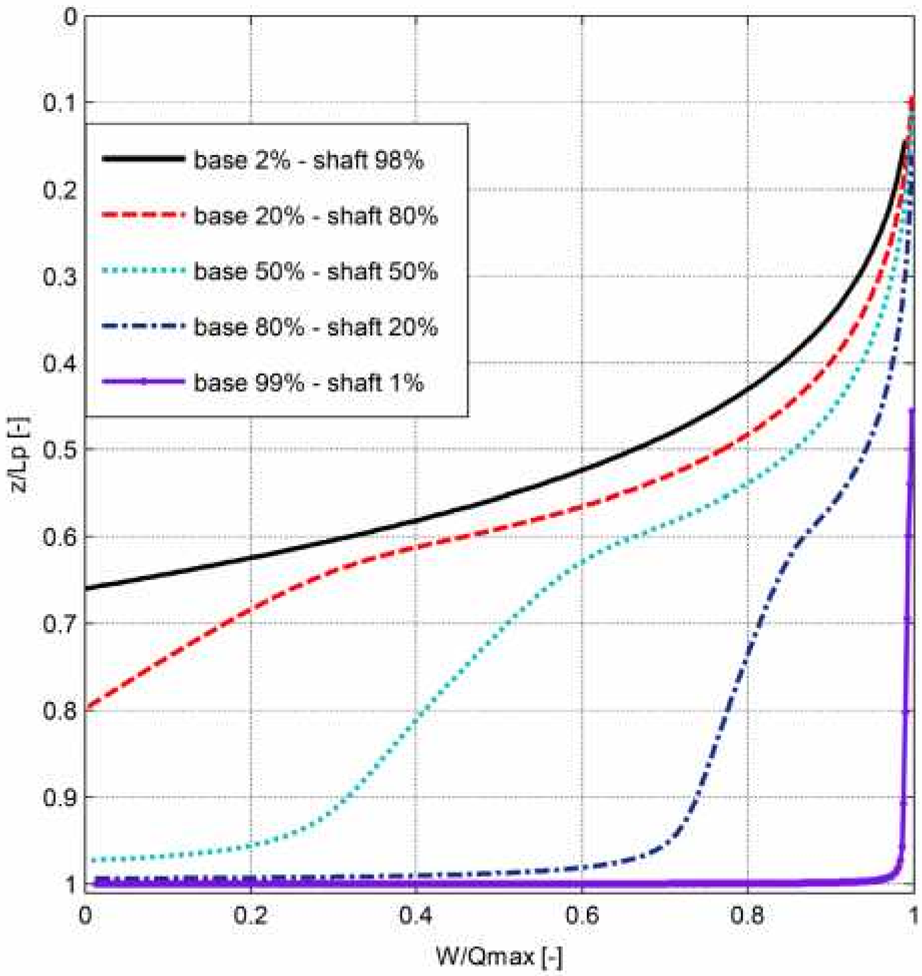




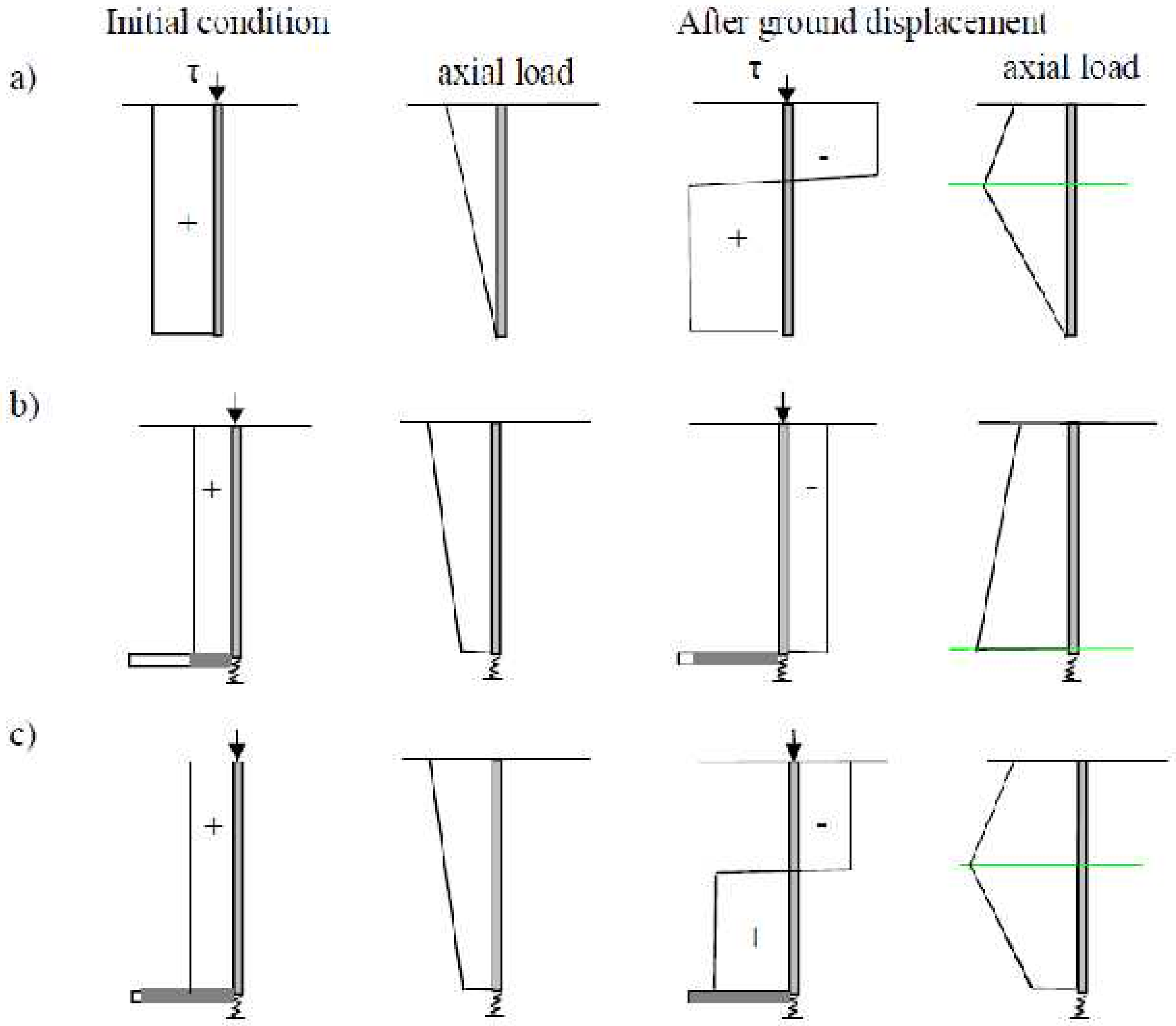
Friction pile
Shaft friction constant
with depth in this example
Pile infinitely stiff
deltaS/Dz=1 - 100

3 Combination negative skin friction and soil deformation



Shaft friction increases with depth in this example (factor 5)
Pile infinitely stiff
deltaS/Dz=2

End bearing or friction pile?



Friction pile

End bearing pile

Combination

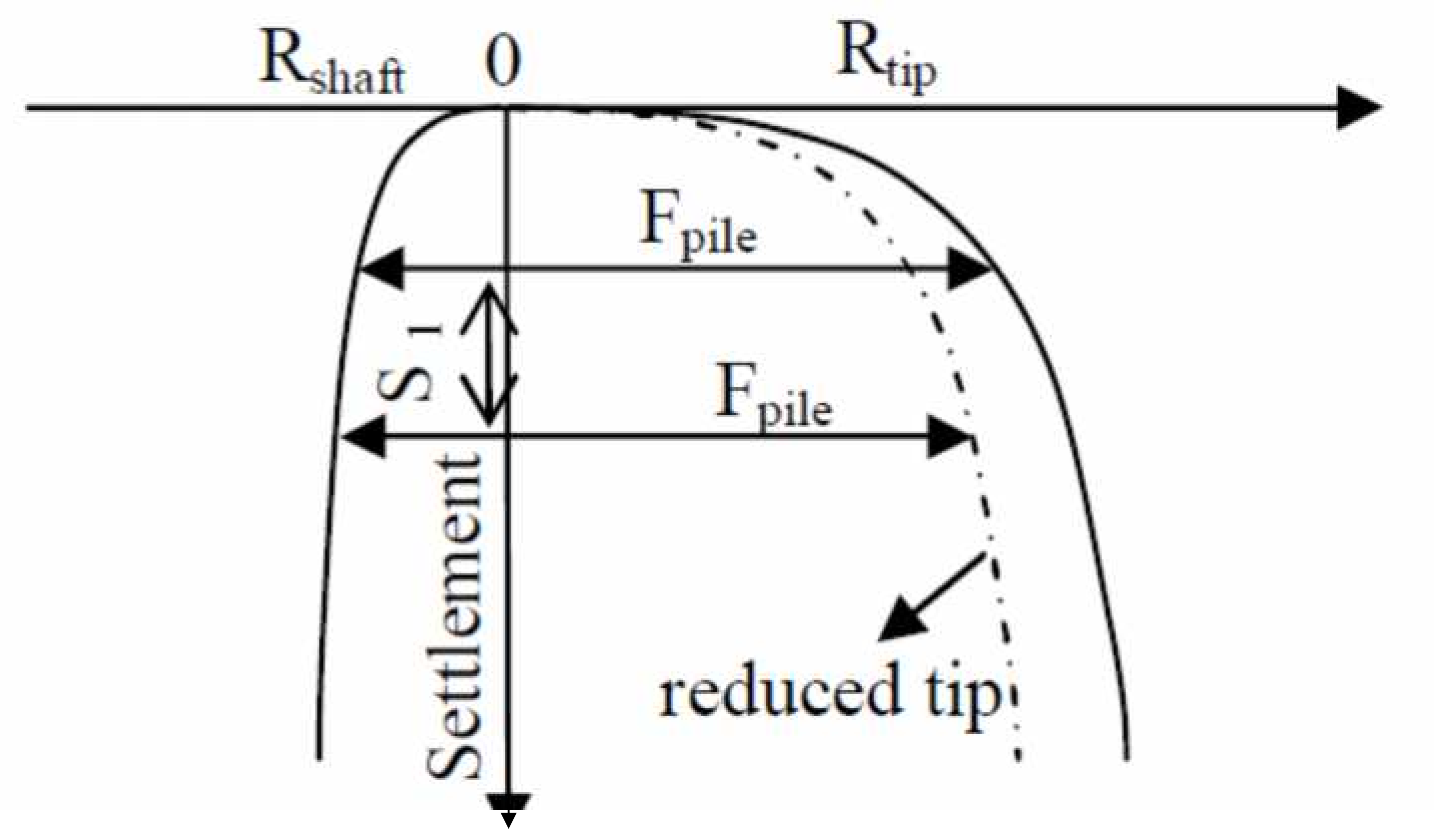
3 Combination negative skin friction and soil deformation

This interaction level z/L depends on the following dimensionless factors:

- the working load on the pile compared to the maximum failure load
- the percentage of end bearing and shaft friction
- the shape of the soil settlements with depth
- the distribution of the maximum shaft friction with depth

$$\frac{W}{W_{\max}} \qquad \frac{Q_b}{W_{\max}} \qquad \frac{\Delta S}{D_z} \qquad \frac{{}^{2}{}_{\max;Lp}}{{}^{2}{}_{\max;0}}$$

3 Reduction of pile capacity due to lower stress levels

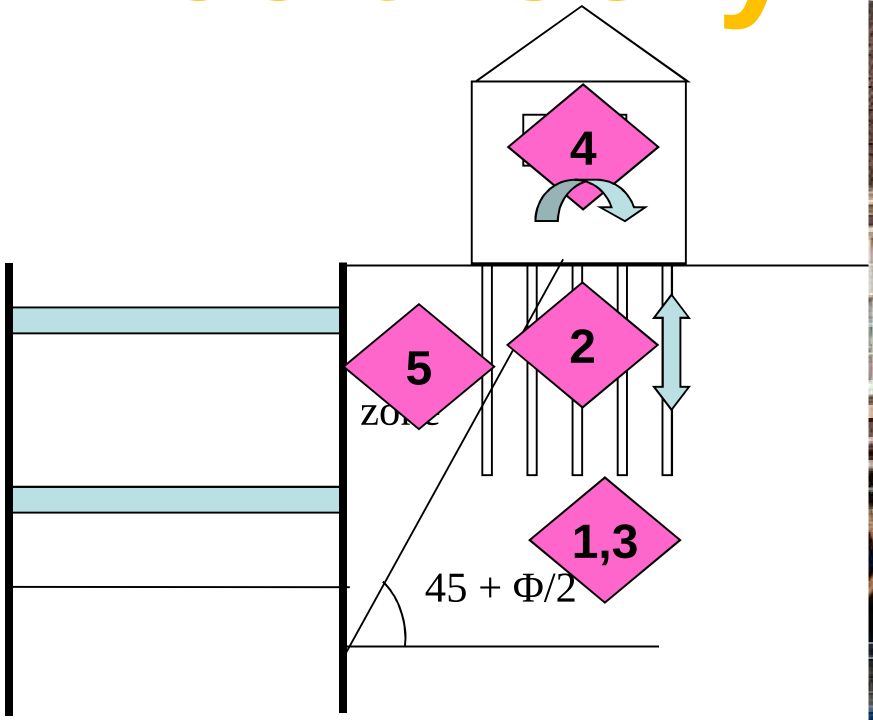


Prediction method for piled structures

The response of piled buildings influenced by settling soil conditions:

- Determine green field soil deformations e.g. with FE-analysis
- Settlement of piled structures can be predicted based on;
  - > working load vs pile capacity
  - > relative soil displacement between surface and base layer
  - > pile flexibility
  - > % end bearing - % shaft friction
- If these are unknown, a large uncertainty remains.

Nice theory



What about reality?

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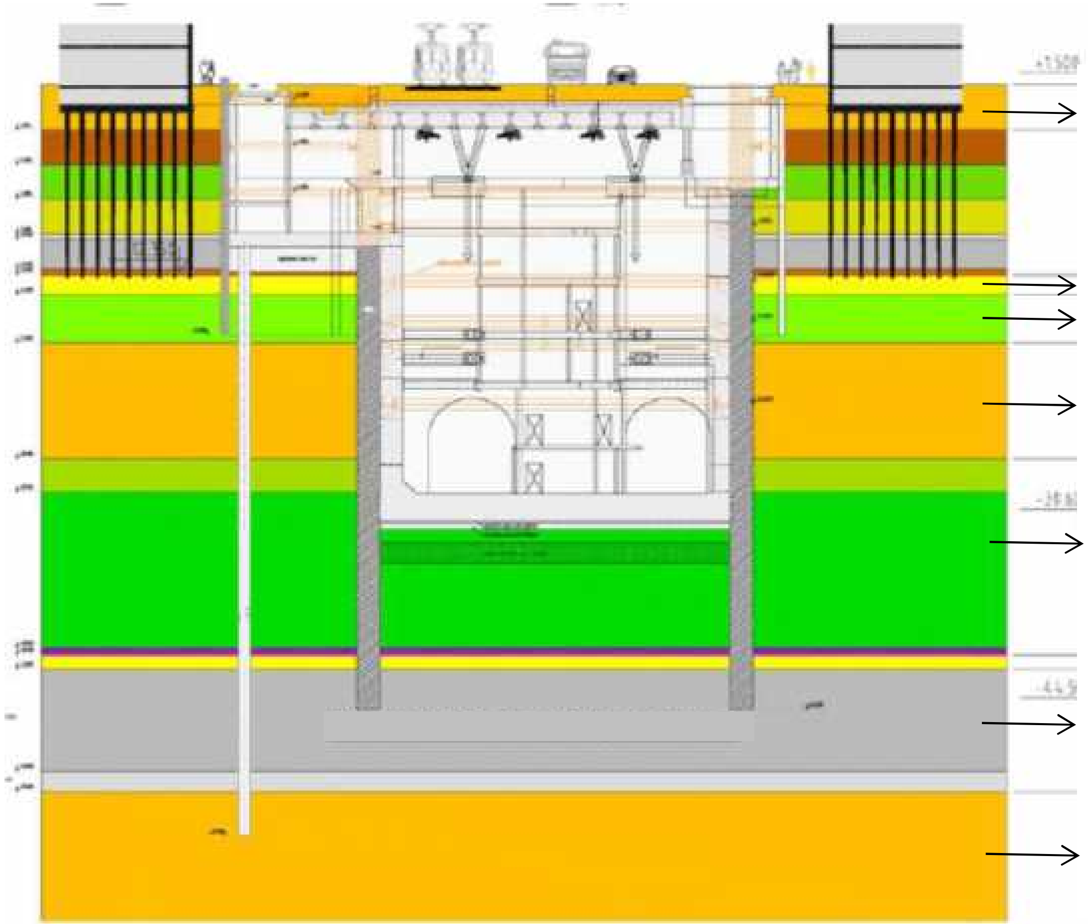
NorthSouth-Line Amsterdam
Construction of deep excavations



Fill

Holocene

1st sand layer

Allerod

2nd sand layer

Eem clay

Glacial clay

3rd sand layer

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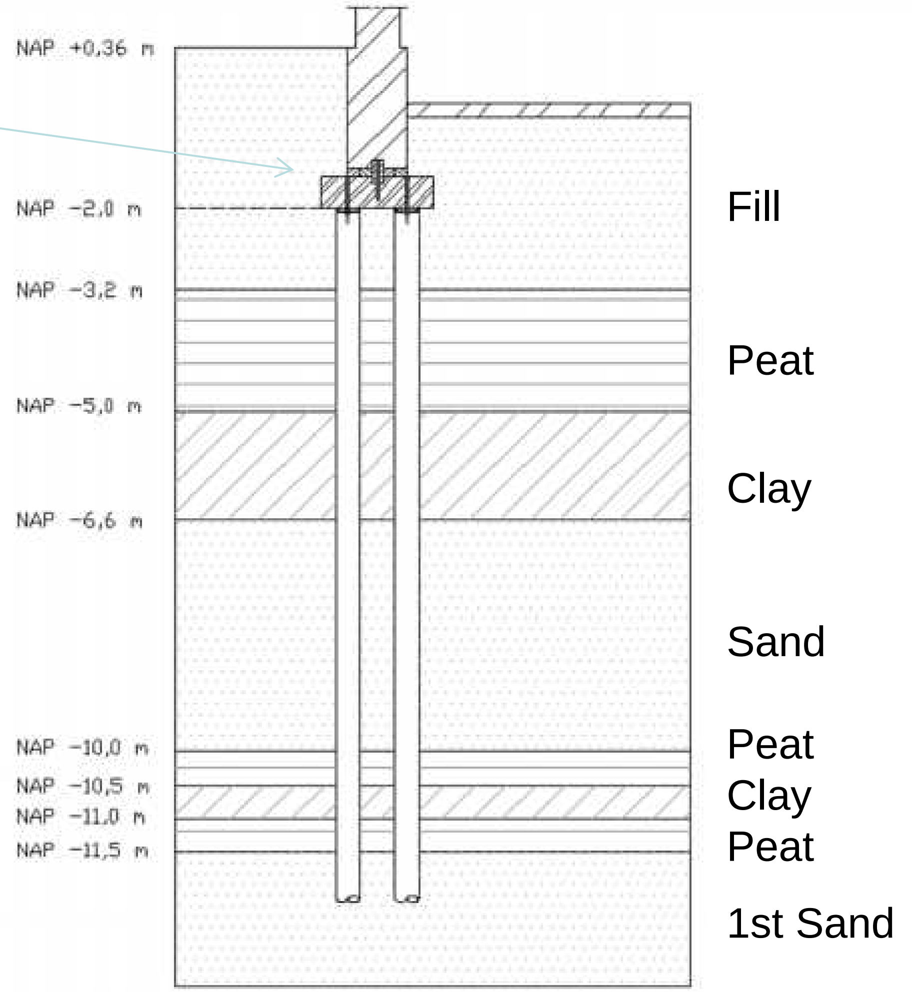
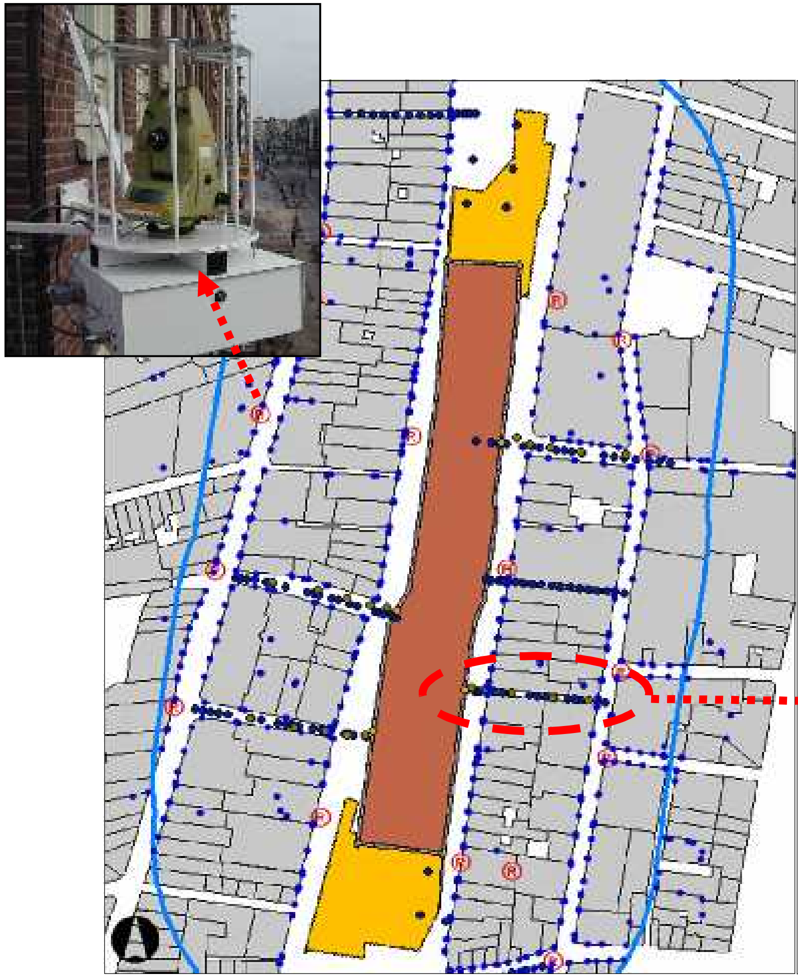
Building types and characteristics

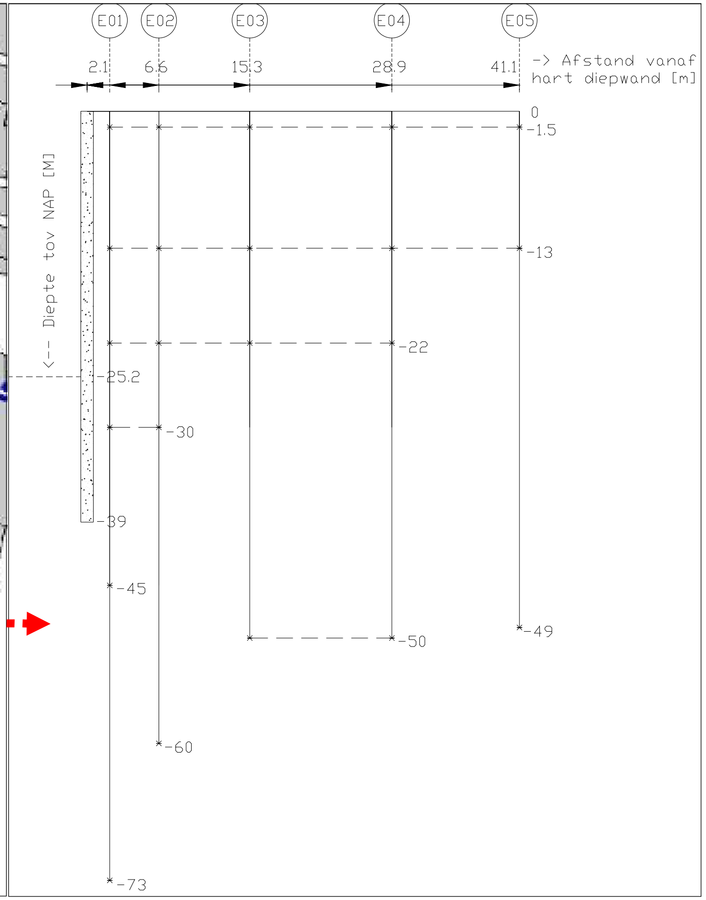


Drawing: NorthSouthline project

Monitoring around Deep Stations



Top view



Cross section extenso- and inclinometers

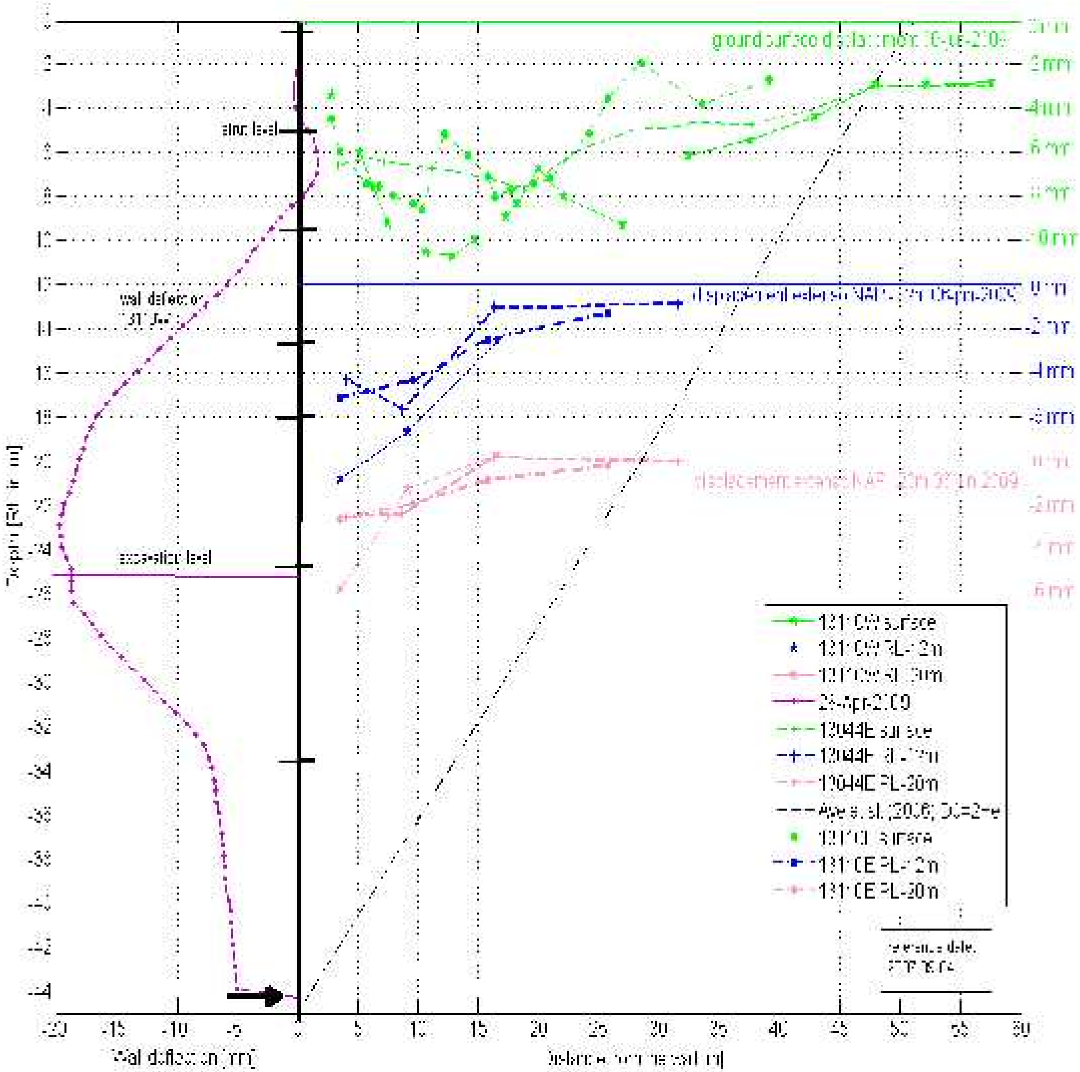
- Robotic Total Stations buildings in X, Y, Z dir.
- Inclinometers in diaphragm wall
- Inclinometers + Extenso in the soil
- Surface manual

Soil displacement profile

Settlement during excavation only

Settlement decreases with depth

Width of the through is smaller at depth



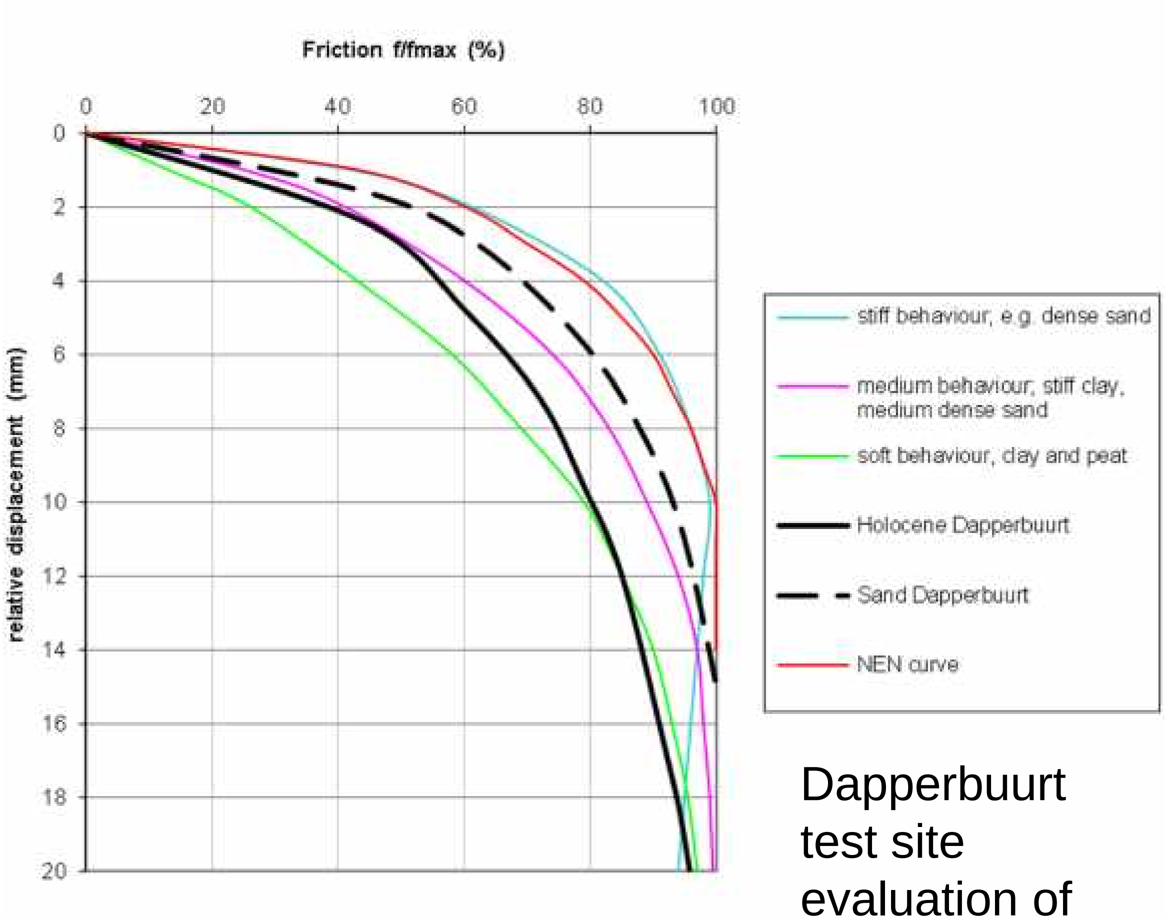
Springs for real (old) timber piles Amsterdam

Shaft friction

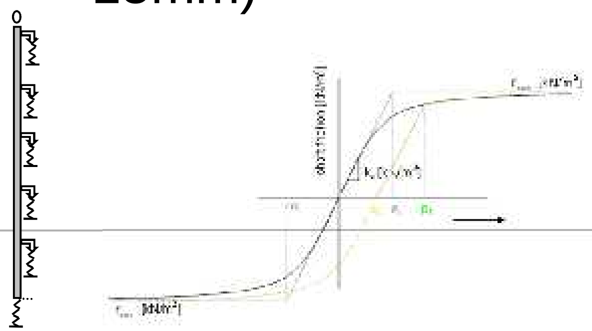
Development

15-25mm of relative displacement is needed to reach full friction

Similar relative displacements for base capacity (0.1D ≈ 10-15mm)



Dapperbuurt test site evaluation of old timber piles



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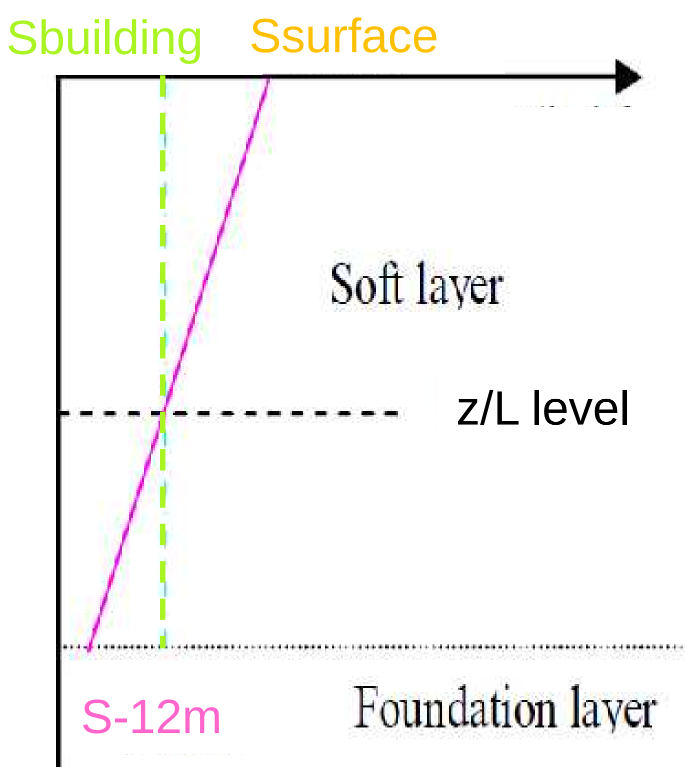
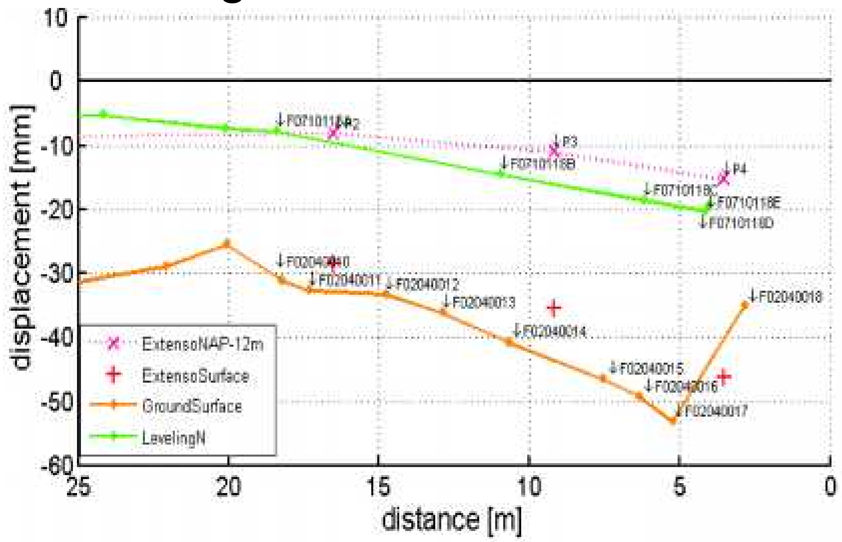
Check hypothesis soil- pile int. with real data

Analysis of 3 deep stations, with all construction stages, comparing surface, building and subsurface monitoring:





Assumptions:
No load redistribution
No stress relief
Linear soil displacement profile

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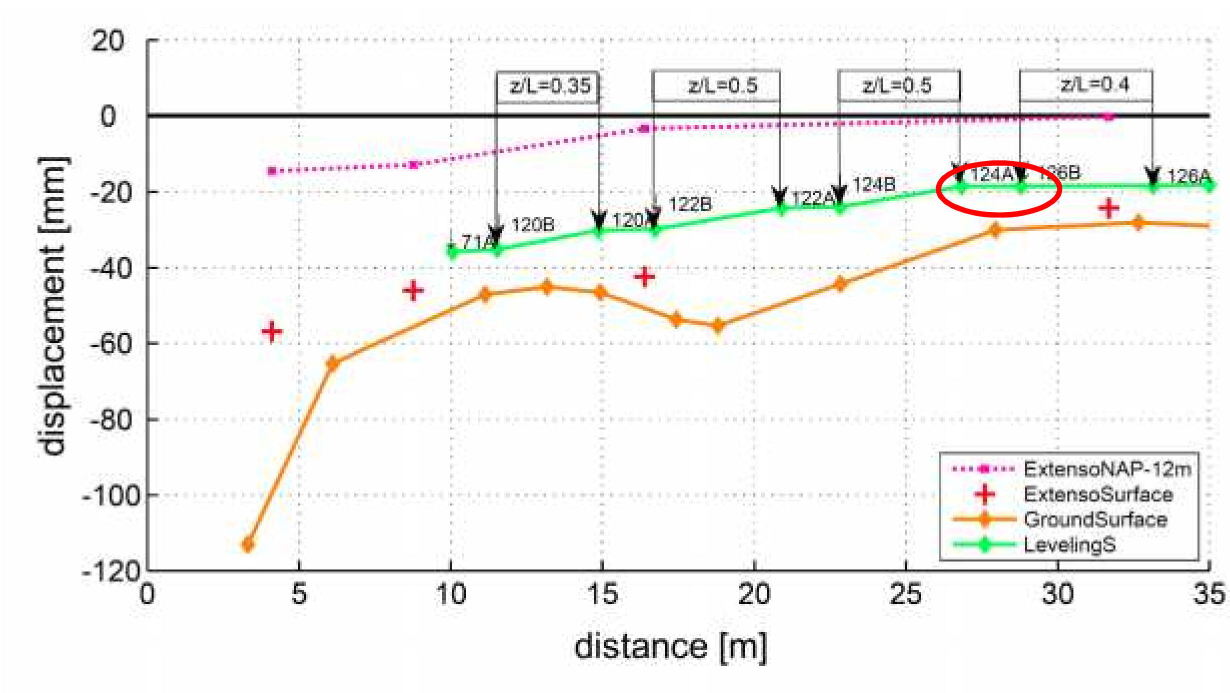
Real buildings at Ceintuurbaan Station



Original timber piles
>100y old

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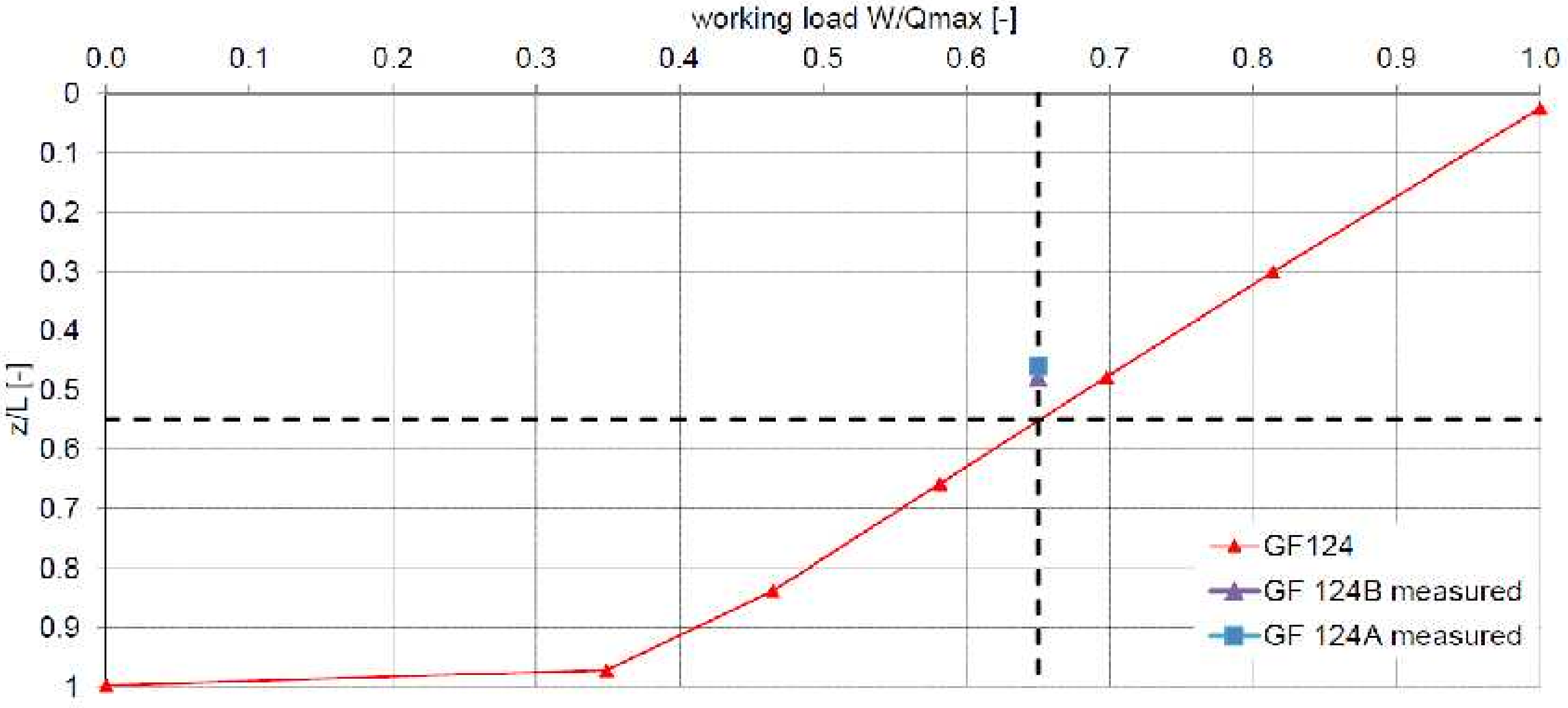
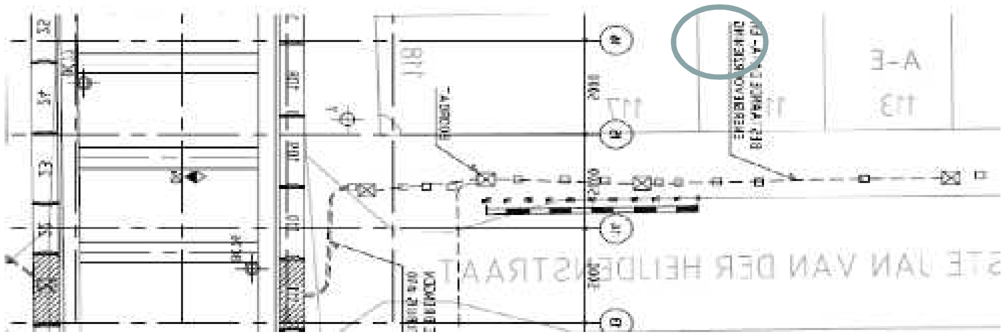
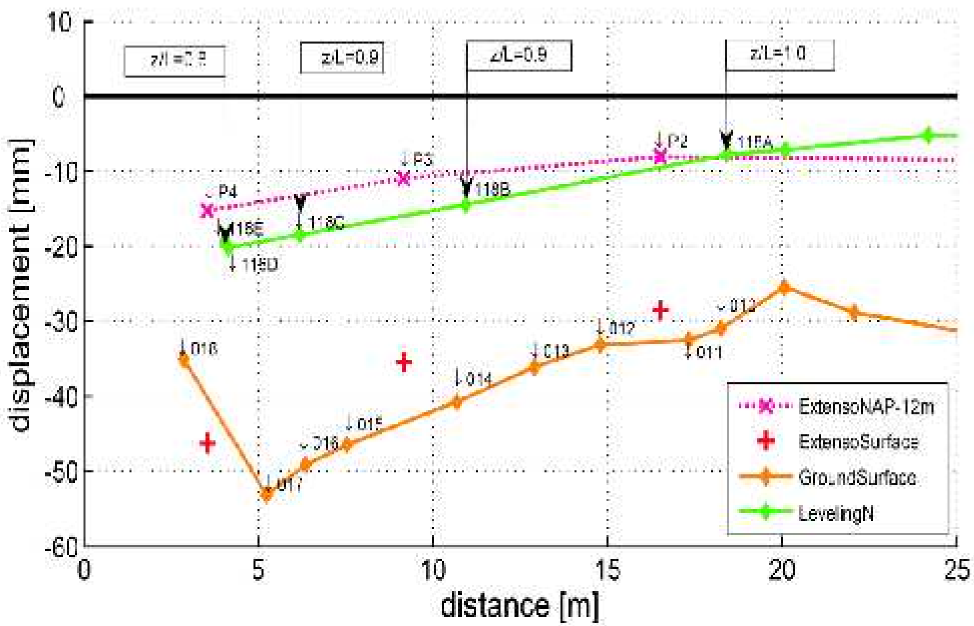
Theory vs practice GF124



Real buildings at Ceintuurbaan Station

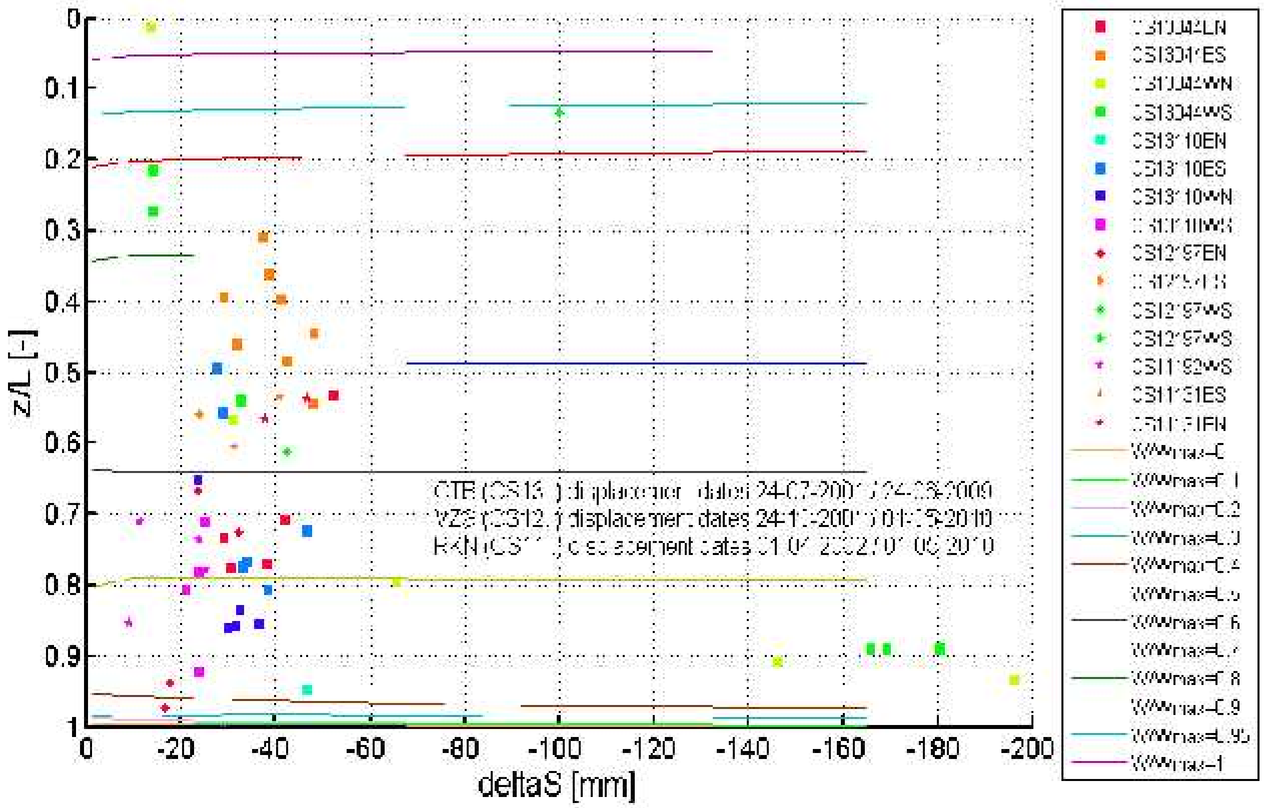




Renewed foundation
timber piles + steel piles

Check hypothesis soil- pile int. with real data

Analysis of 3 deep stations, with all construction stages, comparing surface, building and subsurface monitoring:



Possible other factors:

- Stiffness building?
- Age foundation?
- Type foundation?
- ….?

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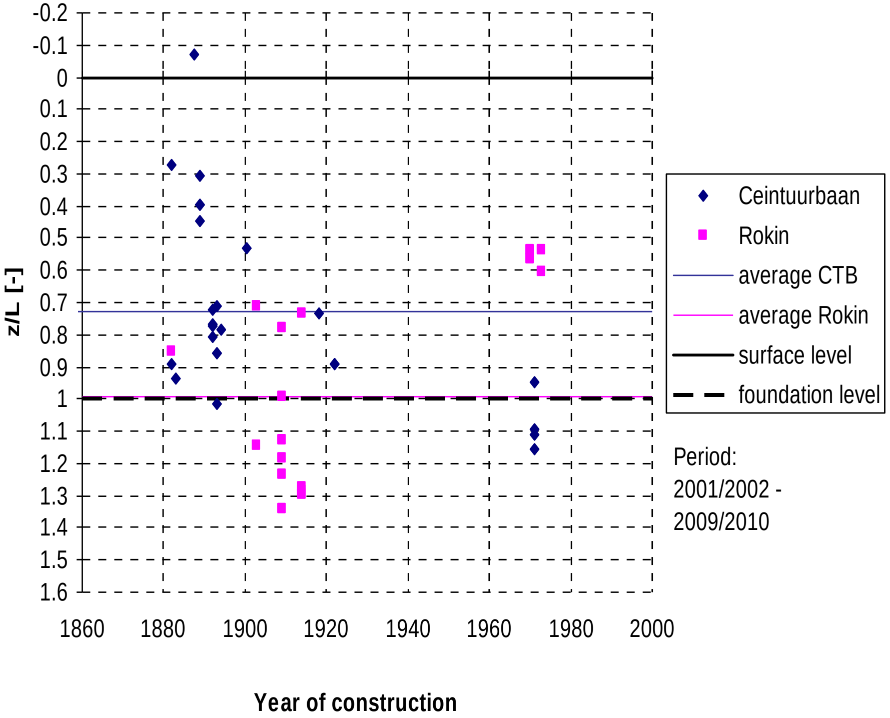
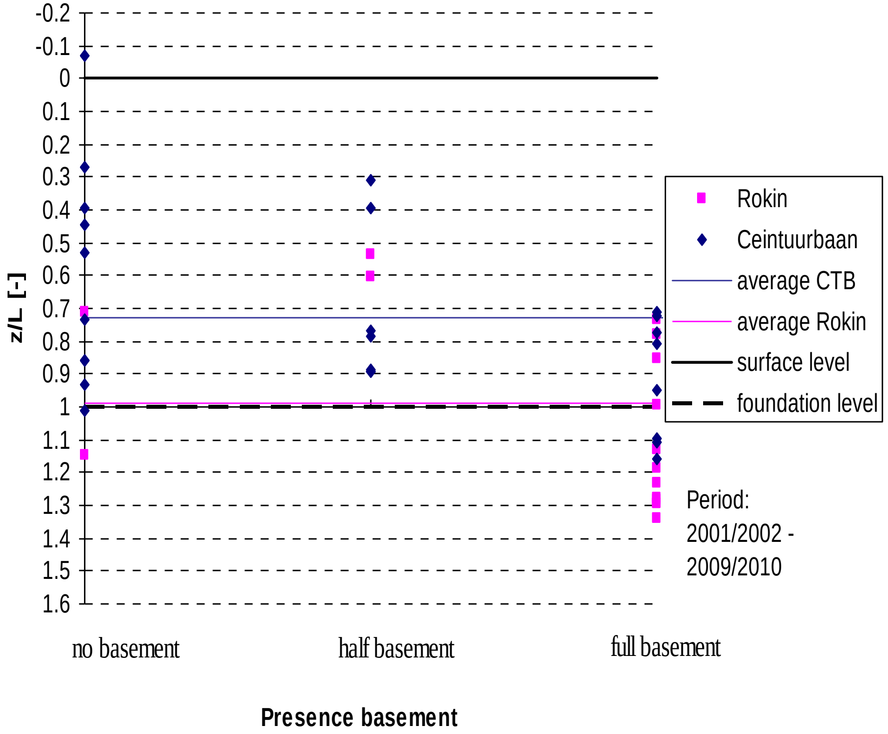
Factors that influence z/L factor





Low interaction factor between 0 and 0.5 (=high neutral level):
- Buildings built before 1900, with Foundation Class 3 (out of 4)
- Buildings without basement

All other buildings: z/L between 0.5 and 1.0 depending on W/Wmax.

Prediction method for piled structures

The response of piled buildings influenced by settling soil conditions:

- Determine green field soil deformations e.g. with FE-analysis
- Settlement of piled structures can be predicted based on;
  - > working load vs pile capacity
  - > relative soil displacement between surface and base layer
  - > pile flexibility
  - > % end bearing - % shaft friction
- If these are unknown, a large uncertainty remains.

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Conclusions

The response of piled buildings influenced by settlement from deep excavations :

- Stress relief at pile tip leads to extra positive shaft friction.
- Building settles less than surface, but more than foundation layer
- Piled buildings tend to follow the soil deformations at interaction level; difference in response end-bearing and friction piles;
  - > Depends on working load vs Wmax
  - > Depends on relative soil displacement
  - > Depends on pile flexibility
  - > Depends on % end bearing - % shaft friction
- Expect significantly higher interaction levels for old buildings without basement than for modern end bearing piles (interaction level old piles z/L = 0.3-0.8, renewed piles 0.8-1.0)
- Interaction level can be predicted sufficiently good if working load and pile capacity are known. If they are unknown, a large uncertainty remainsLoad redistribution will influence the settlement depending building stiffness.

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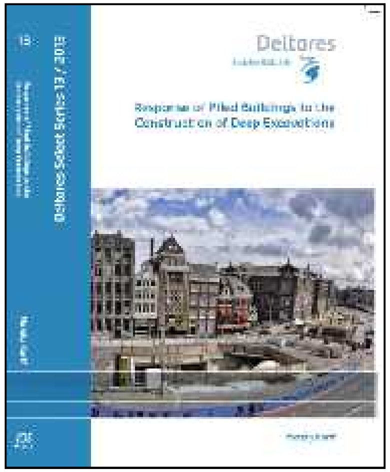
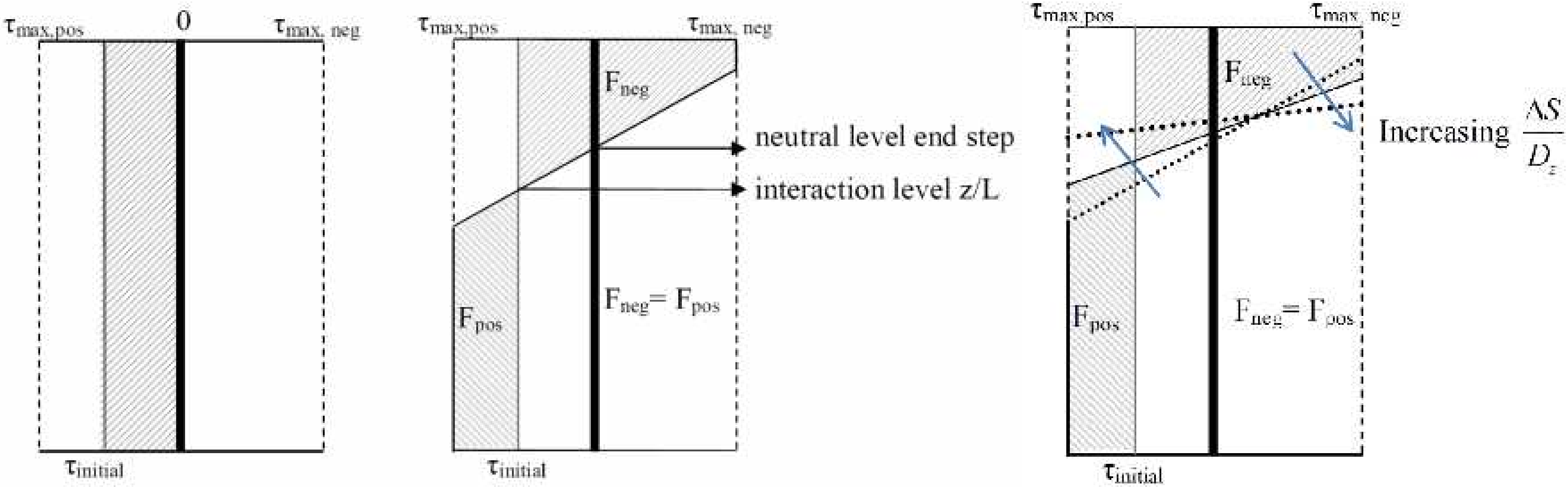
Thank you very much for your attention!

References:

2016 Pile-soil interaction and settlement effects induced by deep excavations
Mandy Korff, Robert Mair, Frits van Tol
Journal of Geotechnical and Geoenvironmental Engineering

2013 Response of Piled Buildings to the Construction of Deep Excavations
Mandy Korff IOS Press , ISBN: 978-1-61499-273-8





τmax,pos
0
τmax, neg
τinitial
τmax,pos
τmax, neg
Fneg
neutral level end step
interaction level z/L
Fpos
Fneg= Fpos
τinitial
τmax,pos
τmax, neg
Fneg
Increasing ΔS/Dz
Fpos
Fneg= Fpos
τinitial

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