Pile Tunnel Interaction During Mechanized Tunnelling

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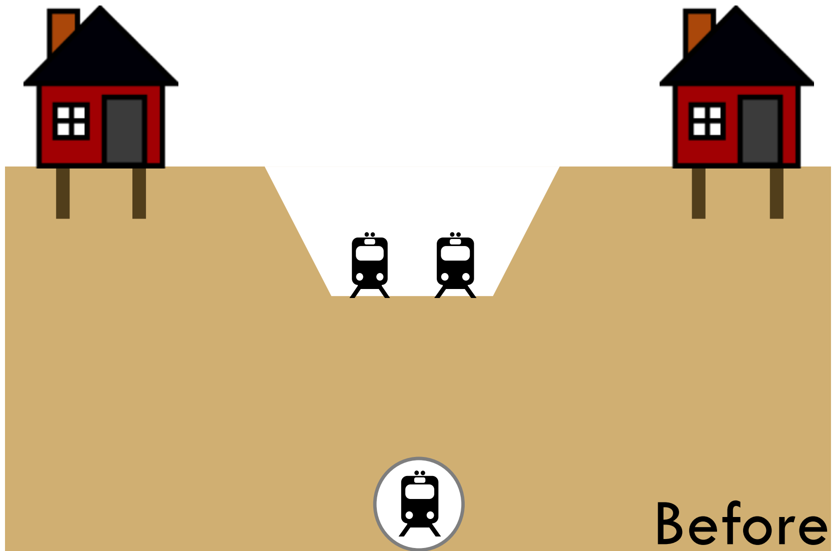
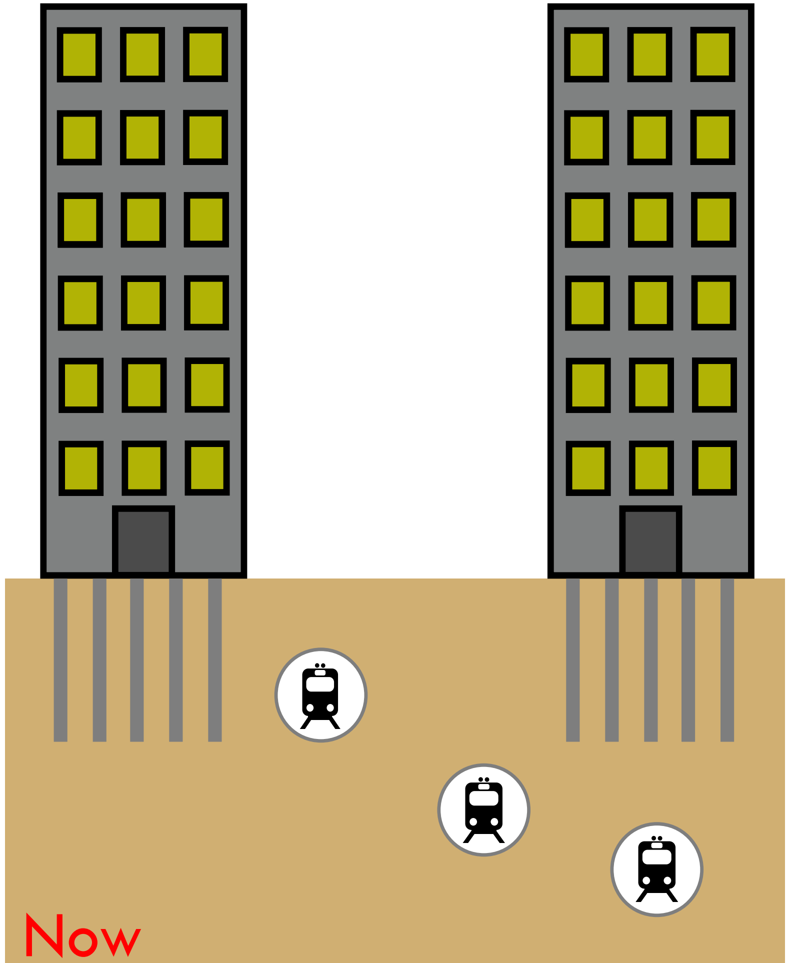
Introduction

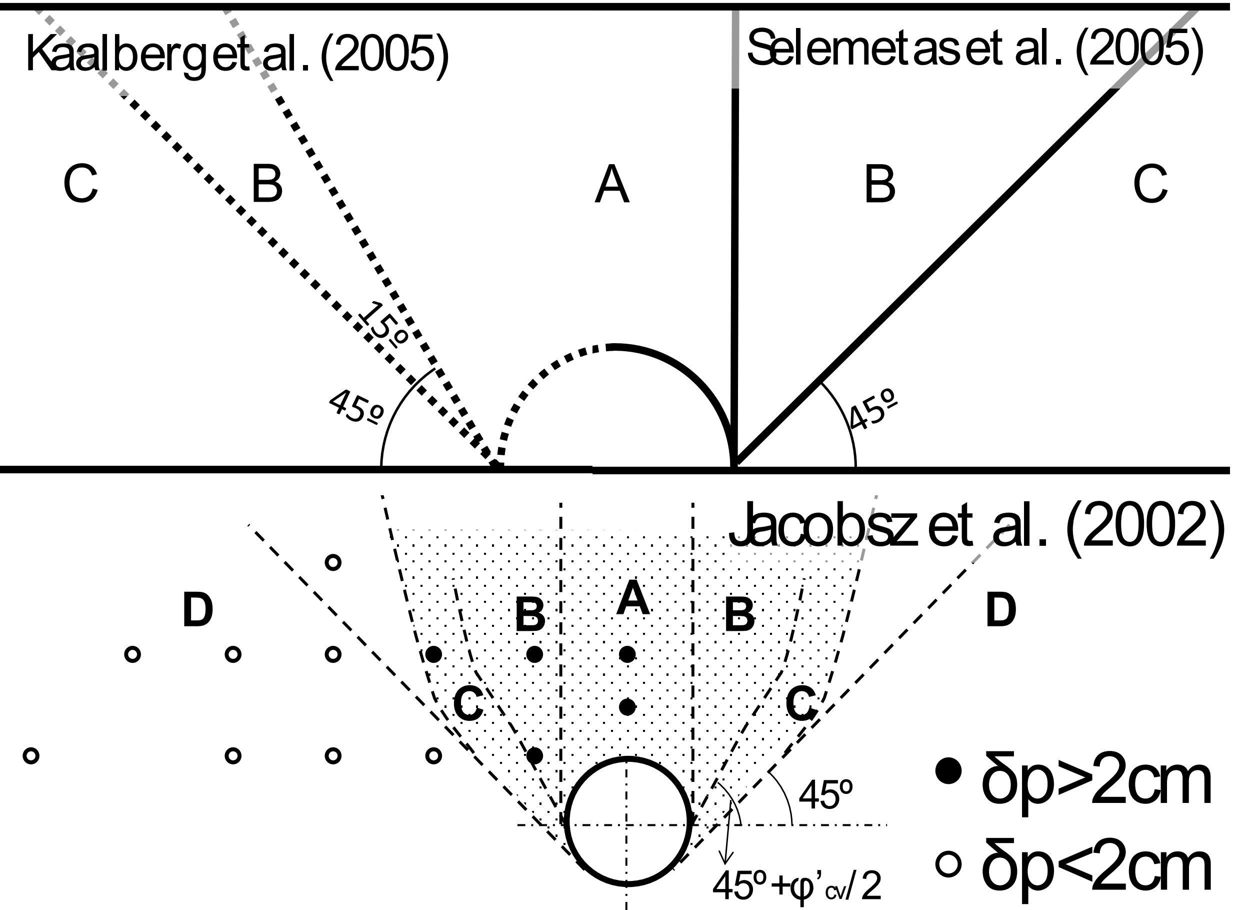
Piles and tunnels are now close enough for their interaction to be significant

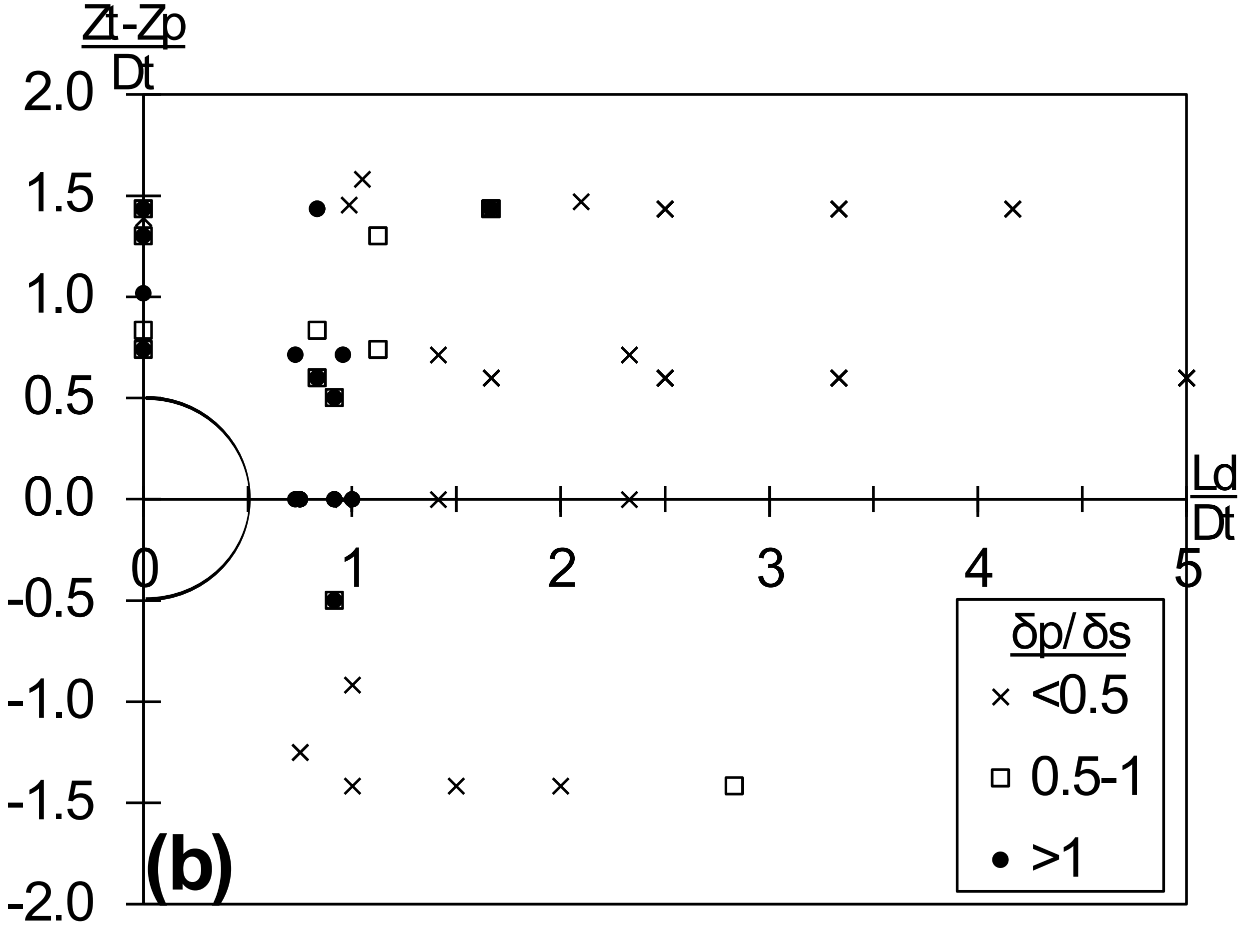




Introduction

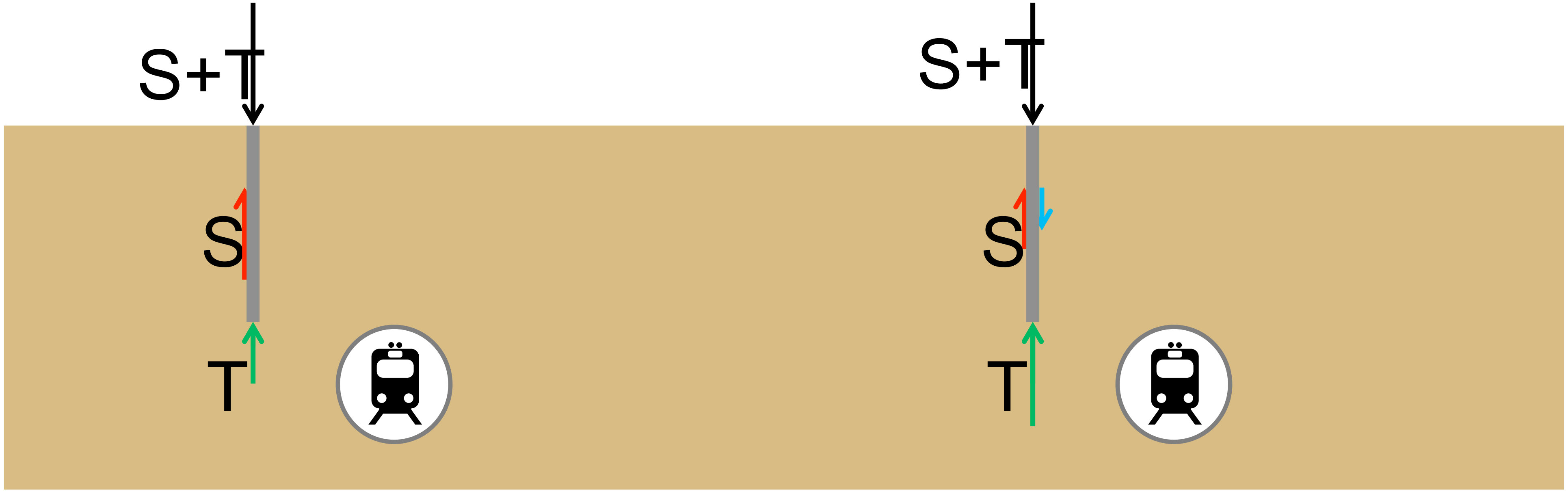
First attempts to define the pile settlement based on the relative position to the tunnel





Introduction

- Tunnelling degrades the pile base capacity
  - Higher mobilization of shaft friction
- Ground settlements induce negative friction
  - Higher mobilization of toe capacity

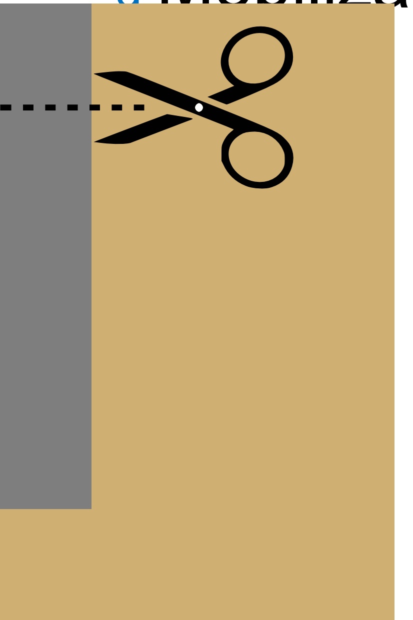


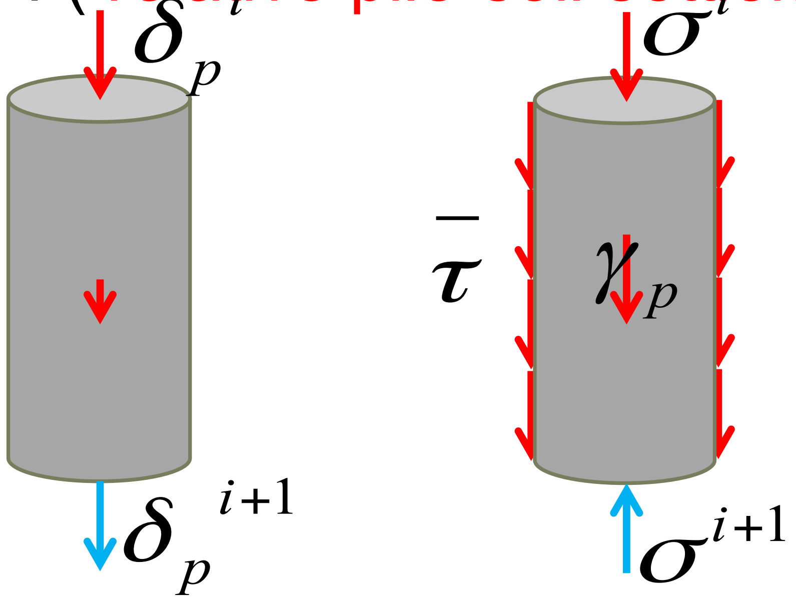
So what was necessary ?

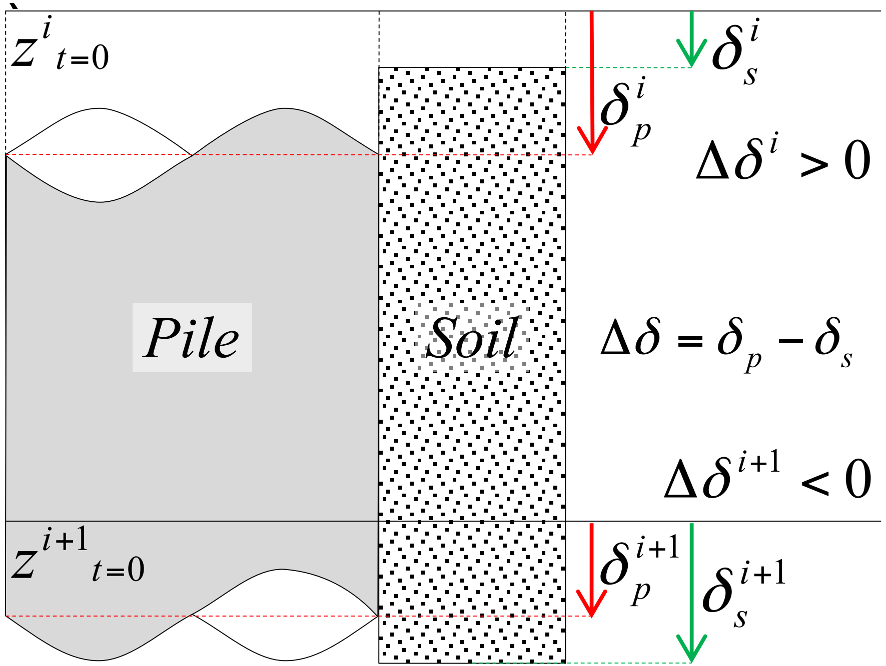
- An accessible method for pile analysis that could react to ground settlements

Modified Load Transfer Method

- Include unloading paths for the load mobilization
- Mobilization = f (relative pile-soil settlements)



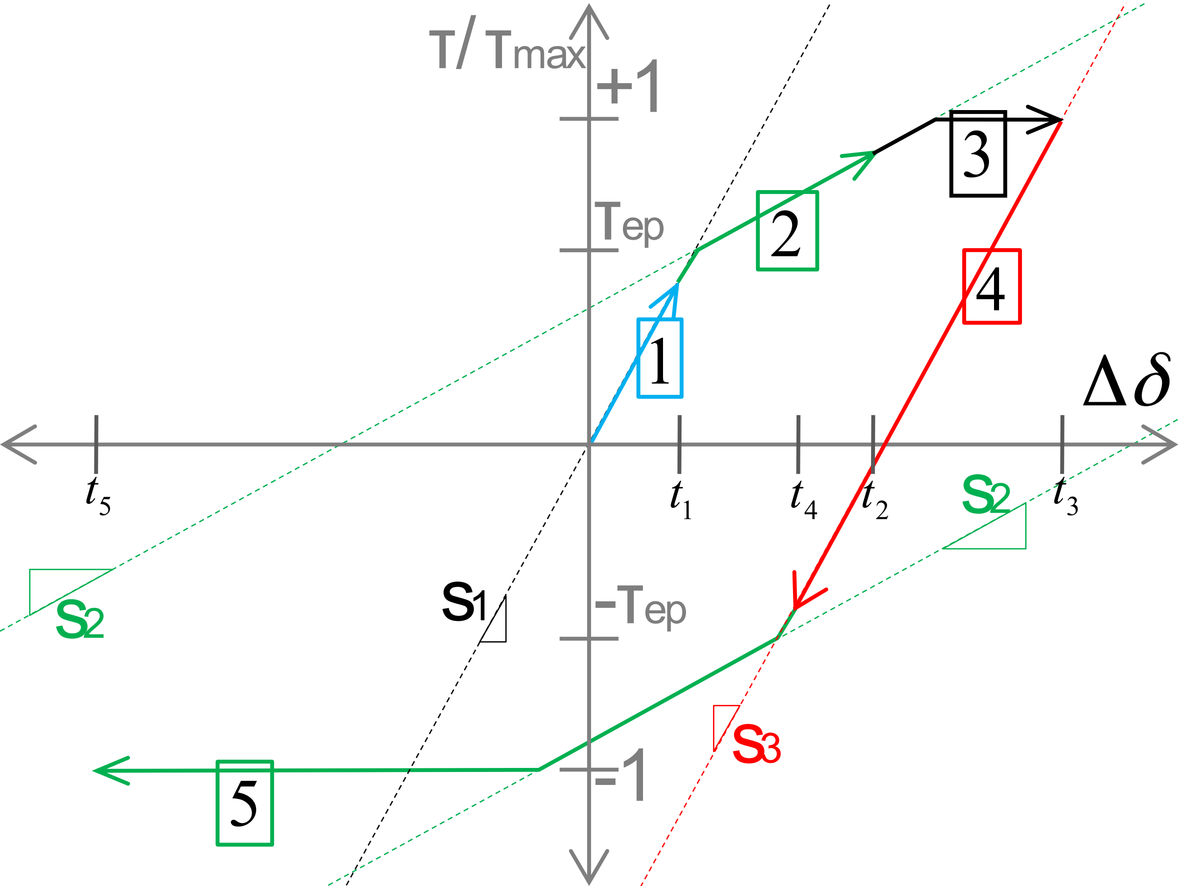


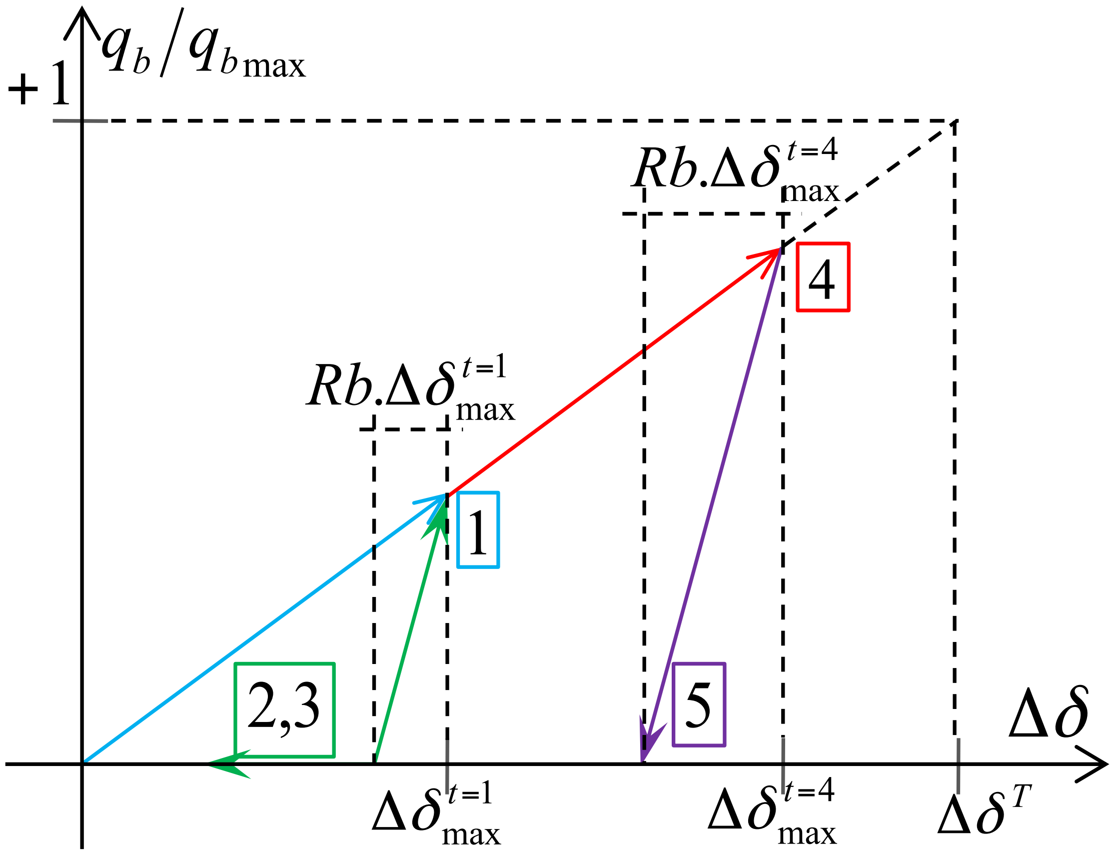


Mobilization Functions = f(Δδ)

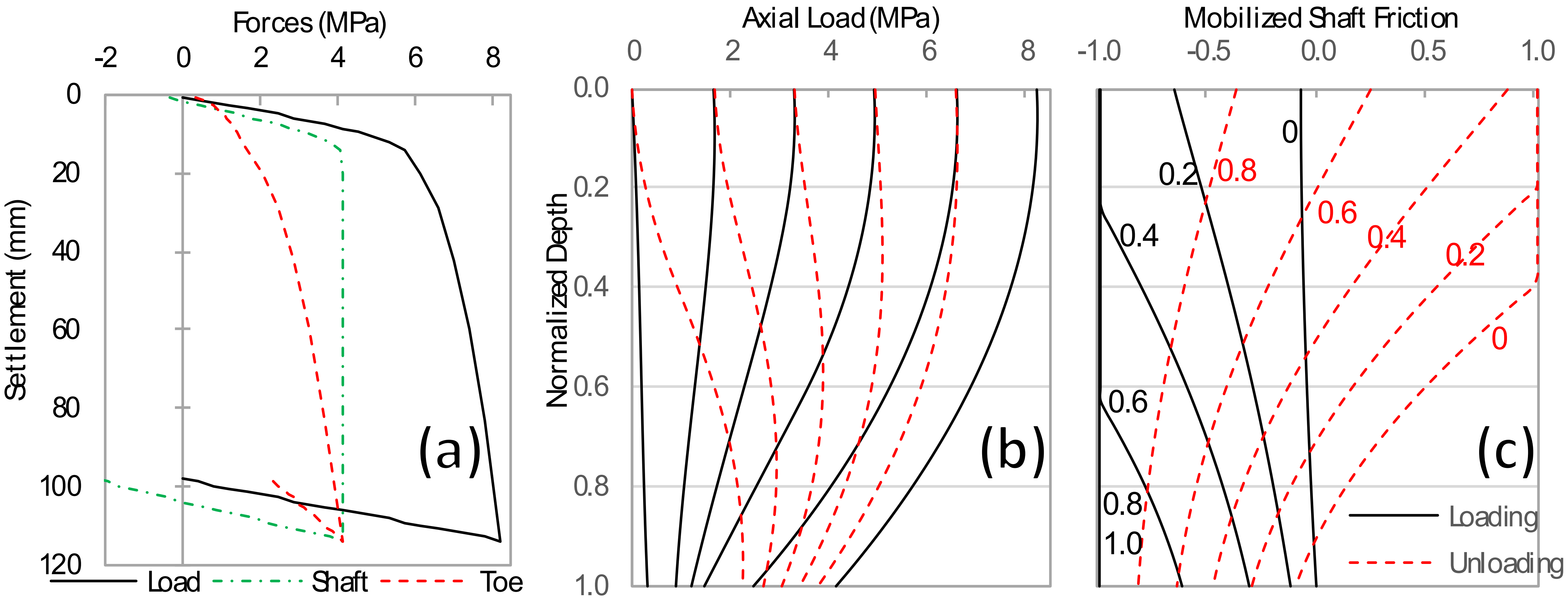
Shaft Friction Tri-linear (bi-directional) mobilization function

Toe Force Exponential loading ; Proportional unloading (Rebound)



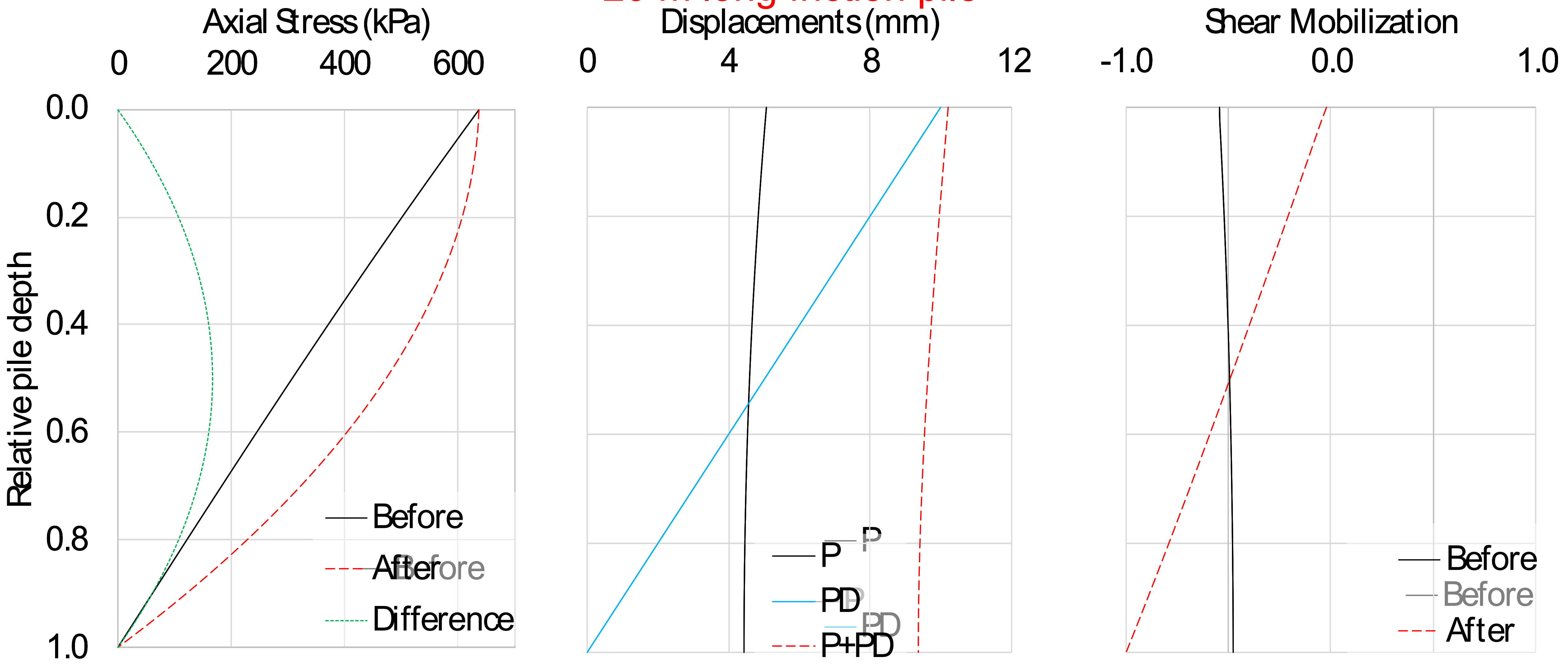


Pile Loading Cycle



Pile Equilibrium with Ground Displacements

20 m long friction pile

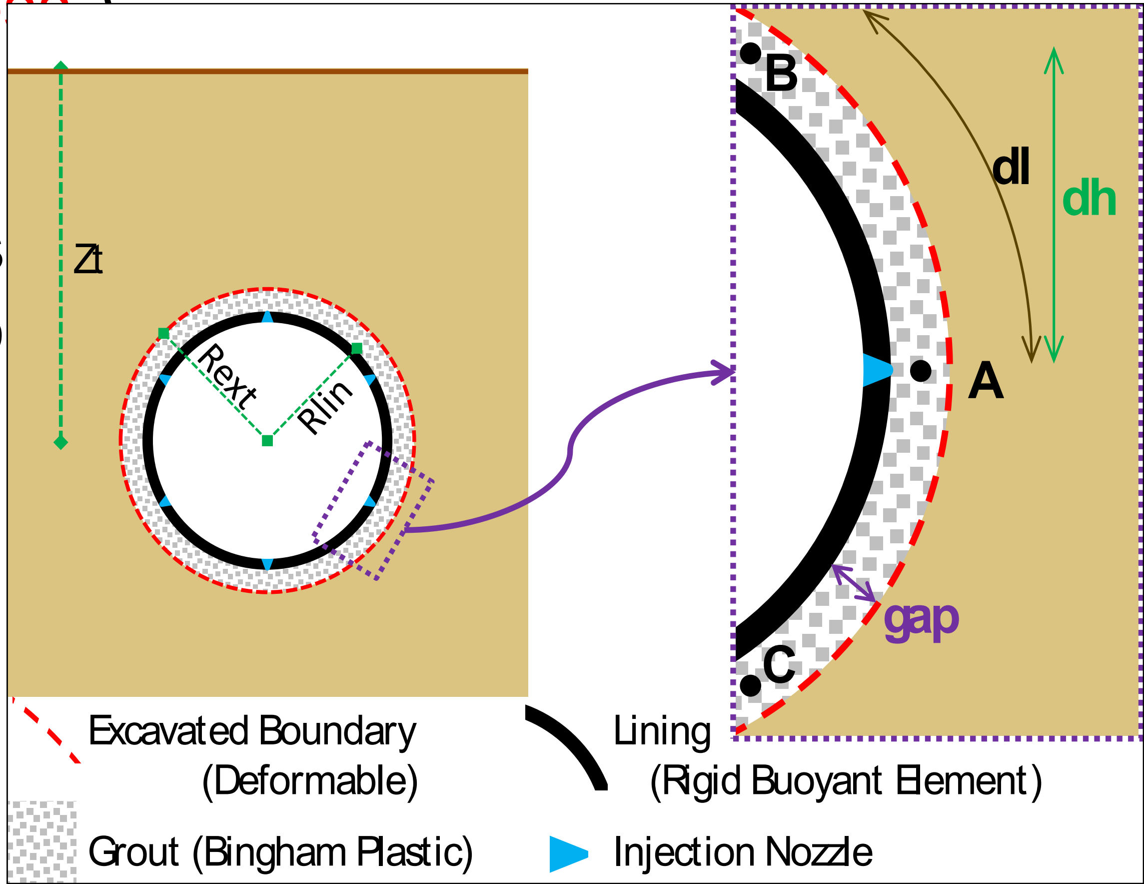


Tunnelling Settlements

- Numerical solution of the equilibrium equations based on the (stress) boundary conditions at the excavation perimeter
  - Boundary Conditions = f (Physical Process)
- Tail Void Grout
  - The injected grout pressure dissipates as grout flows between the lining and the so

p = f (soil-lining gap)

$$p_B = p_A - \frac{\tau_g}{gap}.dl - \gamma_g.dh$$

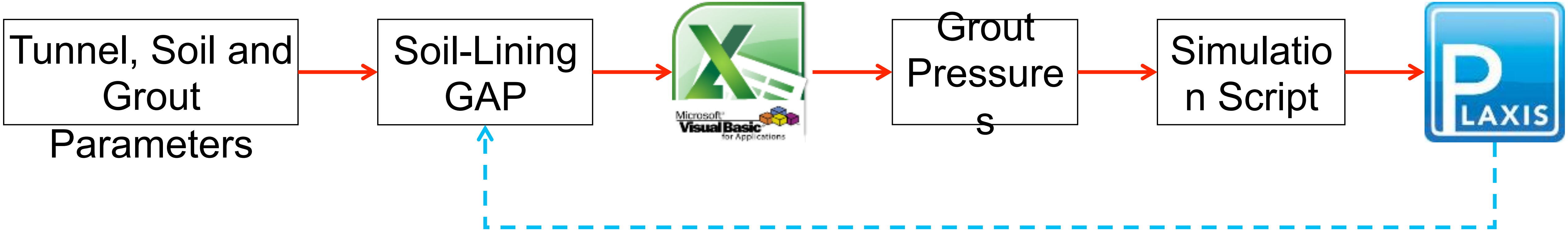


Grout Injection

- How can we model that realistically?
  - Traditional approach = The imposed pressure is constant
  - Iterative calculation = The pressures depend on the ground deformations

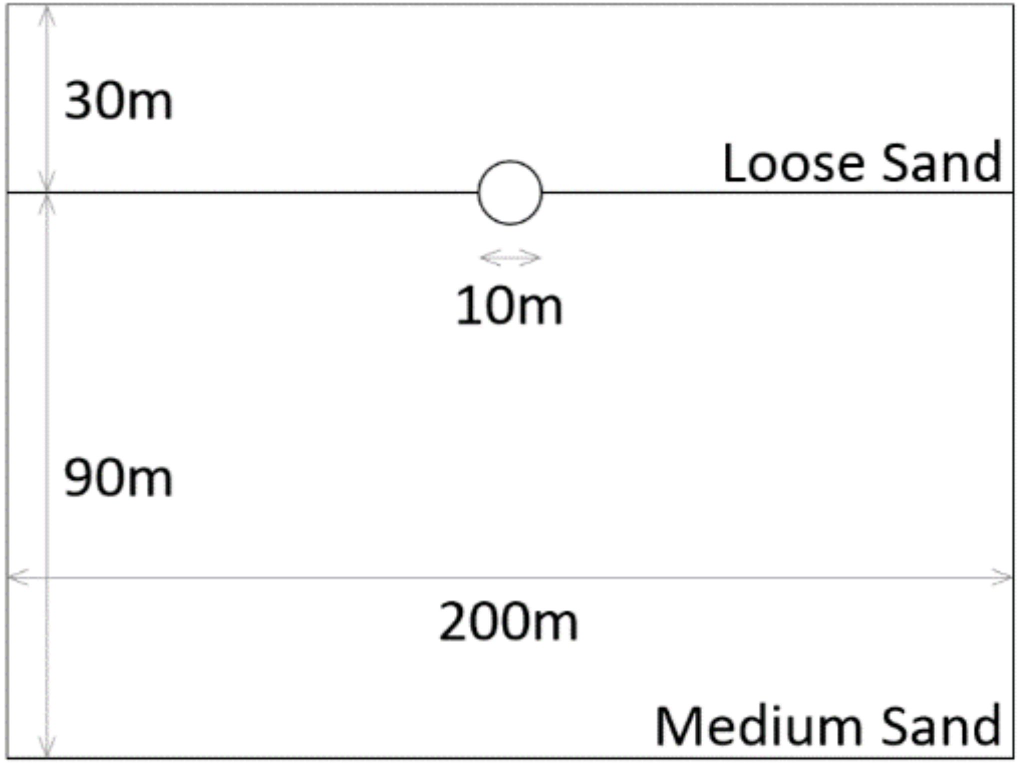
$$\{\sigma\} = \lambda.\{\sigma\}_0$$

$$\{\sigma\} = f(TBM)$$



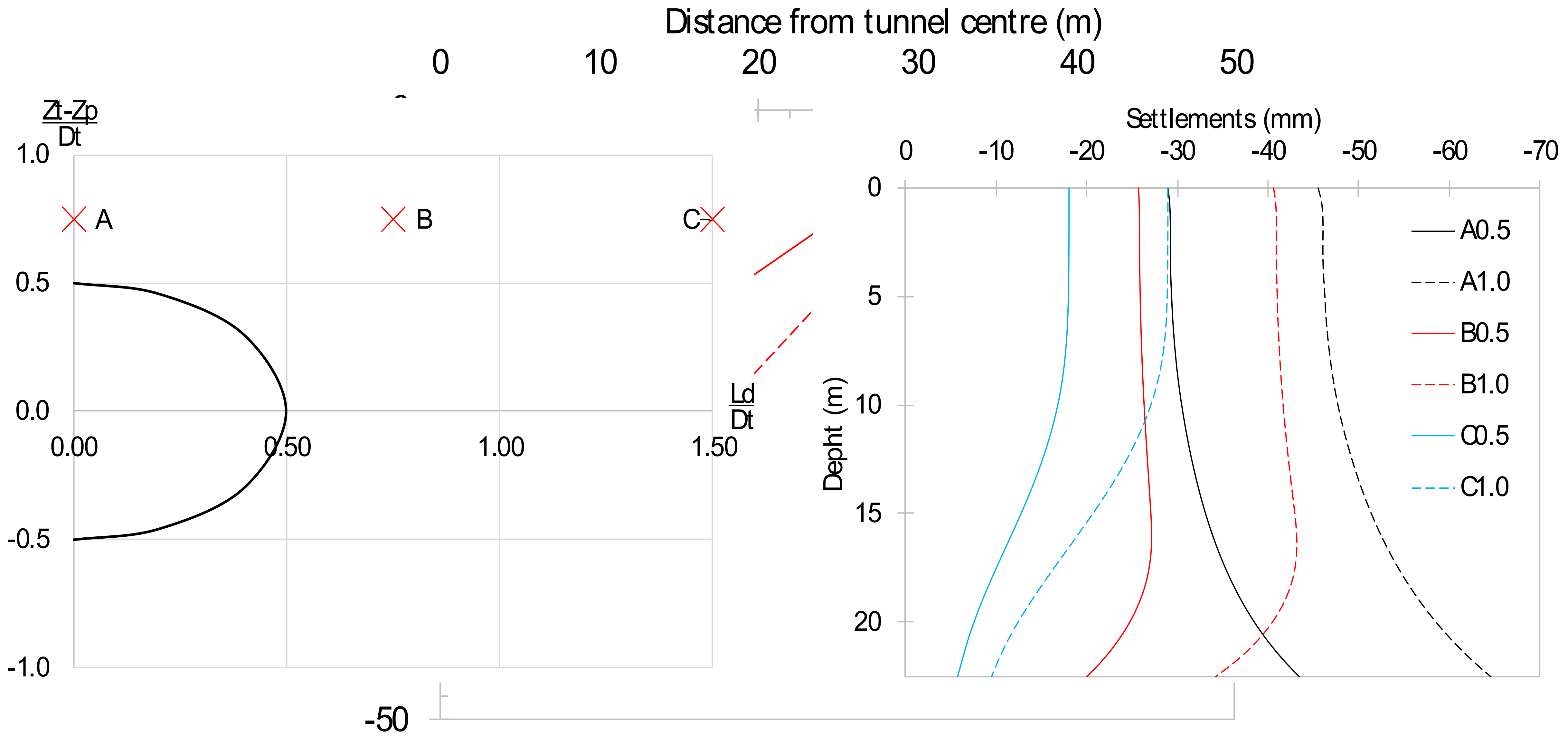
Tunnelling Settlements

- Diameter of 10m, centred at a depth of 30m
  - Initial soil-lining gap of 15cm
- Hardening Soil model
  - Empirical correlations with RD
- Grout Properties
  - Yield stress of 0.5 kPa; $\gamma = 20$ kN/m³



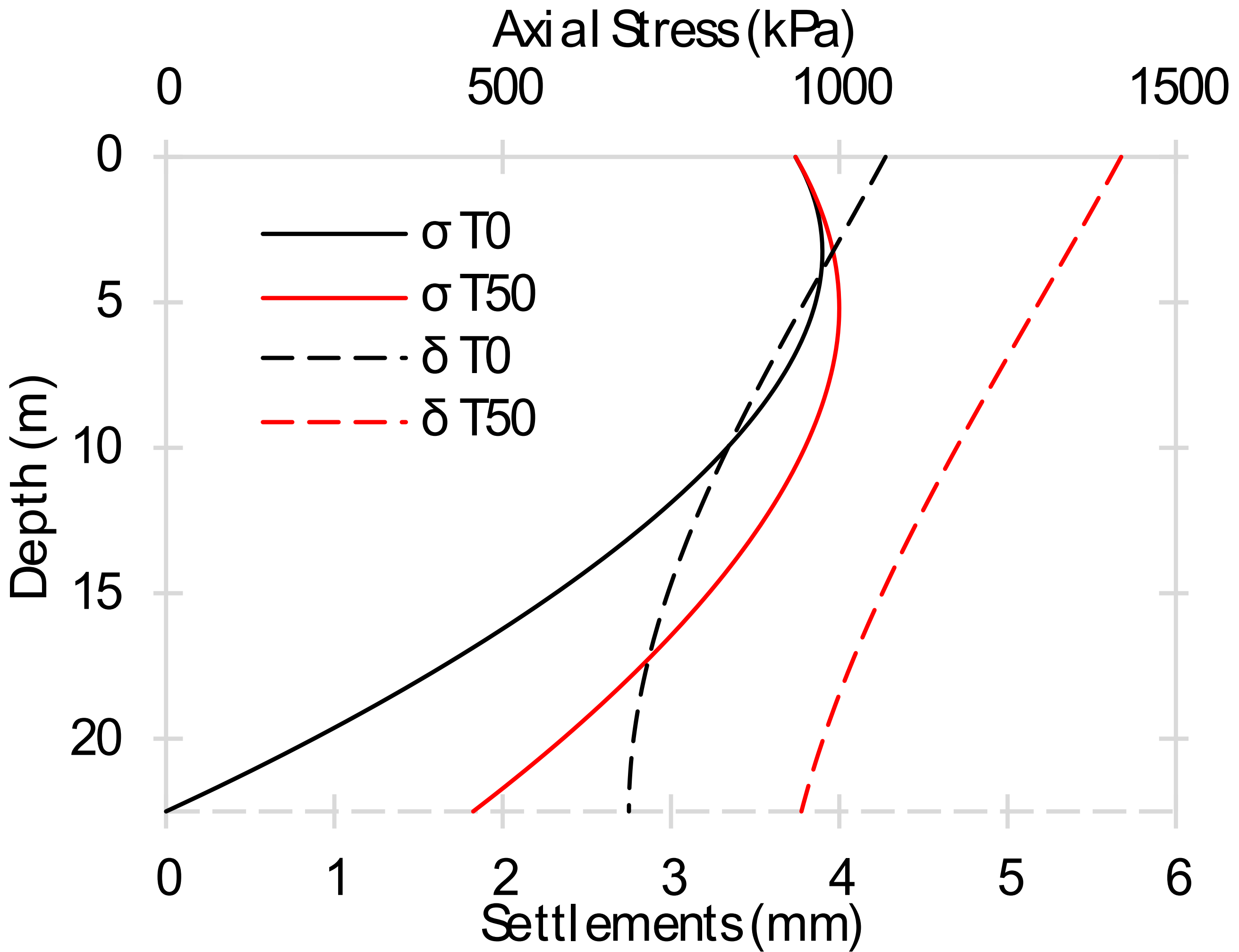
- Injection Strategy
  - Grout p. at the tunnel roof 0.5 and 1.0% volume loss around the tunnel

Tunnelling Settlements



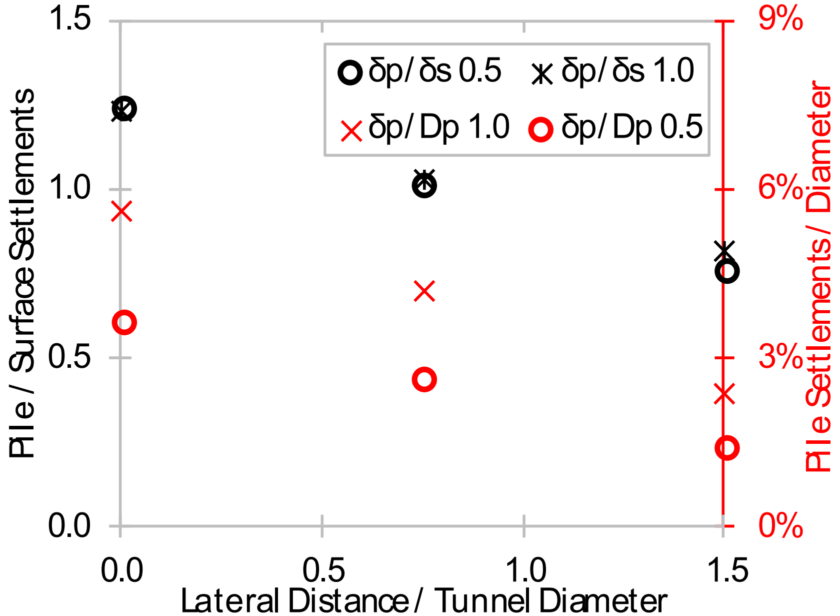
Example Piles

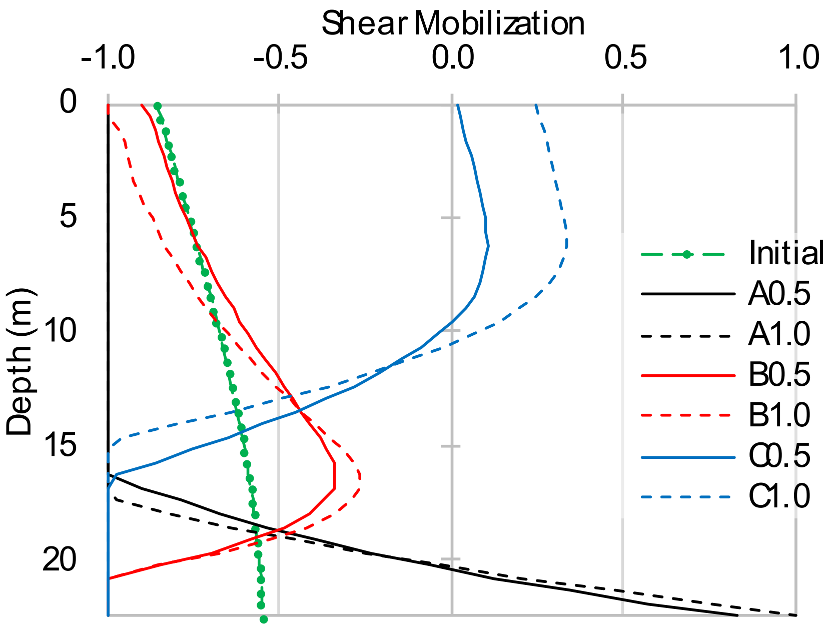
- Piles – 22.5 m / D = 1 m / E = 10 GPa / γ=25 kN/m3
- Shaft – Linear increase
  - S1 = S3 = 0.3 / S2 = 0 / τep = 1
- Toe – Max. mobilization at 100 mr
  - 10% rebound
- Pile Capacity – 1.5 MN
  - 100% Shaft (T0)
  - 50% Shaft and 50% Toe (T50)
- Initial Loading State – FS=2

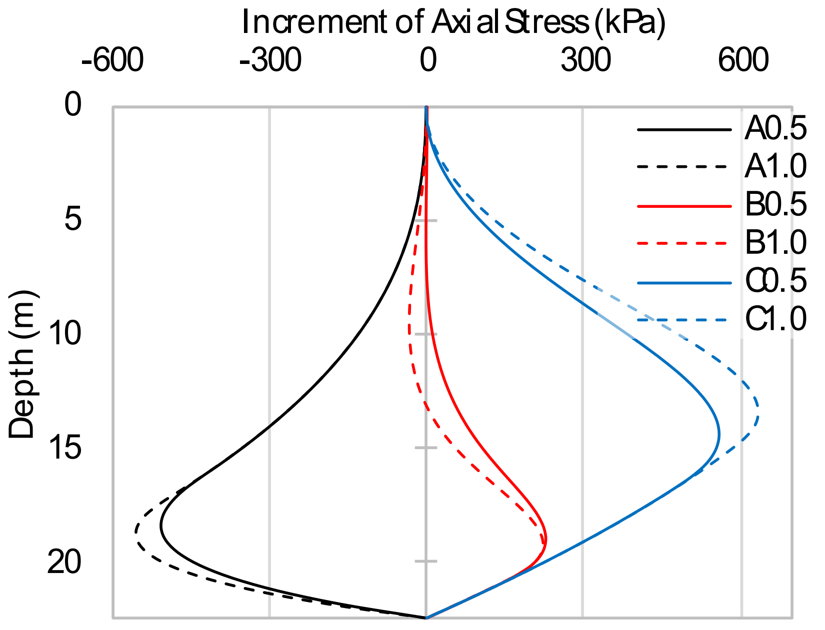


Examples of Pile Tunnel Interaction

- Friction pile
  - Settlements - δp/Dp x δp/δs - o = 0.5% x = 1.0%
  - Shear Mobilization (negative shear - δs > δp)
  - Increment of Axial Stress (decrease at A, but increased at B and C)

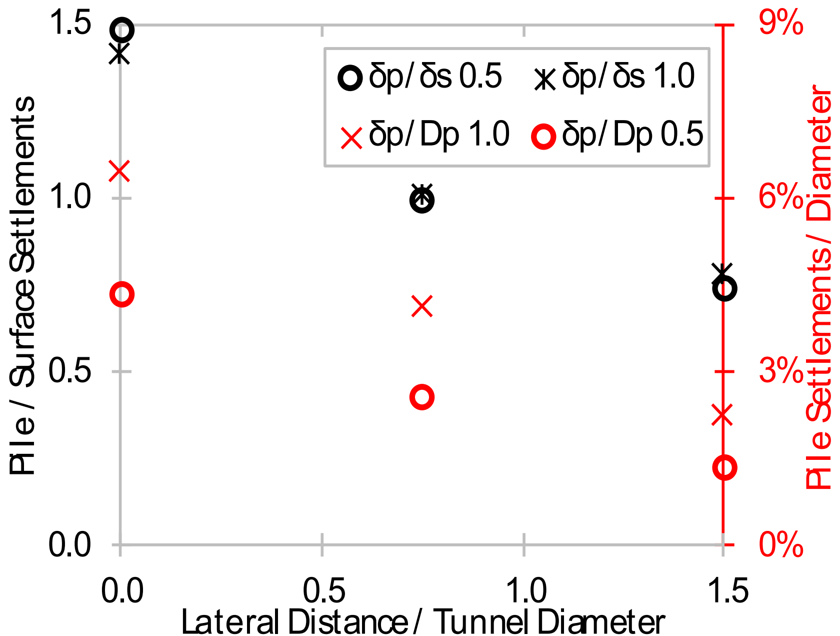


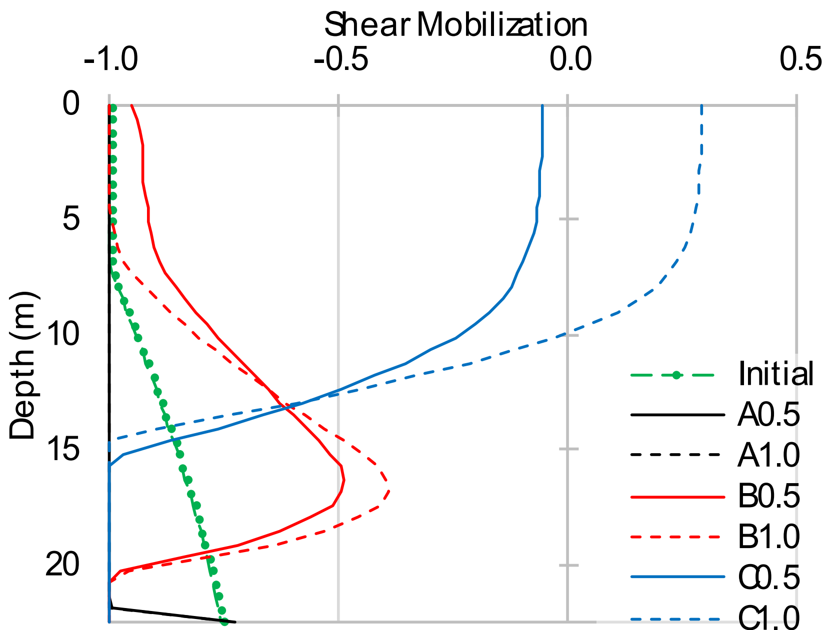


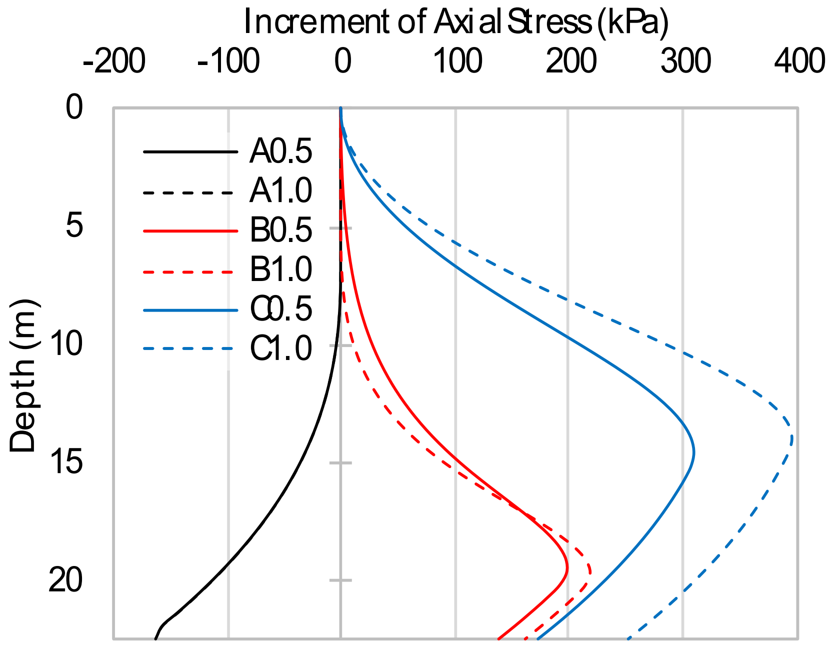


Examples of Pile Tunnel Interaction

- Shaft and Toe Capacities (50 / 50%)
  - Settlements – Higher than T0
  - Shear Mobilization – forces can be transferred to the toe
  - Increment of Axial Stress (decrease at A, but increase at B and C)







Conclusion

- A modified version of the load transfer method can be used to predict how a single pile reacts when subjected to ground displacements, such as the ones induced during a mechanized excavation
- Pile settlements decrease with Ld, but increase with the tunnel VL
  - Between 6.5 and 1.3% of the pile diameter.
- The ratio between the pile and the surface settlements ($\delta p/\delta s$):
  - >1 for a pile located above the tunnel
  - <1 for Ld larger than one tunnel diameter.
- Axial forces decrease when the pile is directly above the tunnel, but increase otherwise

THANK YOU FOR YOUR ATTENTION

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