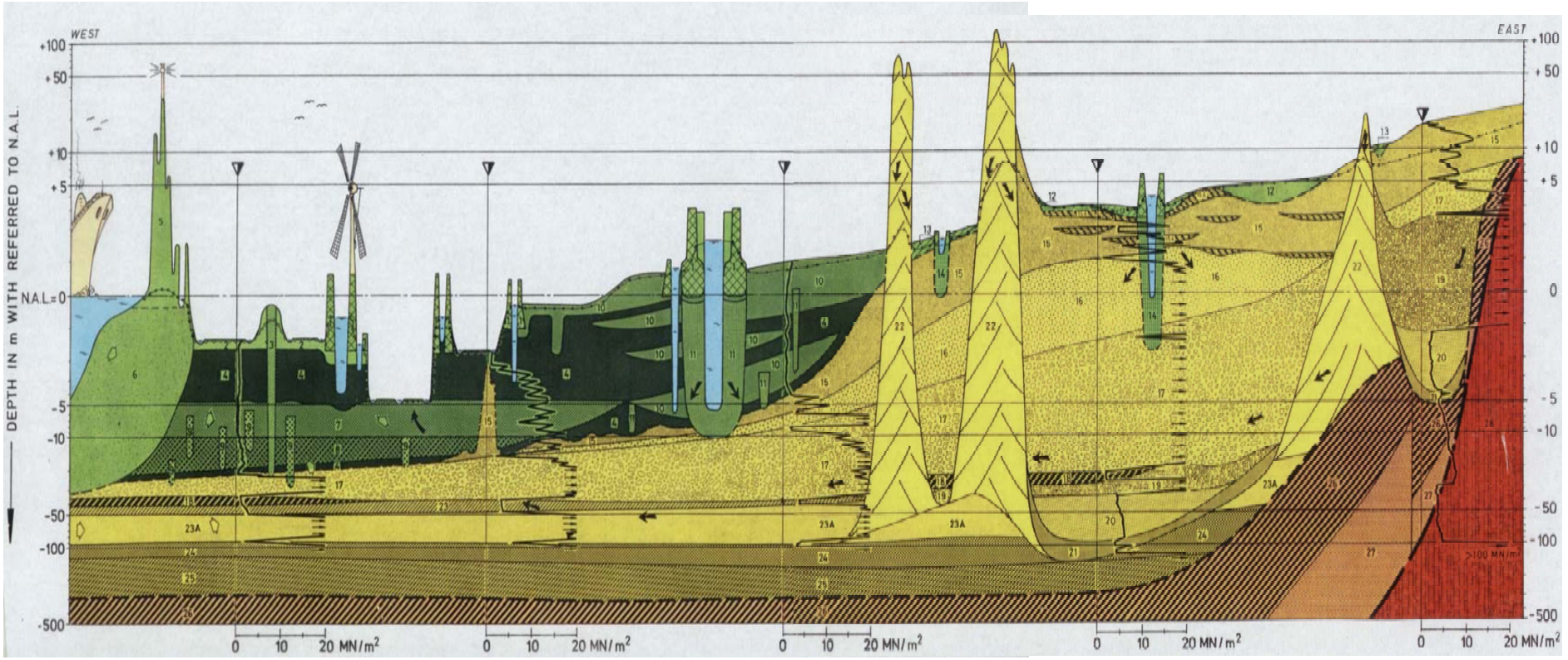
Modelling of Shield Tunnels

Wout Broere

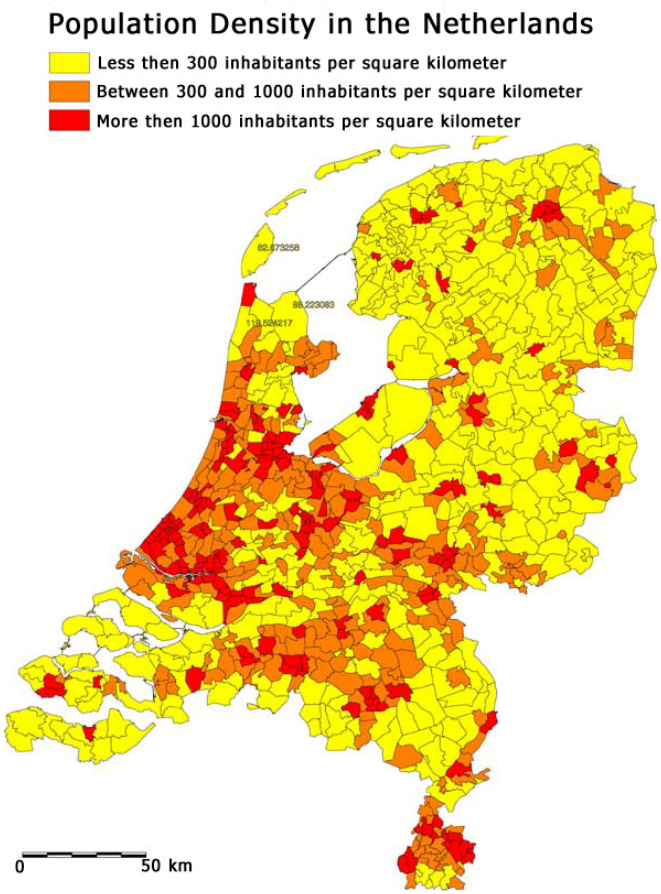
Content

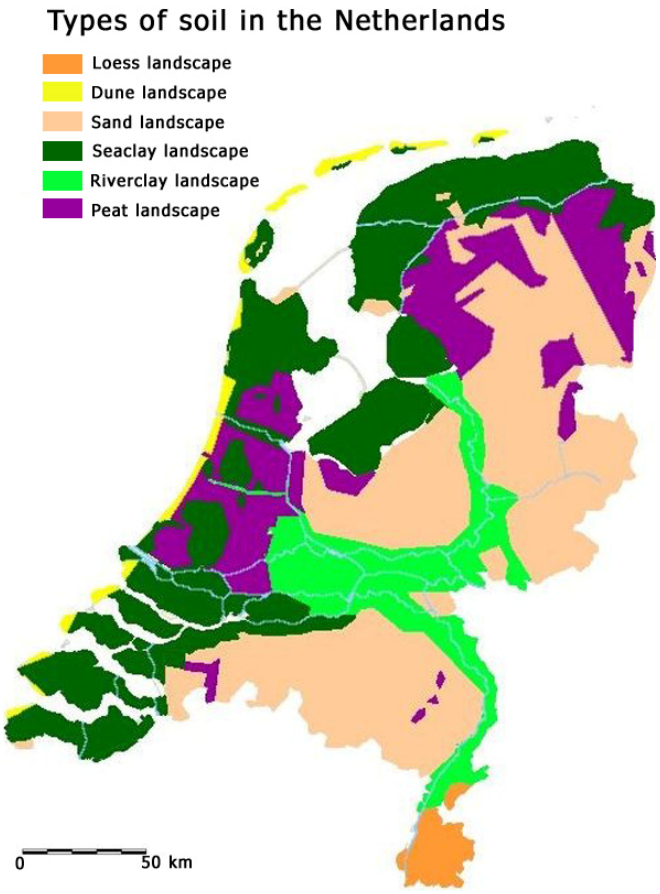
- Shield tunnel construction
  - Examples from the Netherlands
  - Results from research projects
- Modelling shield tunnels in Plaxis
  - Modelling in 2D
  - Modelling in 3D

Geology of the Netherlands



Geology of the Netherlands

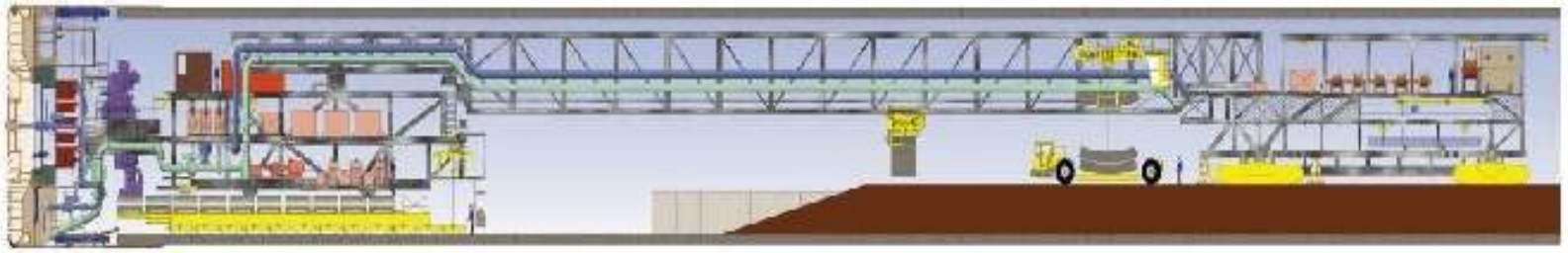




Dutch Polders - Green Heart

Green Heart Tunnel

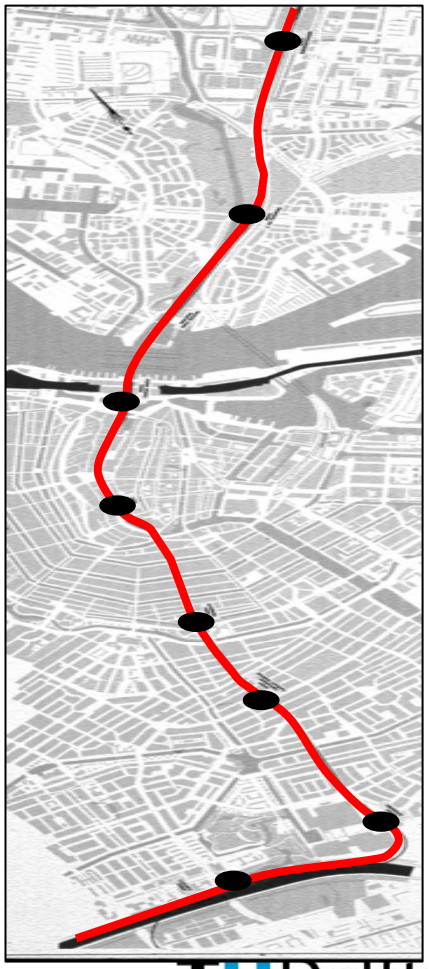
Green Heart Tunnel



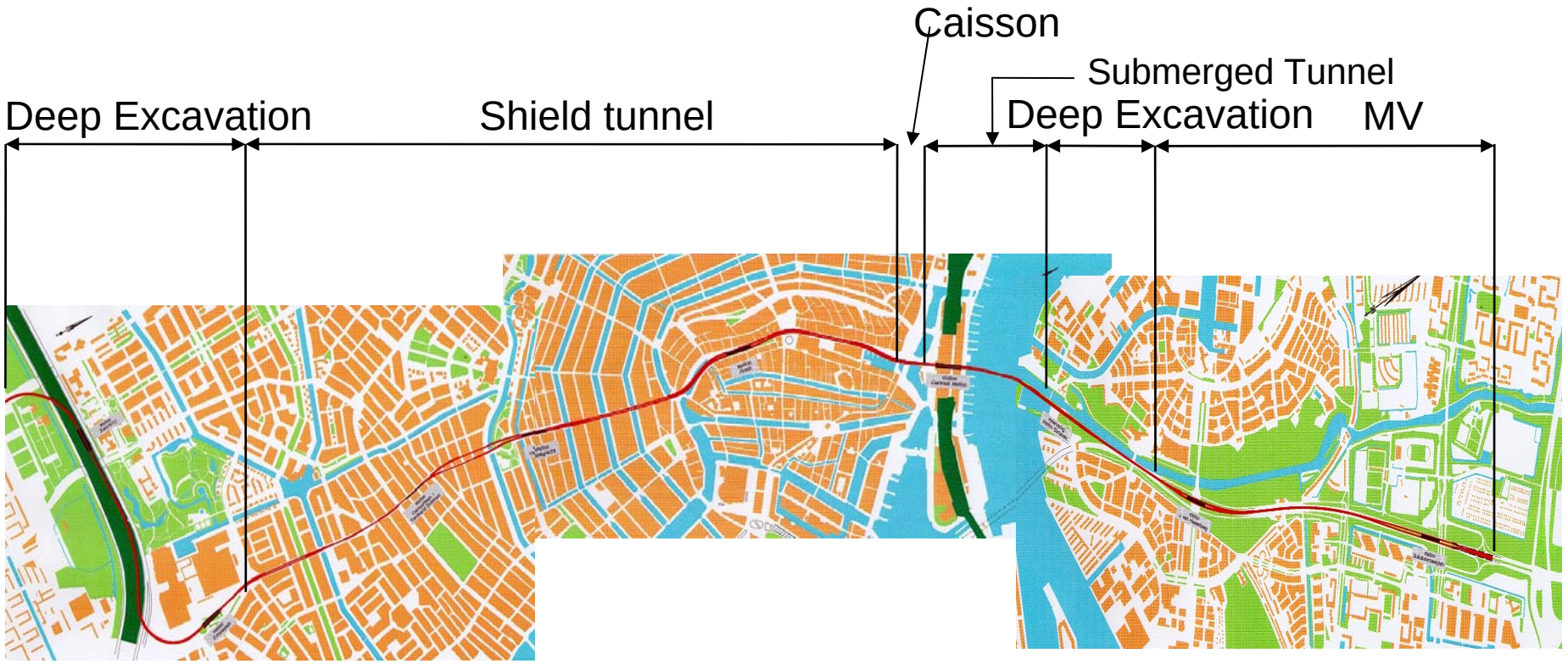
North-South Line

North-South Line

- Buiksloterm. 22.500
- v. Hasseltw. 12.500
- C.S. 62.500
- Rokin 57.500
- Vijzelgracht 27.000
- Ceintuurbn. 35.000
- Europapl. 27.500
- Zuid/WTC 47.500

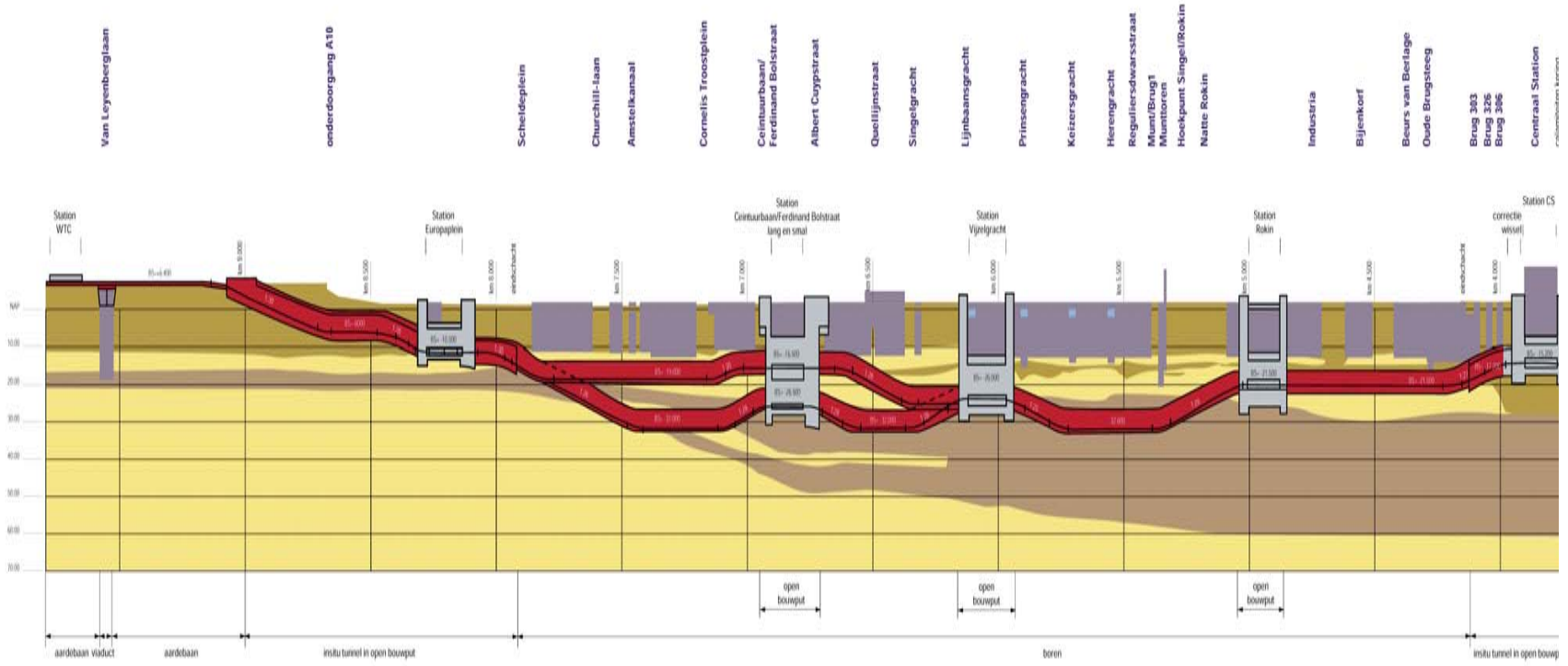


Construction Methods

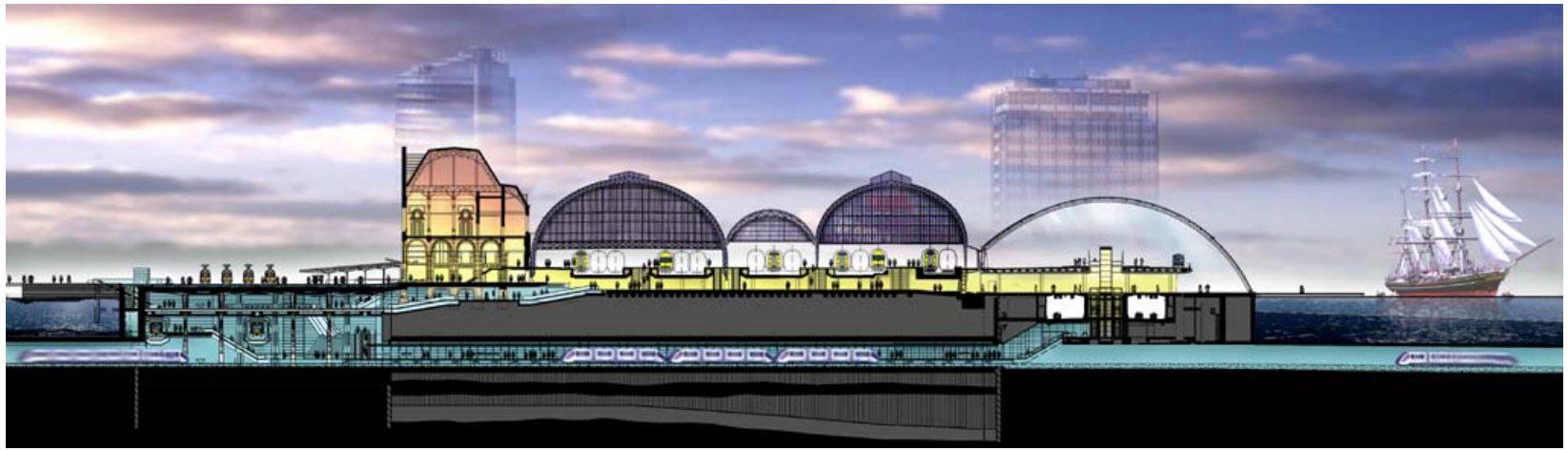


South **Centre** **North**

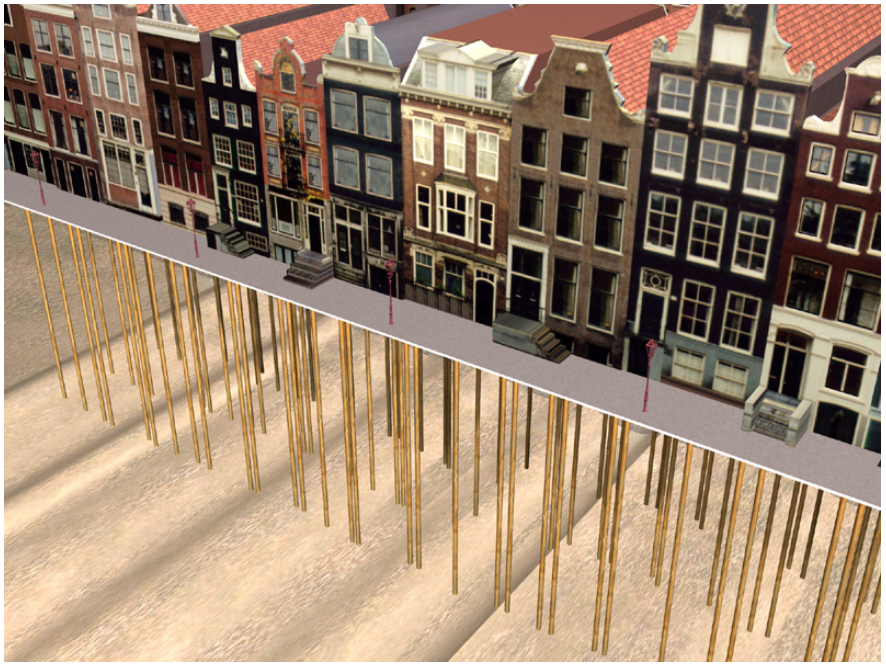
Depth of the Bored Tunnels

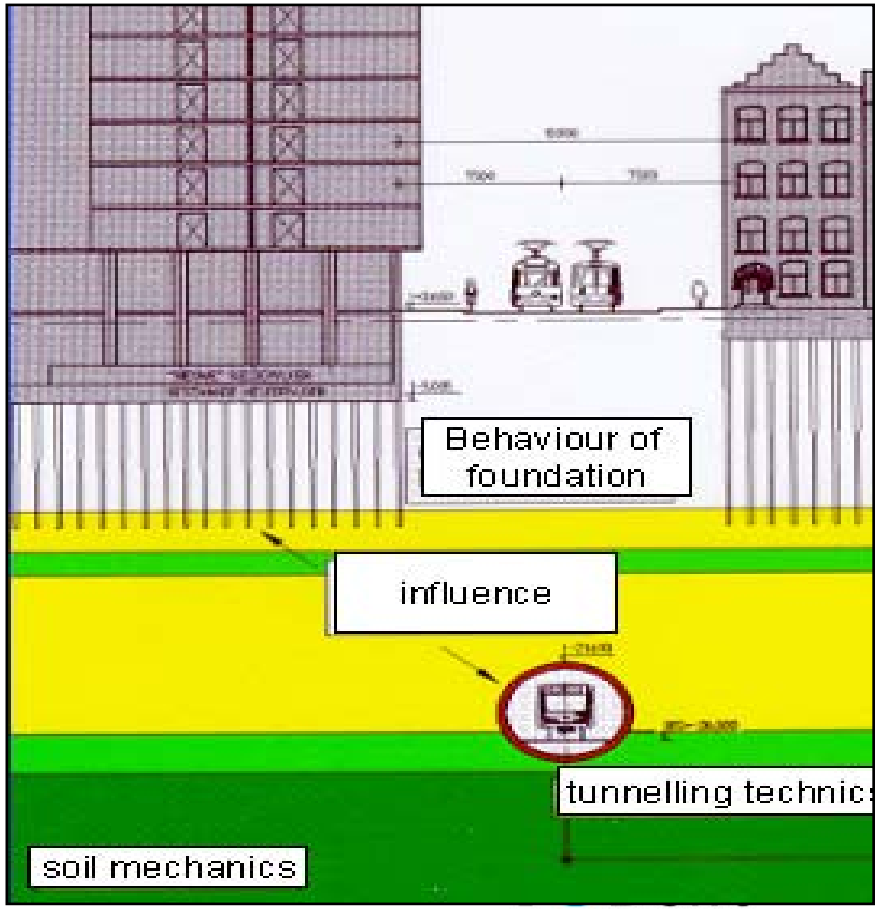


Deep Stations

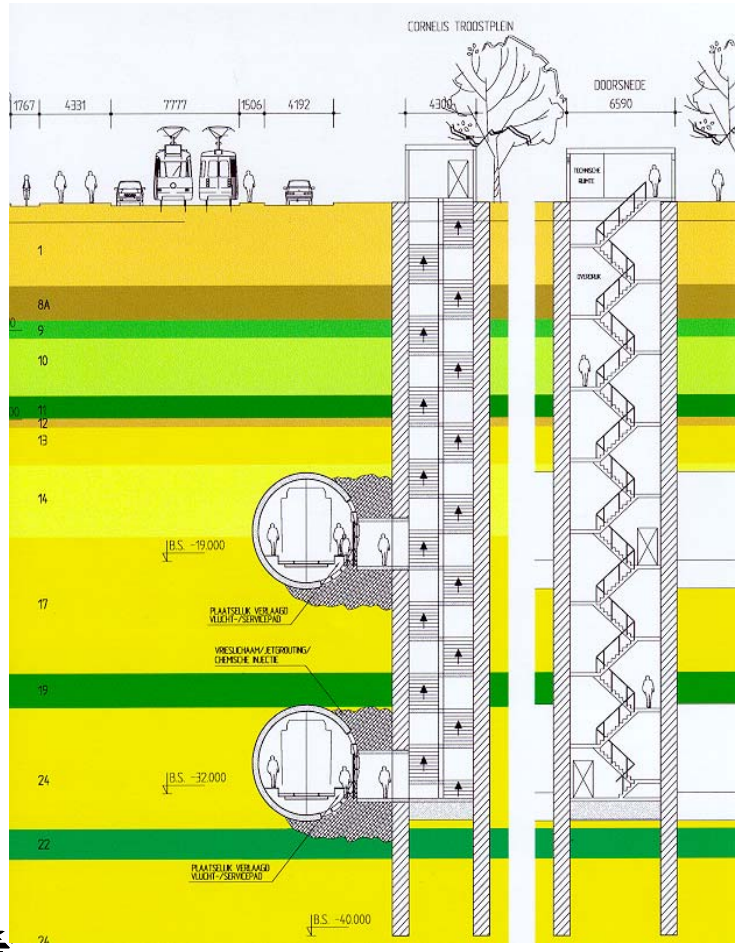


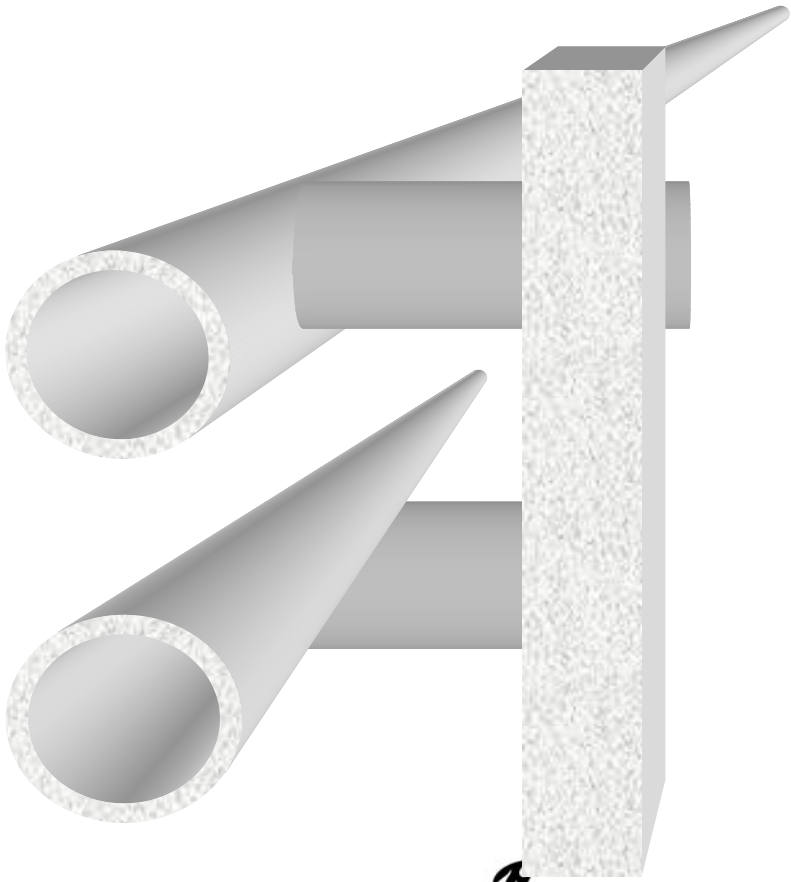
City Surroundings



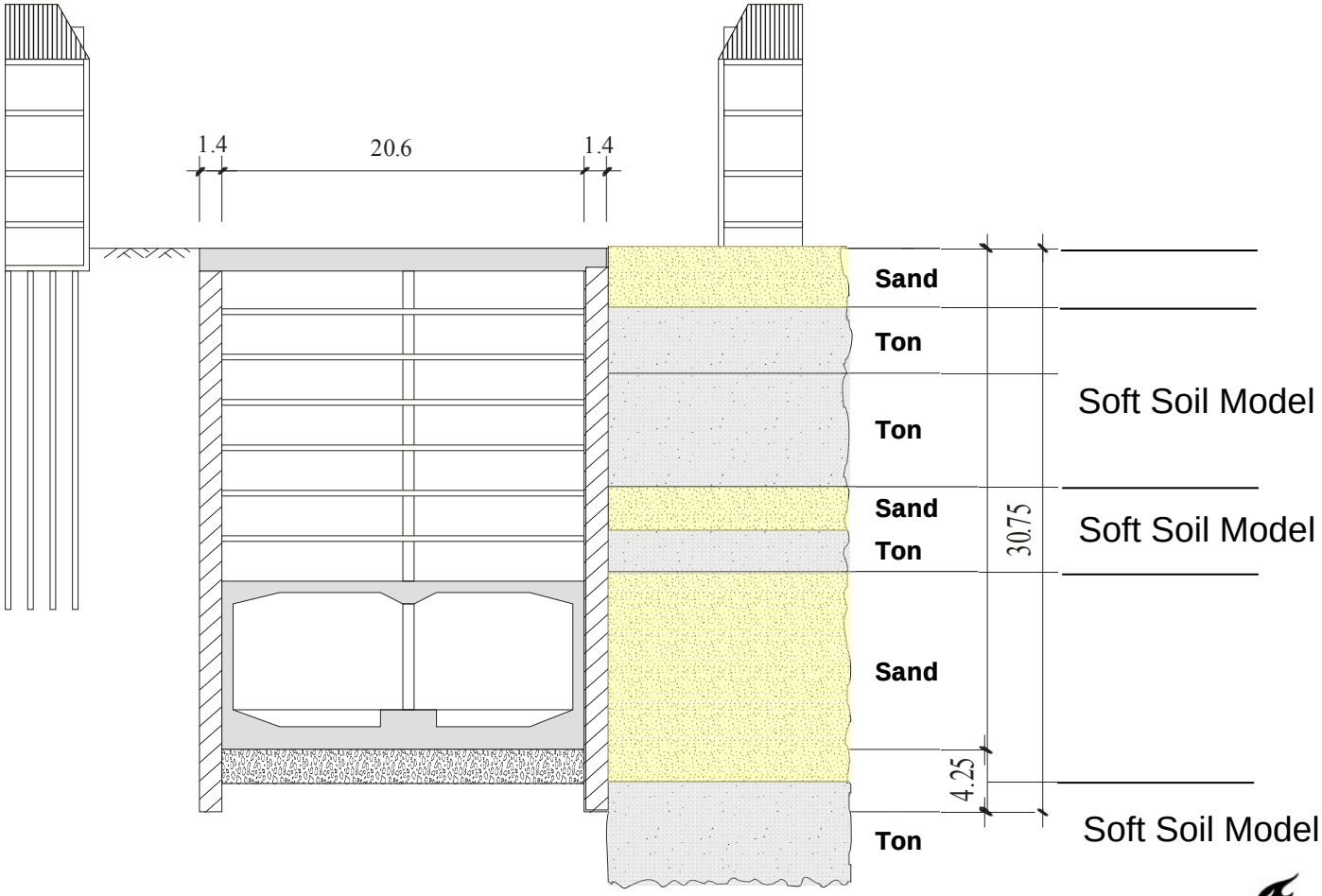


Emergency Exits



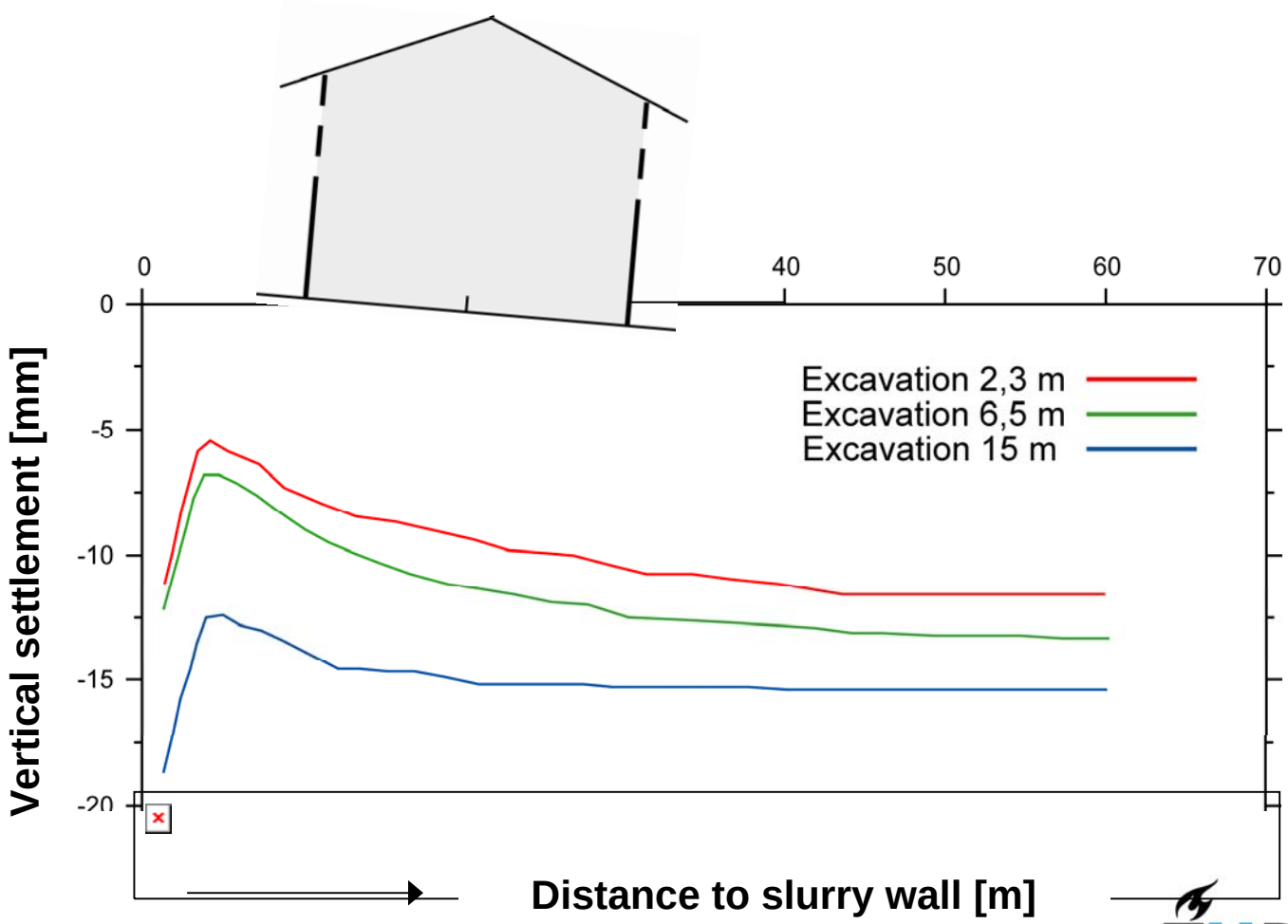


First FEM design efforts

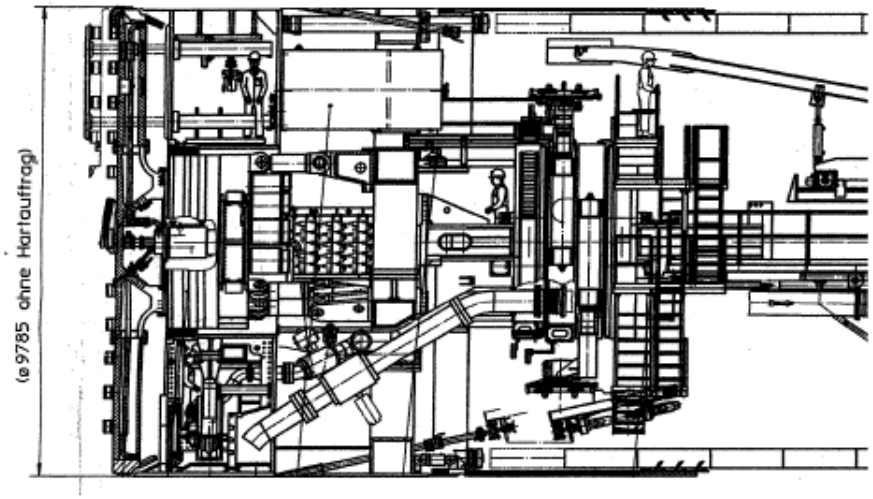


Hutteman, 1994

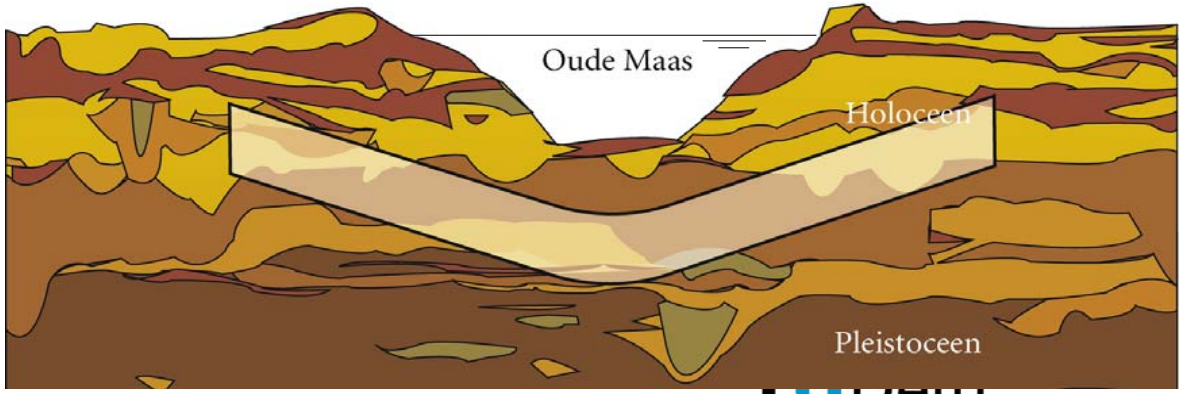
Incorrect settlement profiles



Tunnel Boring Machine

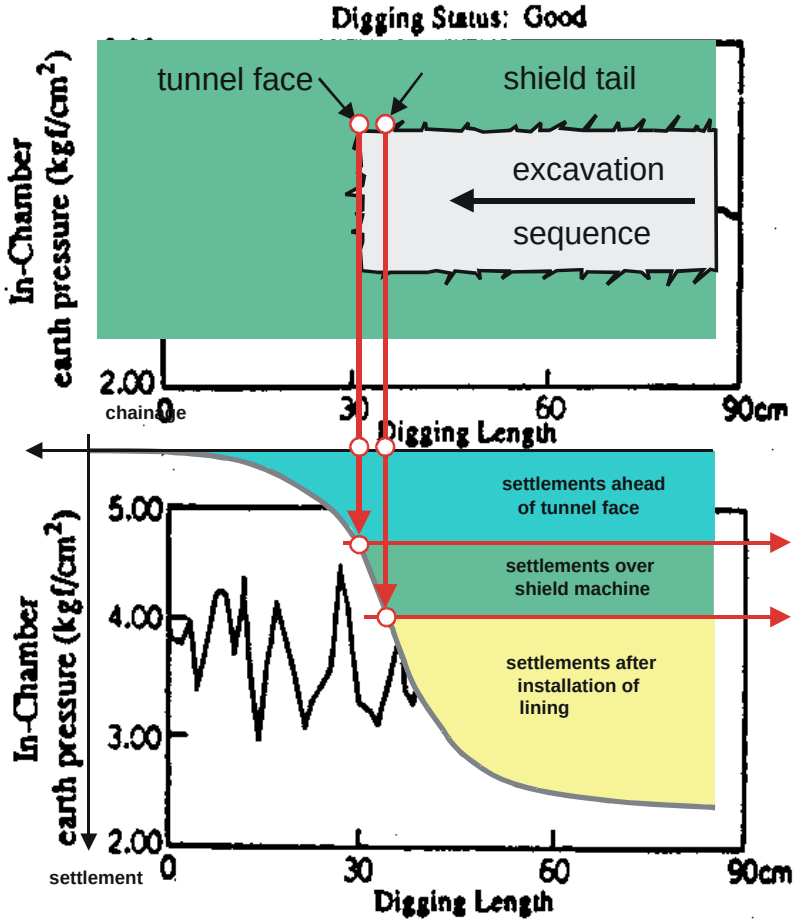


dzijde Noordzijde

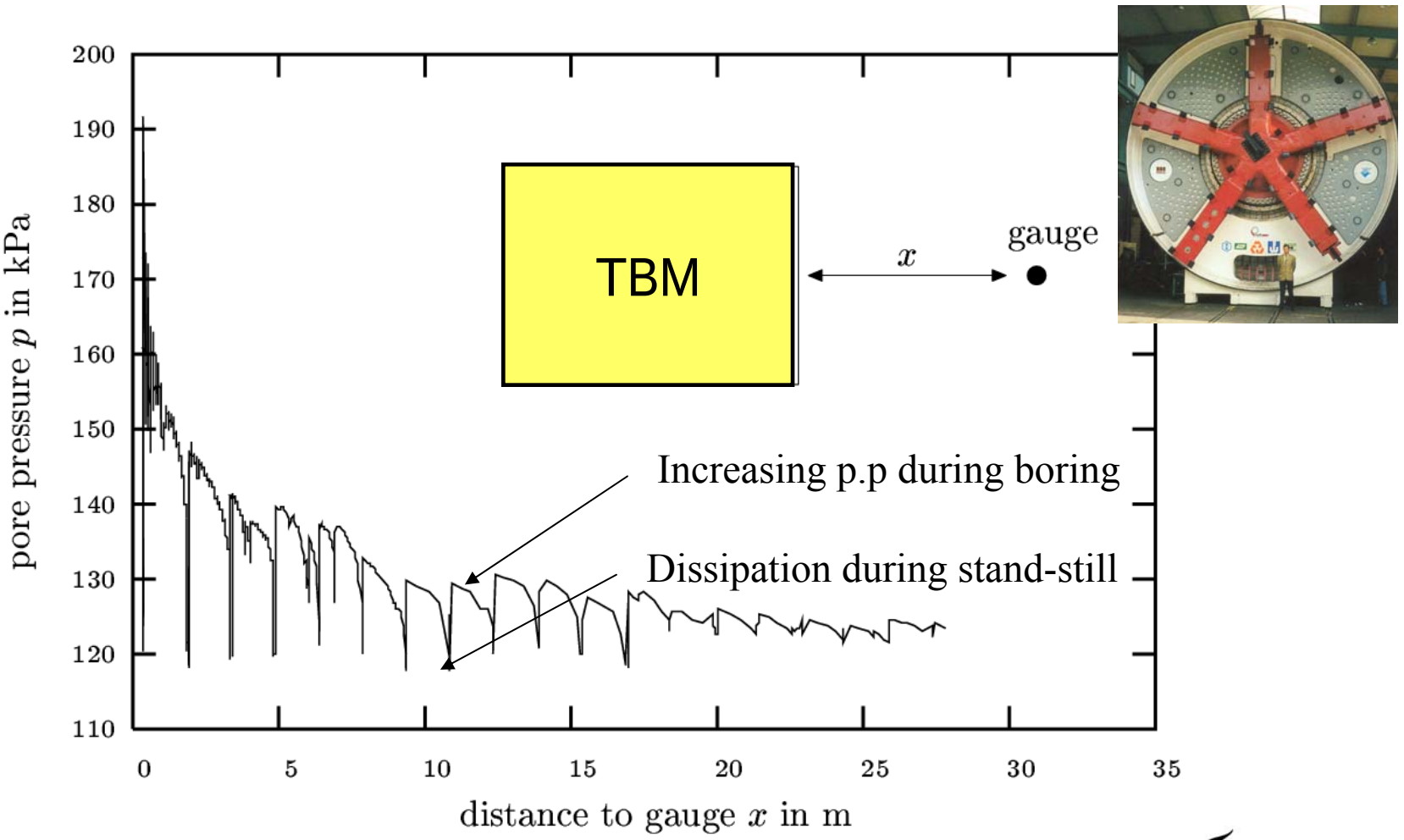


Tunnel Face Stability

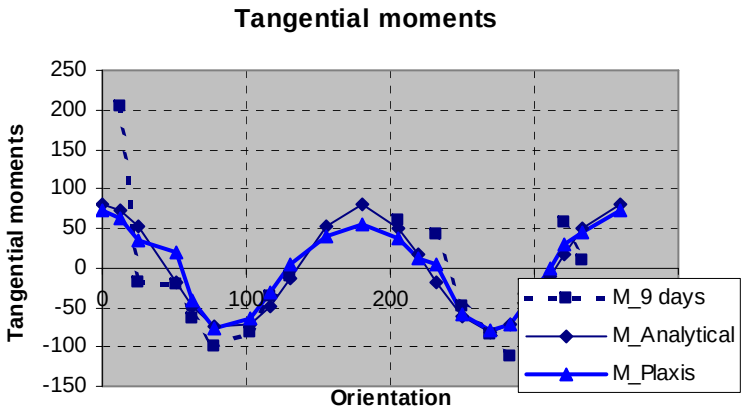
- Minimal and maximal support pressure
  - Pressure fluctuations
    - Limited fluctuations
      - Controlled proces
    - Large fluctuations
      - Layer boundaries
      - Micro-instabilities
      - Clogging
  - Settlement control

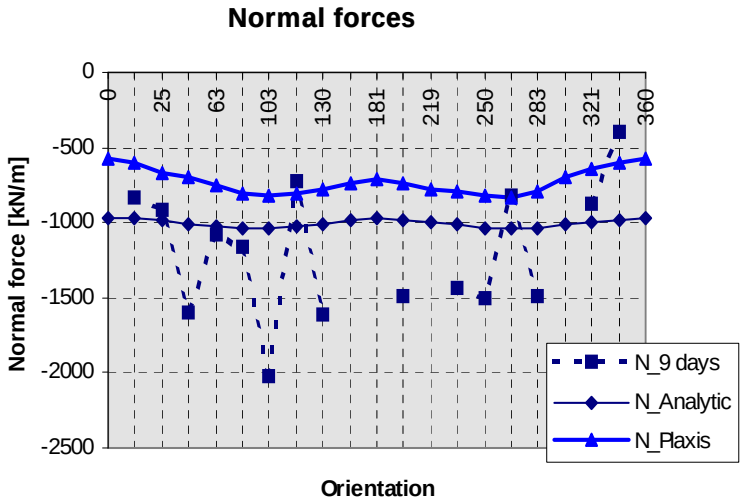


Excess Pore Pressures

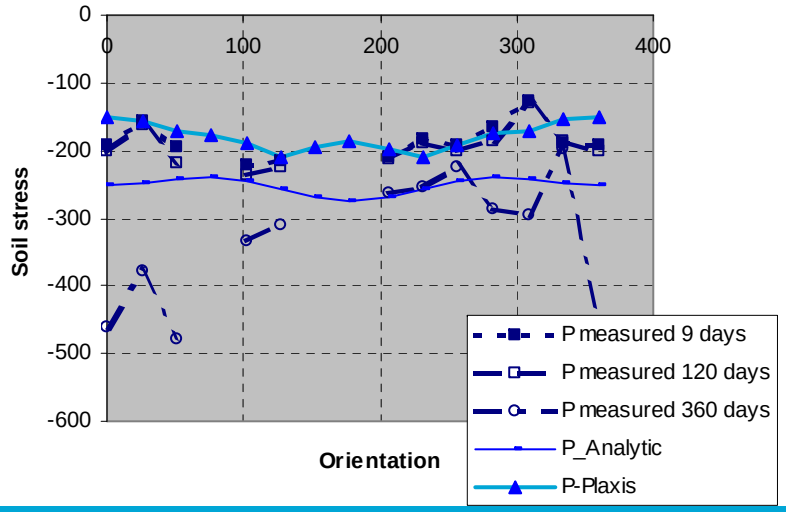


Forces in the Tunnel Lining

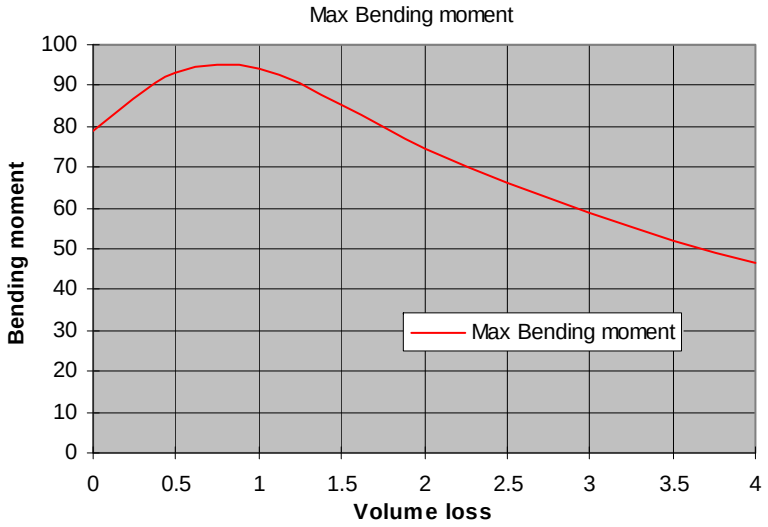




- Normal forces; peaks due to assembly
- Soil loading confirms
- Volume loss 0.5 %

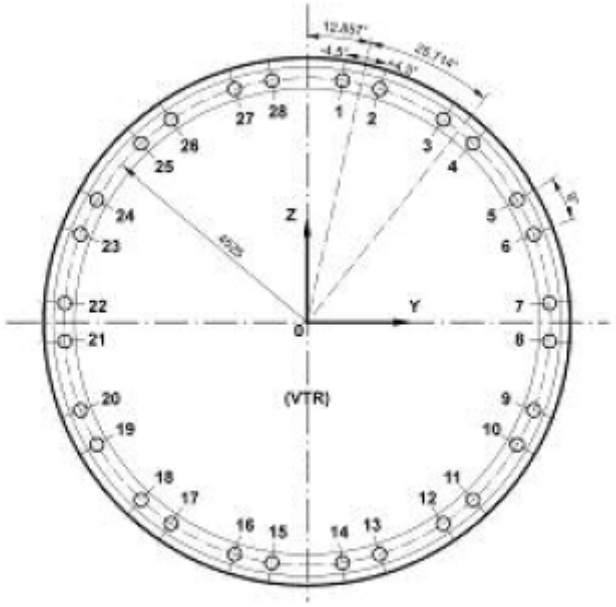


Tangential Moments Influenced by Volume Loss

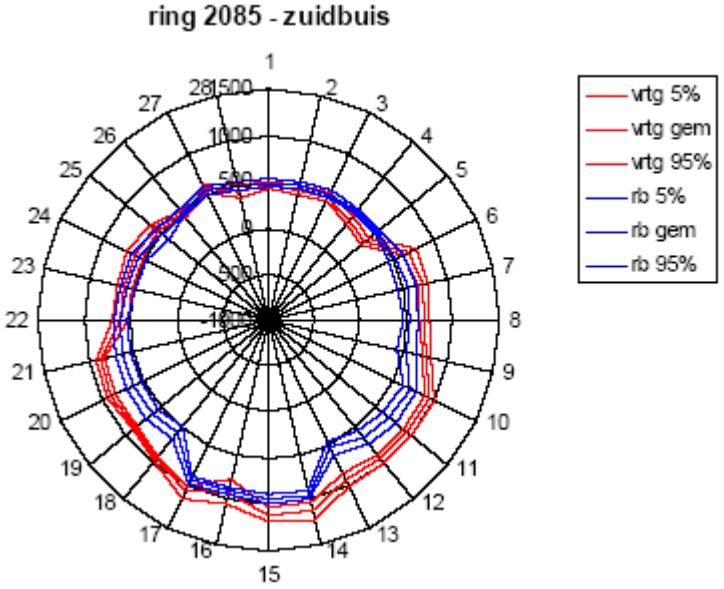


- Maximum bending moment occurs between 0.5 % and 1 % volume loss

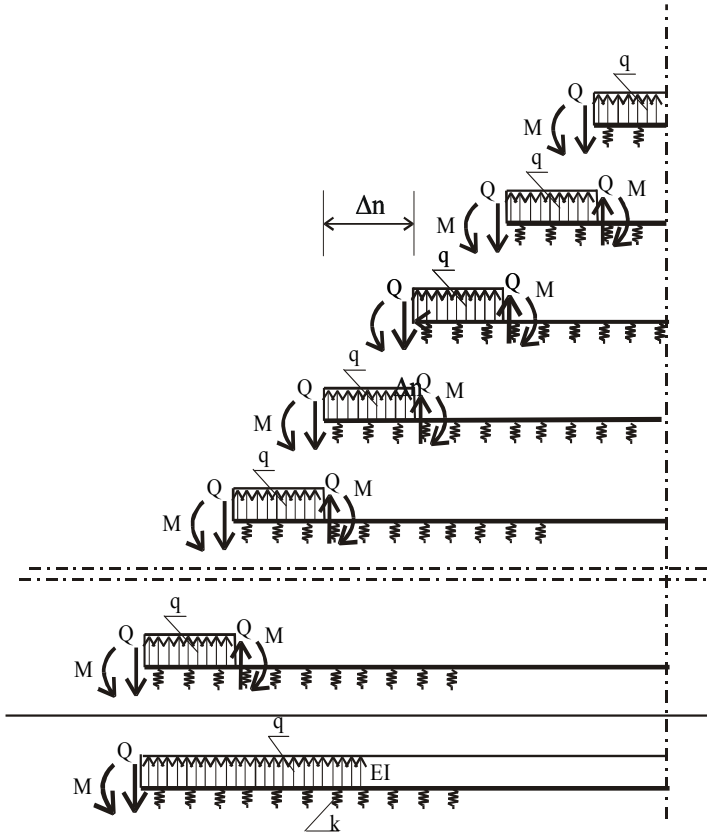
Jack Forces



Figuur 1: De afzetcilinders van de Sophia-TBM, gezien in voortgangsrichting (VTR: Vortriebsrichting)

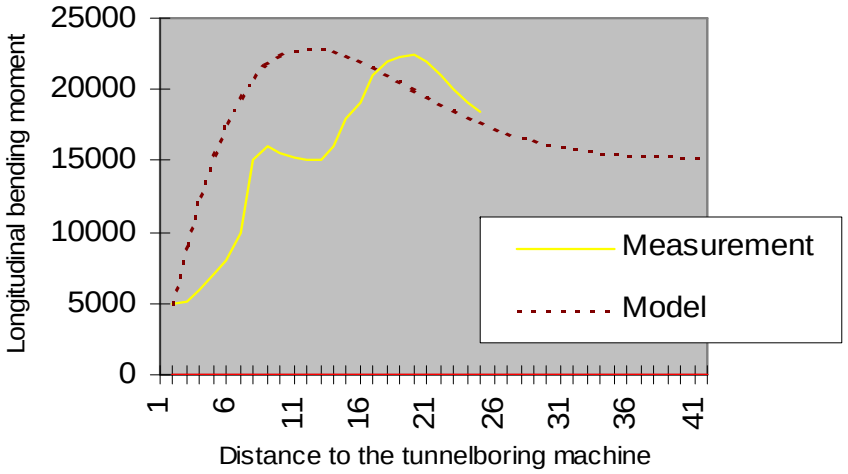


Longitudinal Bending Moments

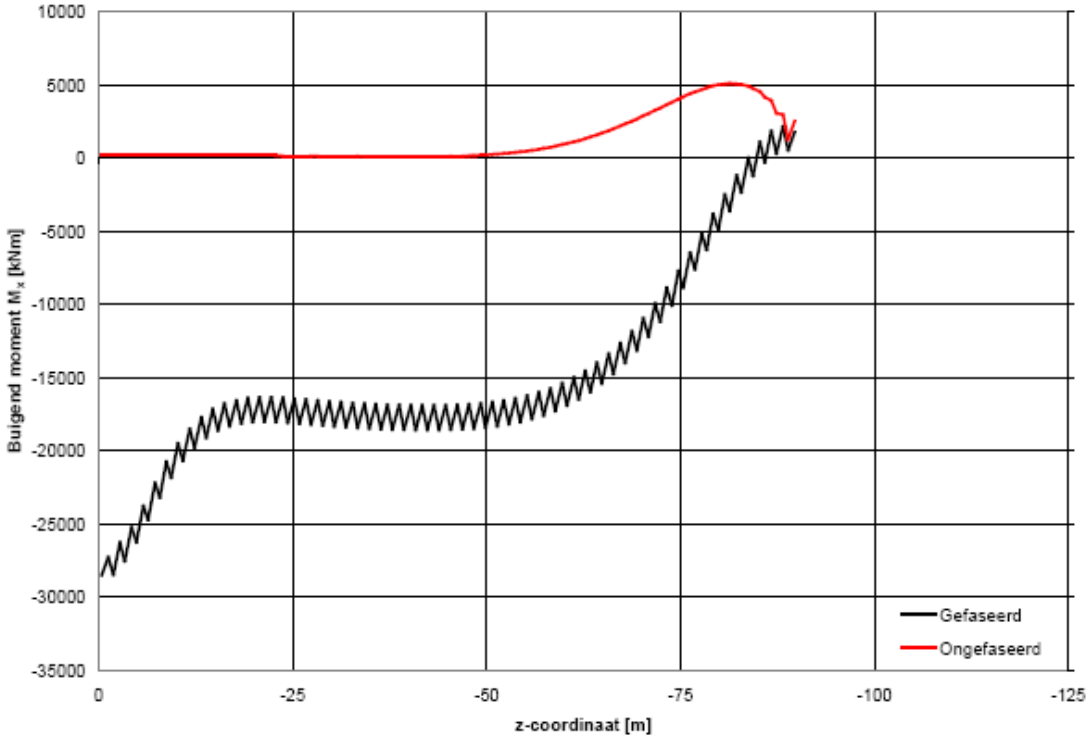


Analytical model

- Bending moments
- Weight TBM
- Bouyancy
- Soil support

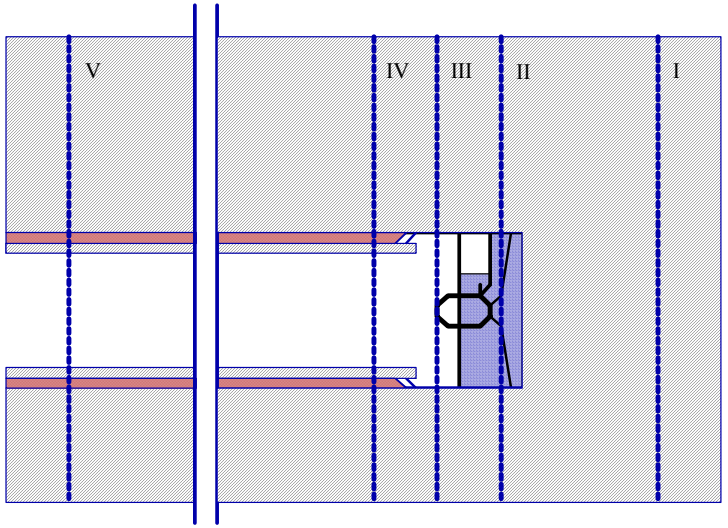


Longitudinal Bending Moments



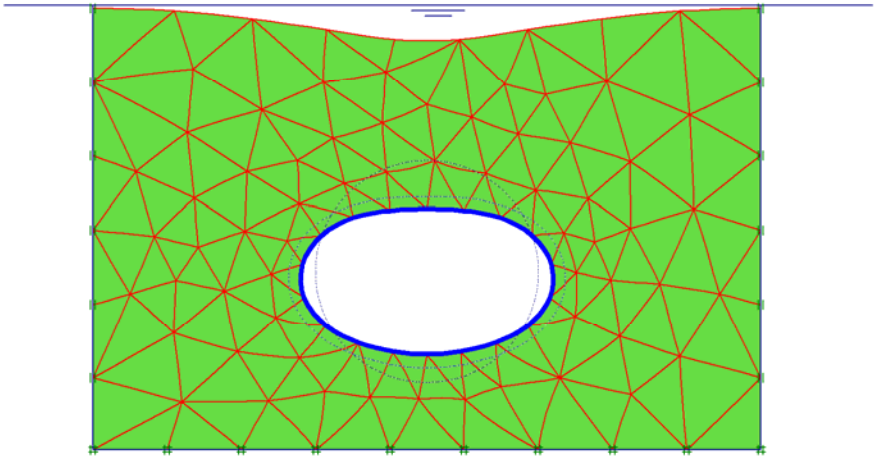
Tunnel Construction

1. Initial conditions
2. Excavation
   - Remove soil/water
   - Install TBM, conicity
   - Tail void
3. Lining installation
4. Grouting
5. Consolidation/creep



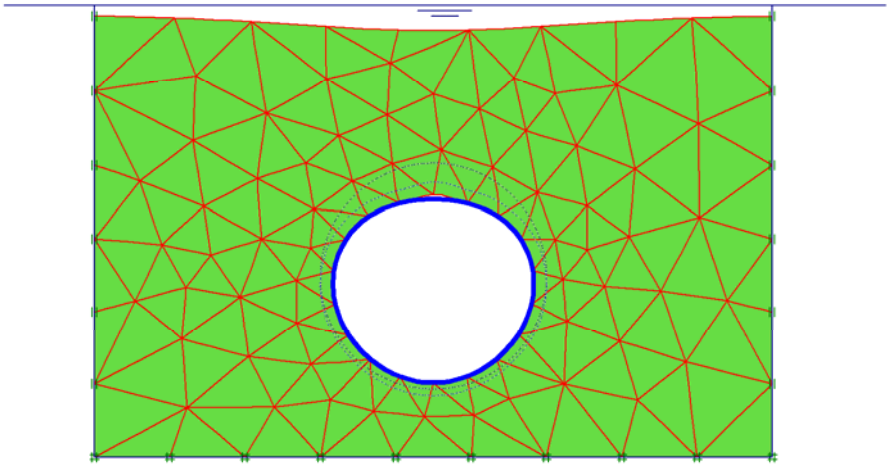
Tunnel Construction

- Activate shield
- Remove soil and water



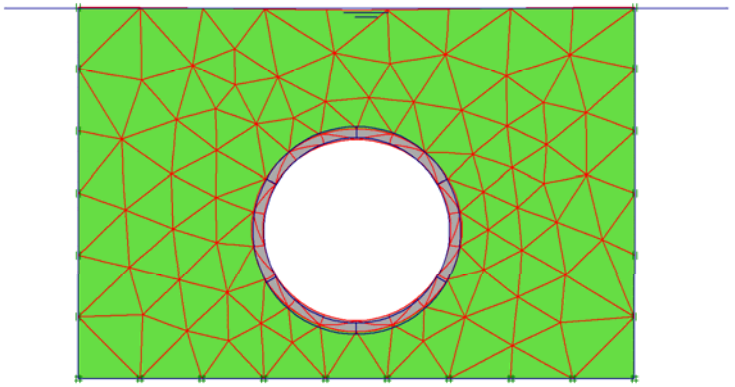
Contraction

- Simulate (combined) effects of volume loss in a staged construction phase

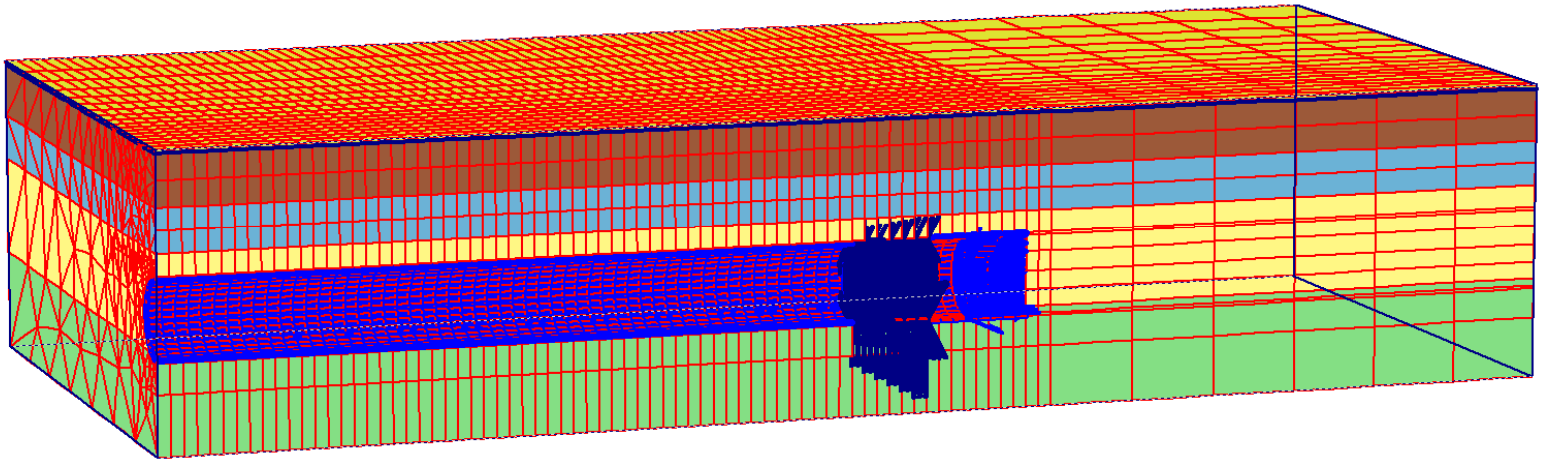


Grout Pressure Modelling

- Simulate conicity and tail void by contraction
- Simulate grouting process (user defined pore pressure)
- Install lining

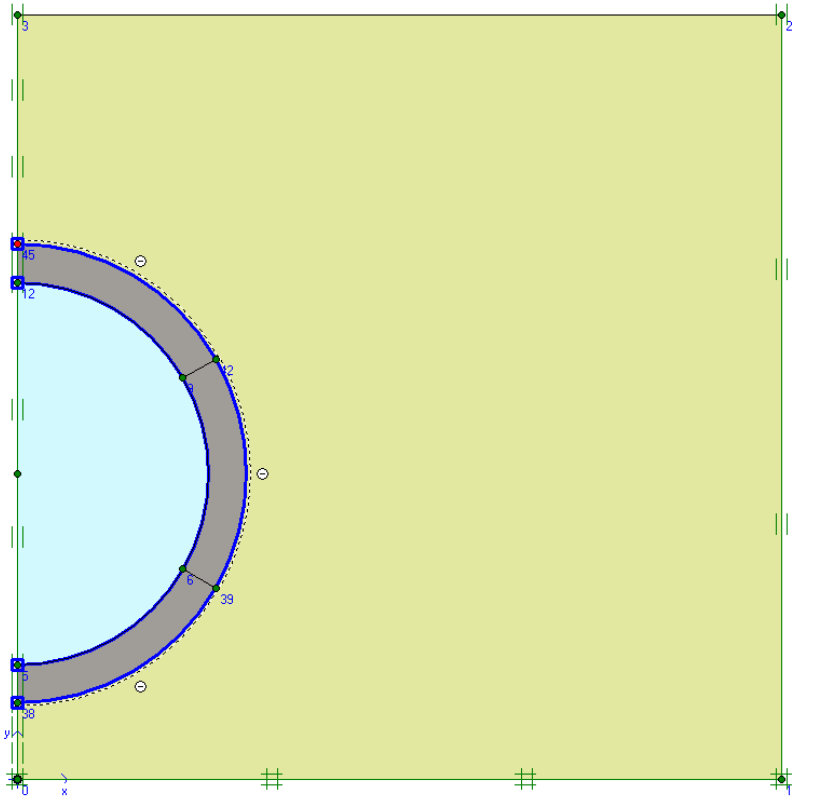


3DT modelling options



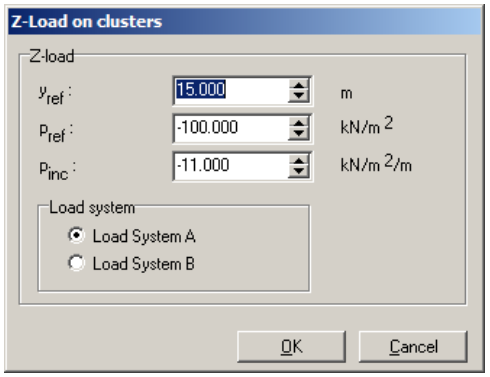
Construction Phases

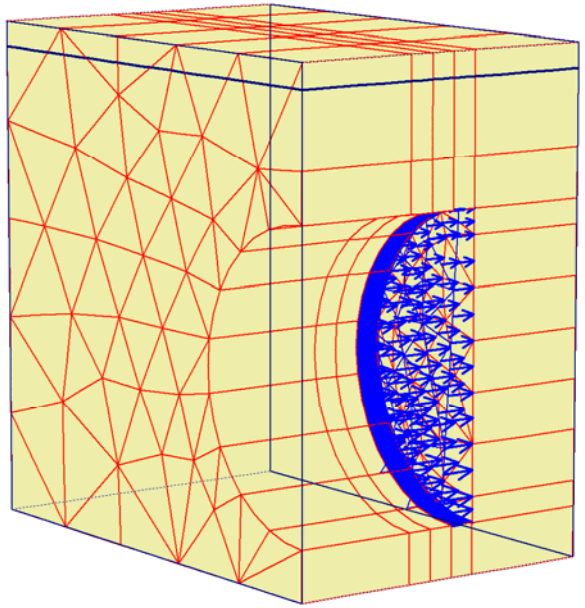
- Geometry
  - TBM
  - Grout body
  - Final lining



Construction Phases

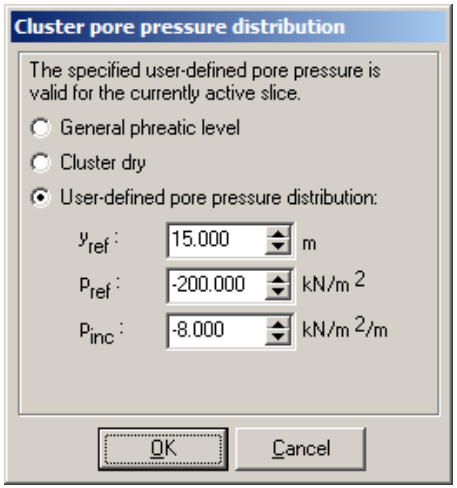
- Face support
  - Z-load in plane

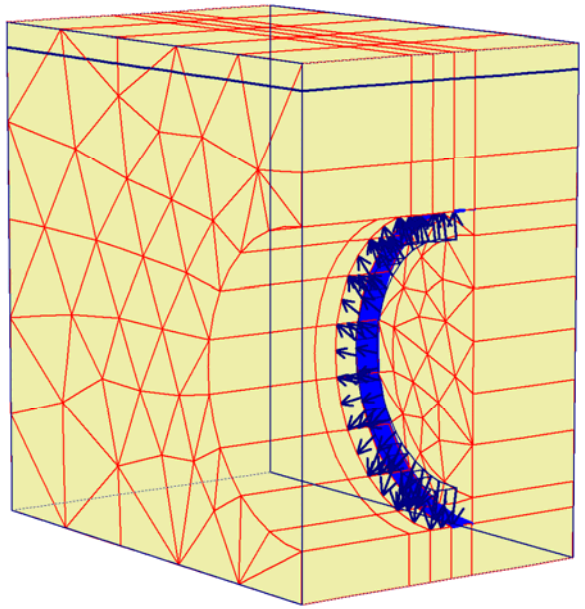




Construction Phases

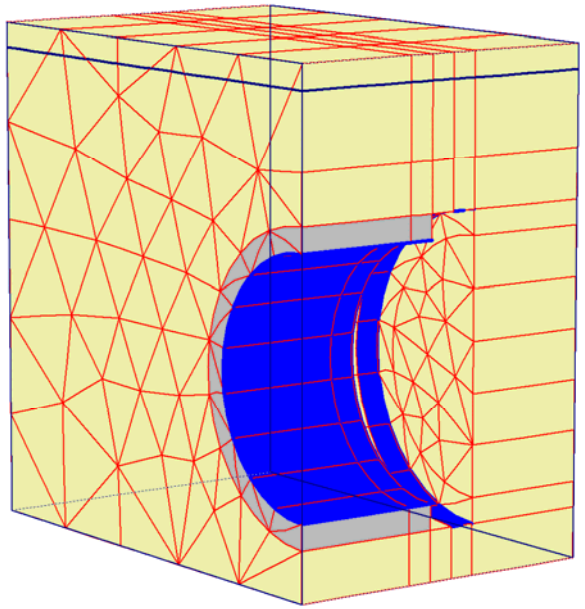
- Liquid Grout zone
  - User-defined pore pressure in cluster



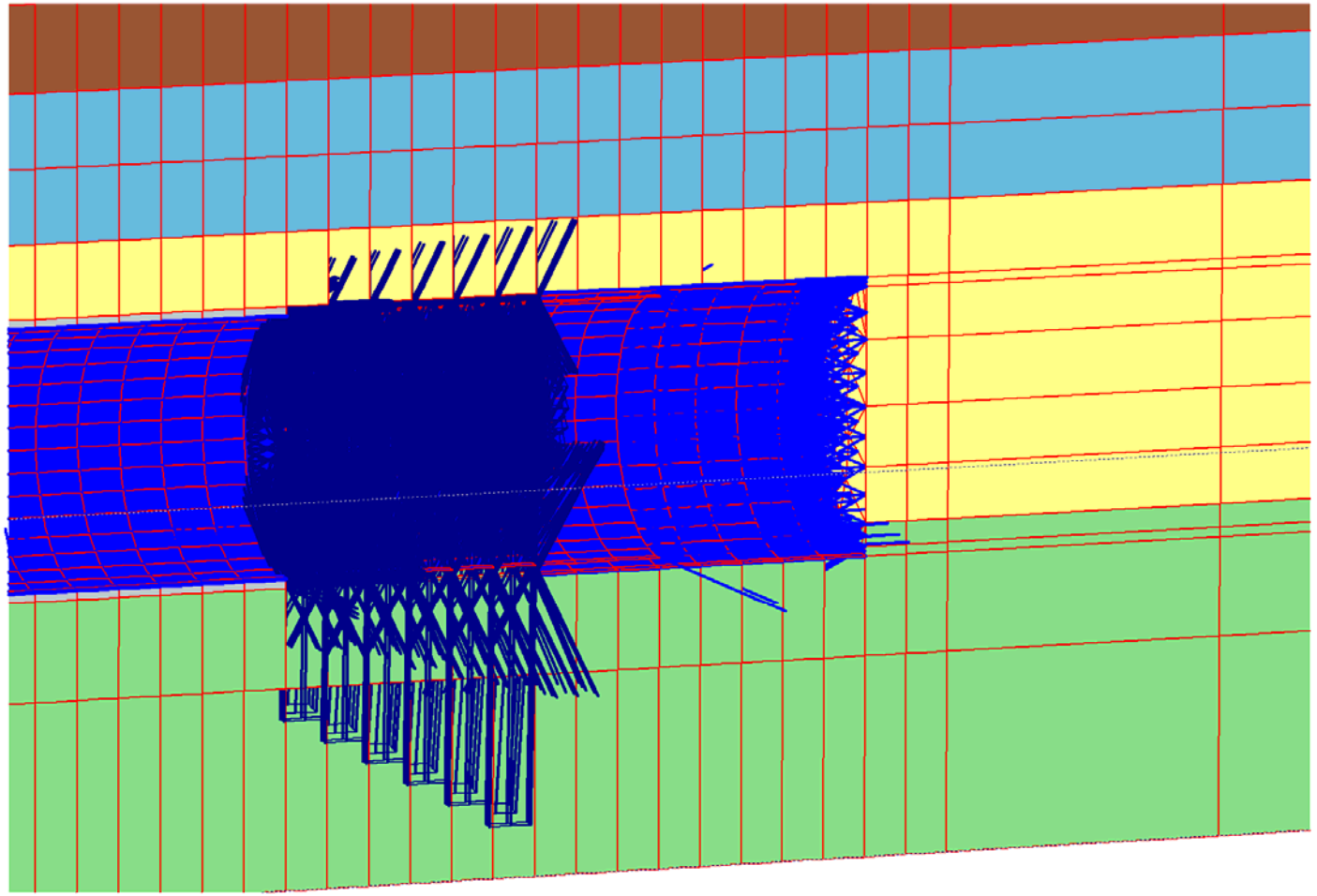


Construction Phases

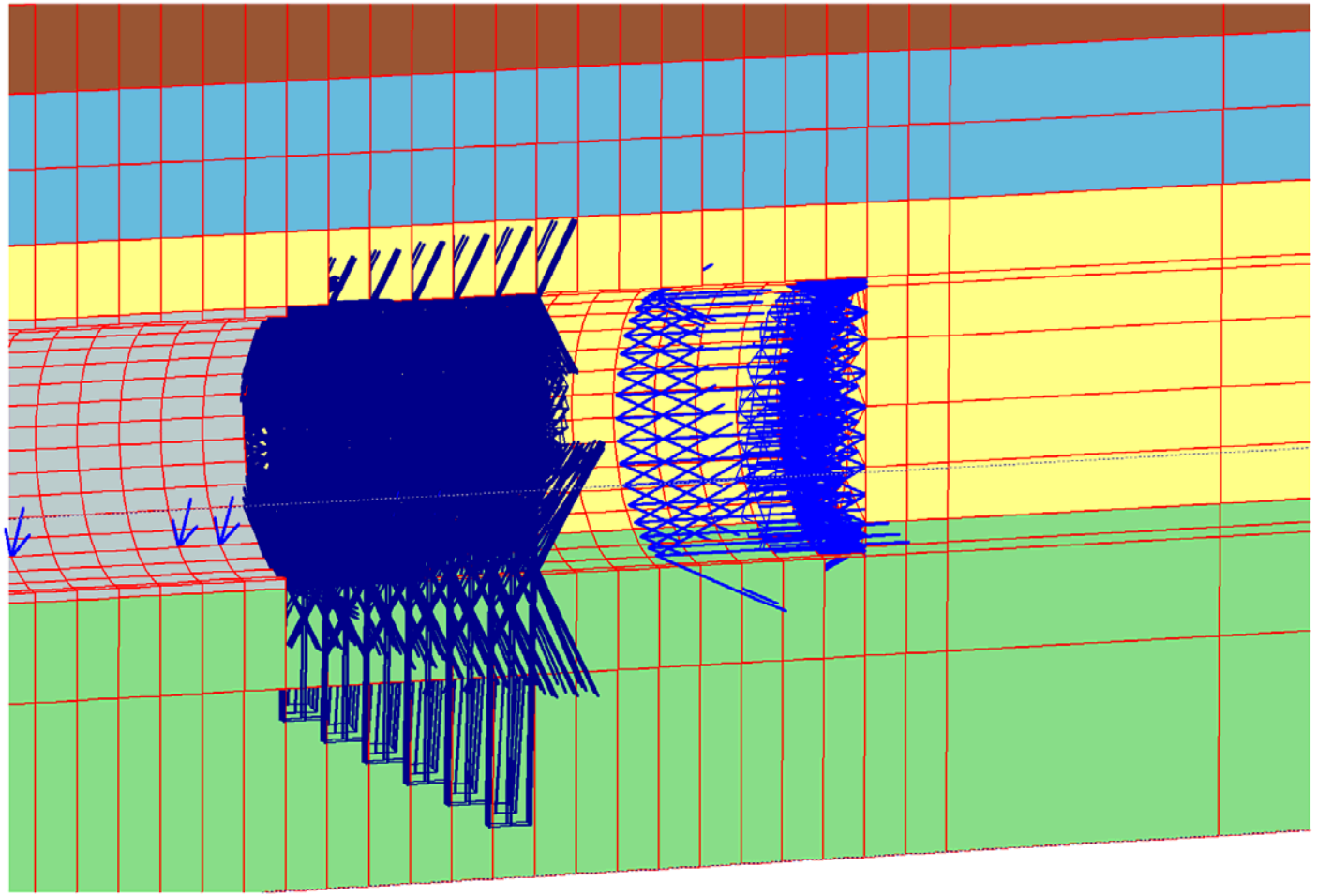
- Hardened Grout zone
  - Soil material with low stiffness
  - Final lining
  - Jack forces



Close up



Close up



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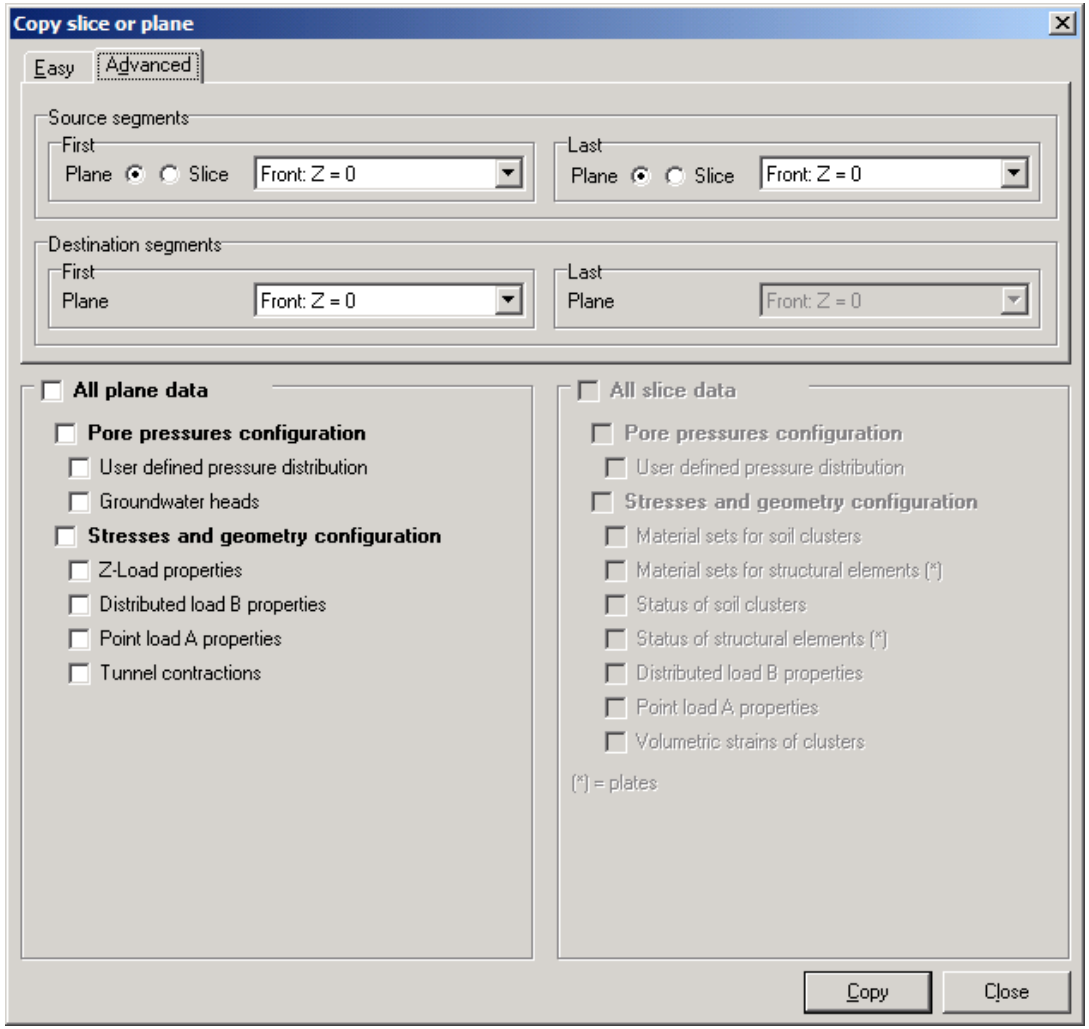
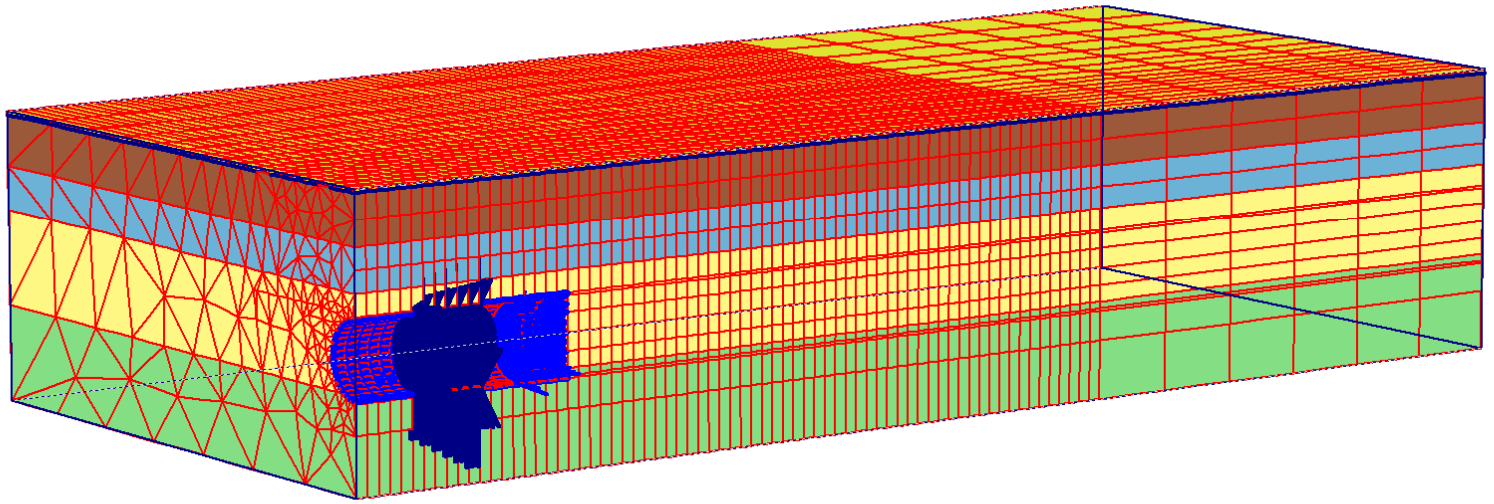
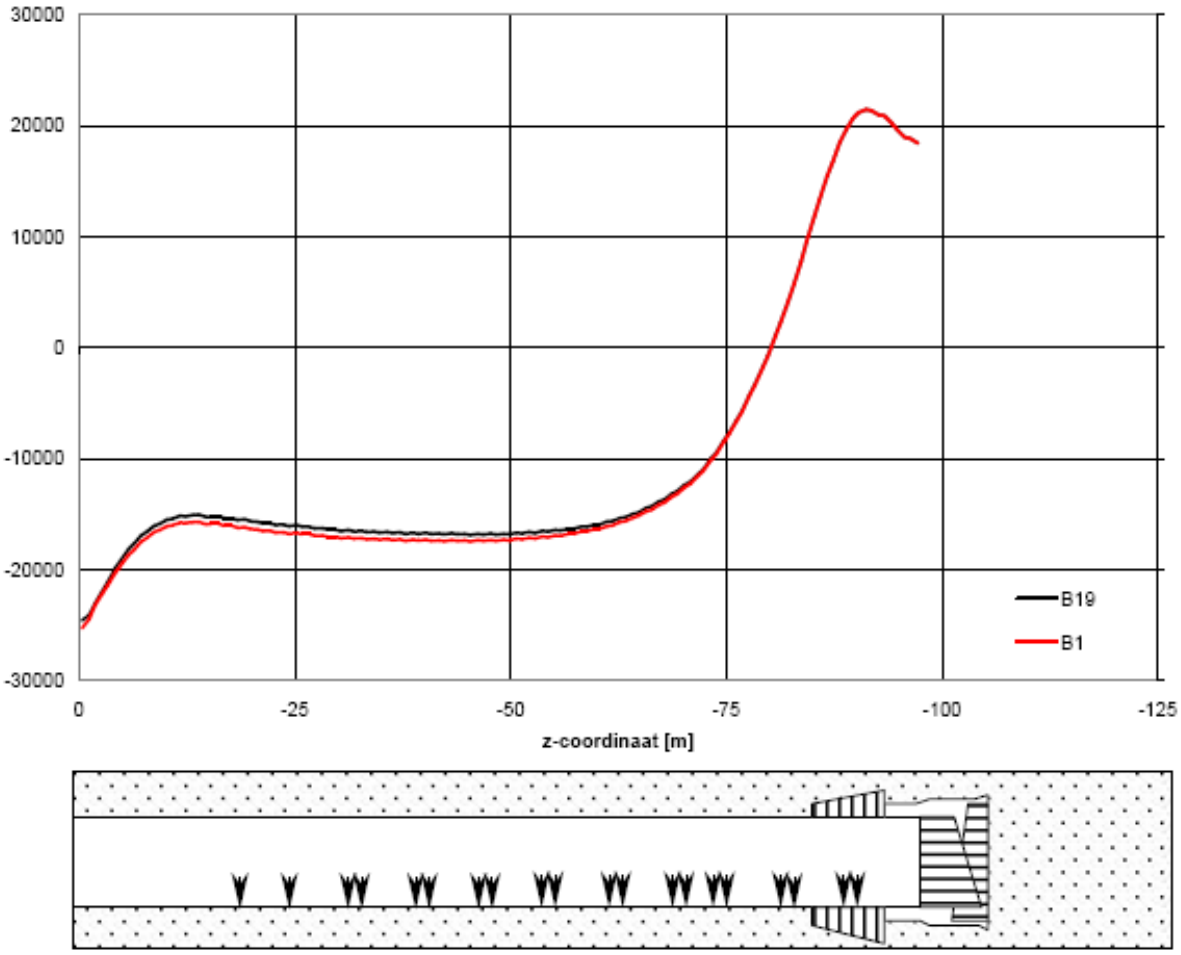

Copy slice or plane
Easy
Advanced
Source segments
First
Plane
Slice
Front: Z = 0
Last
Plane
Slice
Front: Z = 0
Destination segments
First
Plane
Front: Z = 0
Last
Plane
Front: Z = 0
All plane data
Pore pressures configuration
User defined pressure distribution
Groundwater heads
Stresses and geometry configuration
Z-Load properties
Distributed load B properties
Point load A properties
Tunnel contractions
All slice data
Pore pressures configuration
User defined pressure distribution
Stresses and geometry configuration
Material sets for soil clusters
Material sets for structural elements (*)
Status of soil clusters
Status of structural elements (*)
Distributed load B properties
Point load A properties
Volumetric strains of clusters
(*) = plates
Copy
Close

Step-wise excavation



Longitudinal Bending Moments

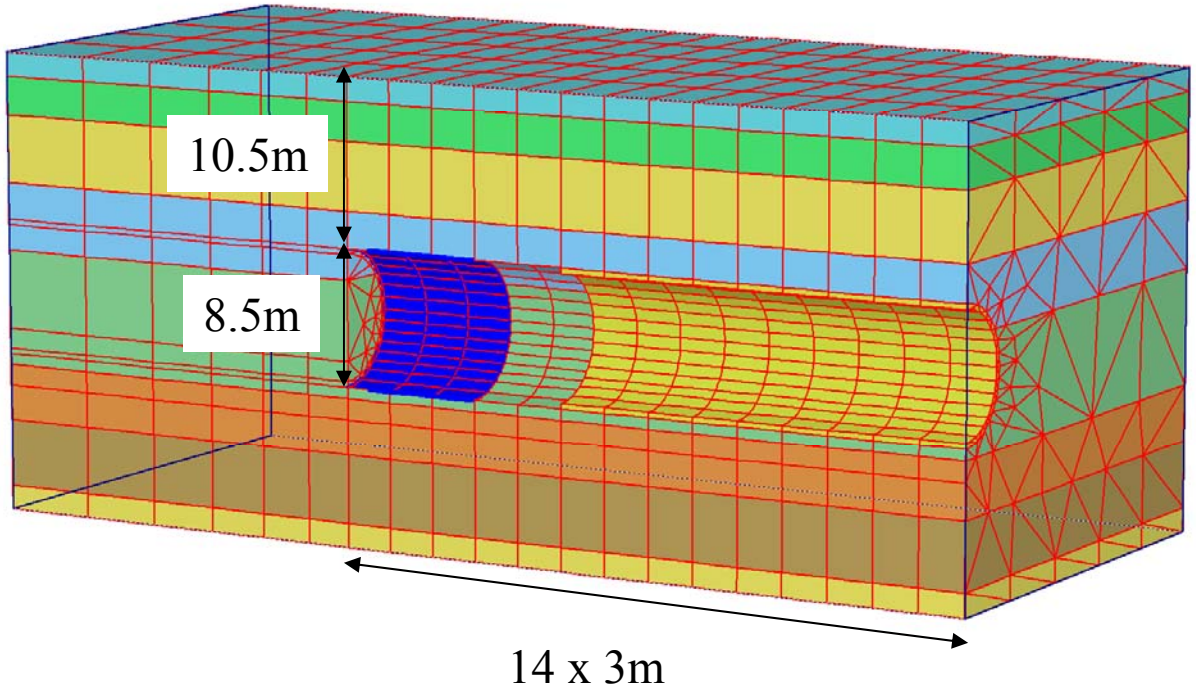


Example

- Second Heinenoord Tunnel (shield Tunnel)

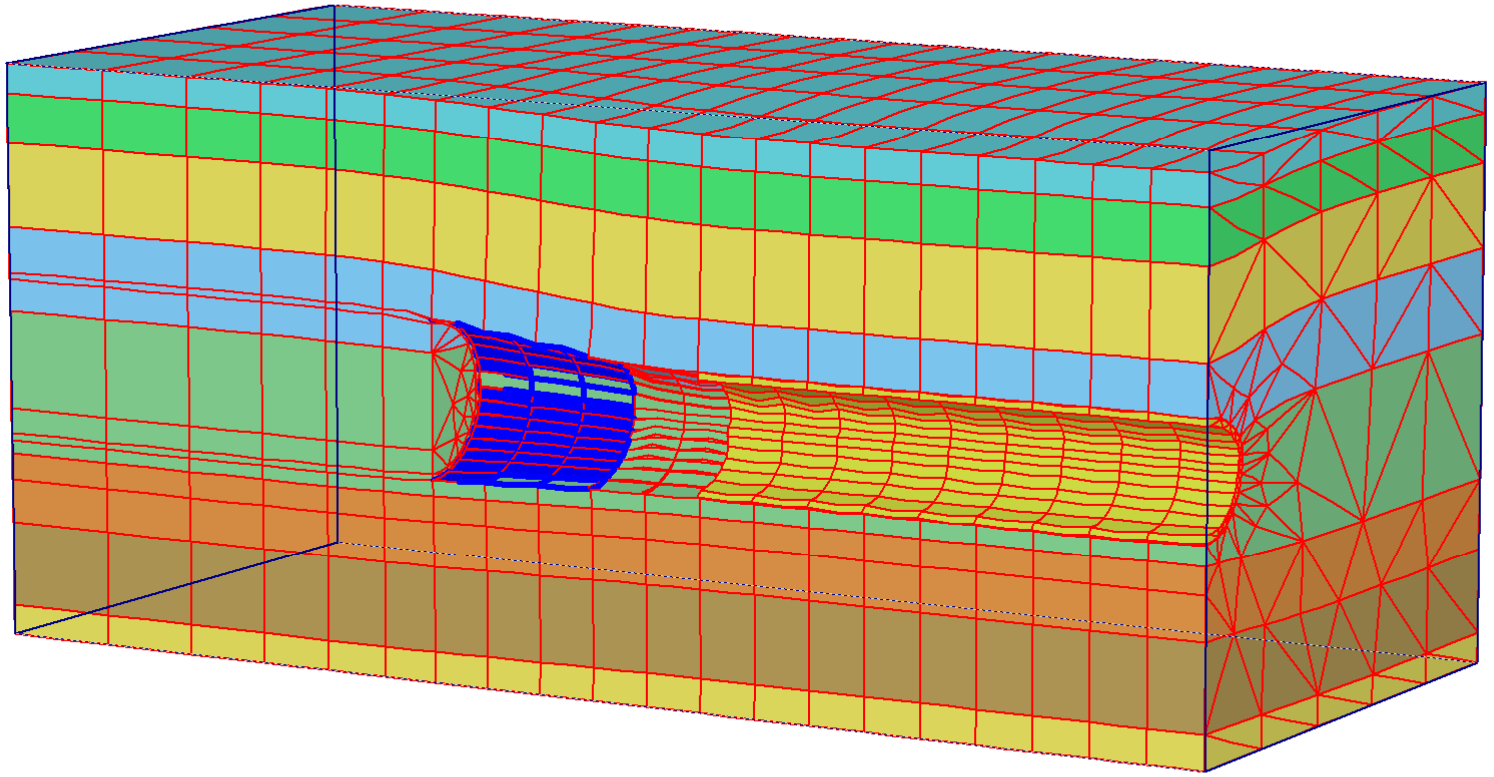
ID	Type	g_unsat	g_sat	nu	E_ref	c'	phi	psi	K0
		[kN/m3]	[kN/m3]	[-]	[kN/m2]	[kN/m2]	[°]	[°]	[-]
0B	Drained	16.5	17.2	0.34	3900	3.0	27.0	0.0	0.58
0A	Undrained	16.5	17.2	0.34	3900	3.0	27.0	0.0	0.58
3	Drained	19.5	19.5	0.30	19300	0.0	35.0	5.0	0.47
2	Drained	19.0	19.0	0.31	18500	0.0	33.0	3.0	0.47
18	Drained	20.5	20.5	0.30	29600	0.0	36.5	6.5	0.45
32 stiff	Drained	20.5	20.5	0.30	444000	0.0	36.5	6.5	0.50
38 stiff	Undrained	20.0	20.0	0.32	119000	7.0	31.0	1.0	0.55
38F stiff	Drained	21.0	21.0	0.30	593000	0.0	37.5	7.5	0.56

Example

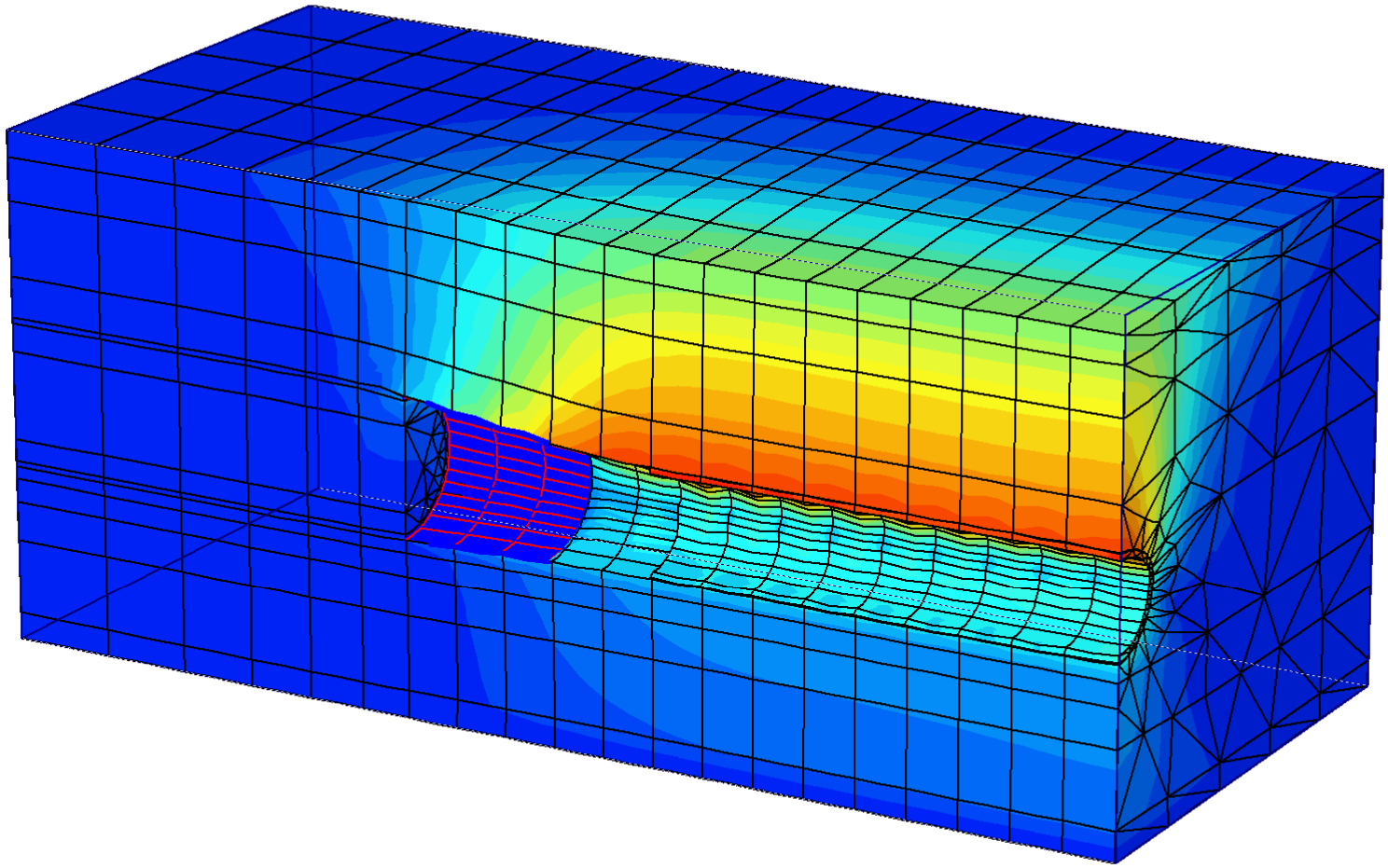


Example

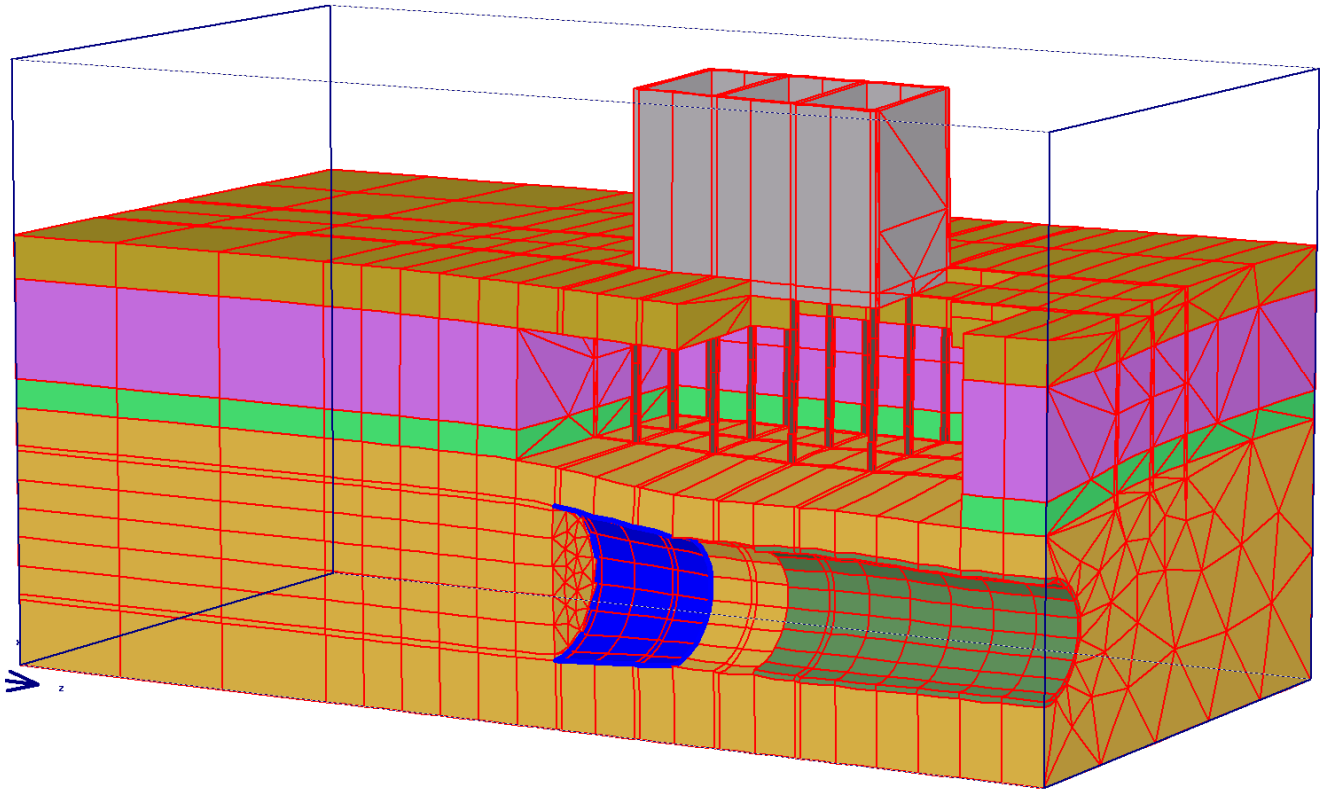
- Phases:
  - TBM advances one slice (3m) in every phase
  - TBM front: face pressure
  - TBM tail: Contraction 0.5%
  - Between TBM and lining: Groutpressure, jack forces
  - Application of lining



Deformed mesh

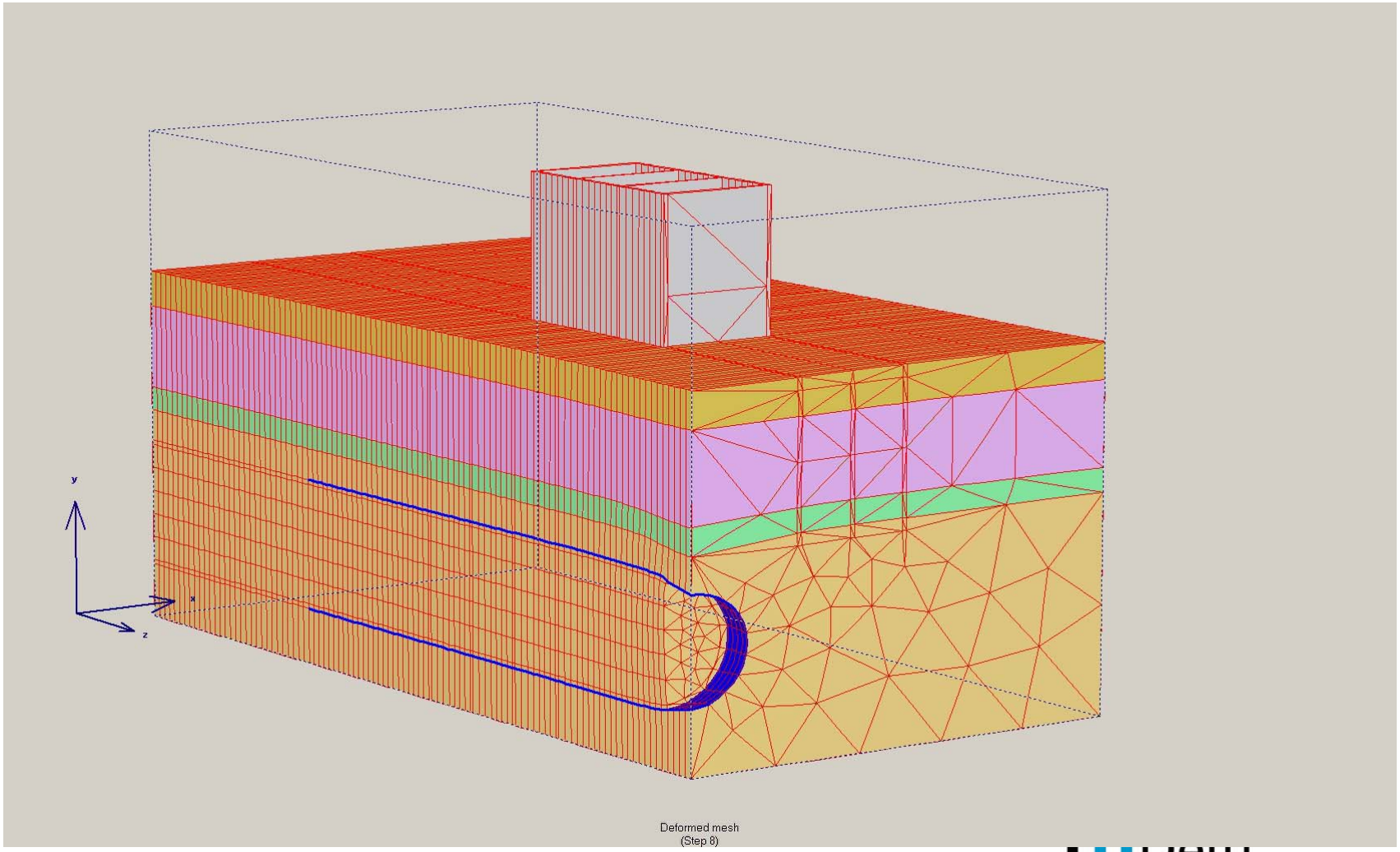


Influence on pile foundation

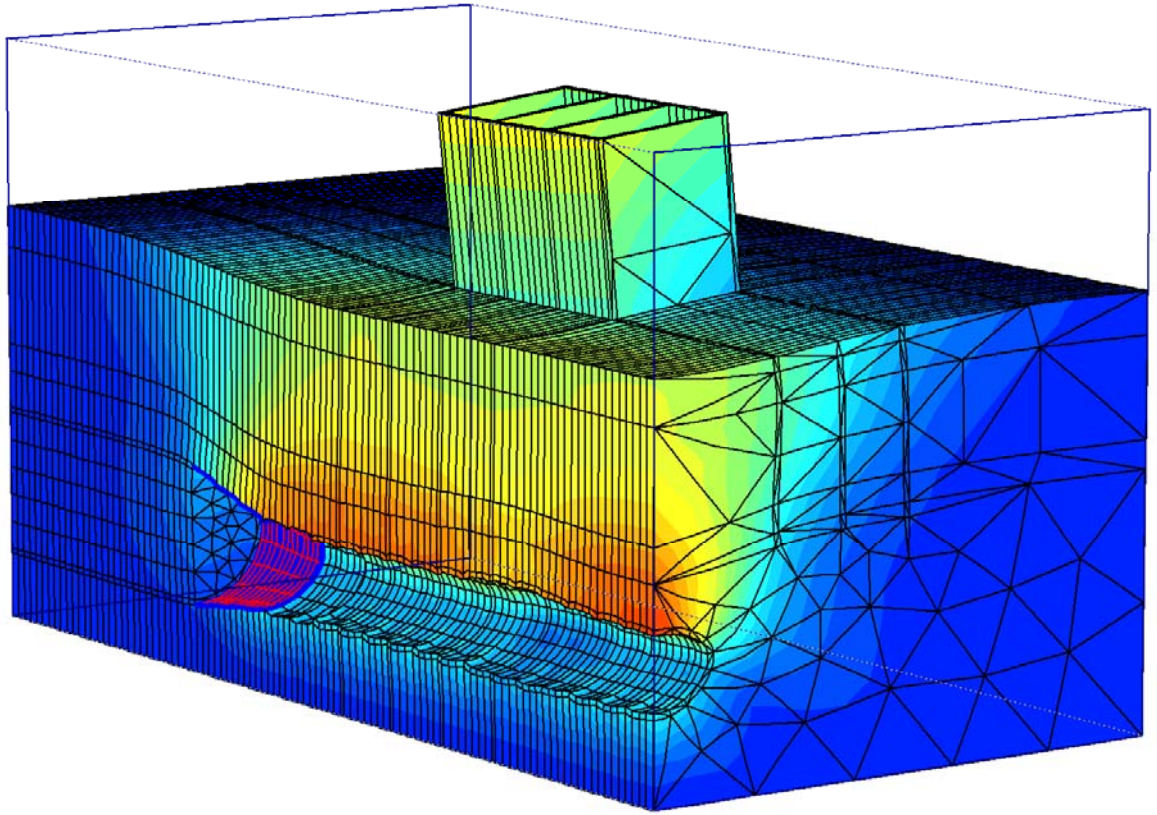


22644 elements
61879 nodes
13 hours on PC

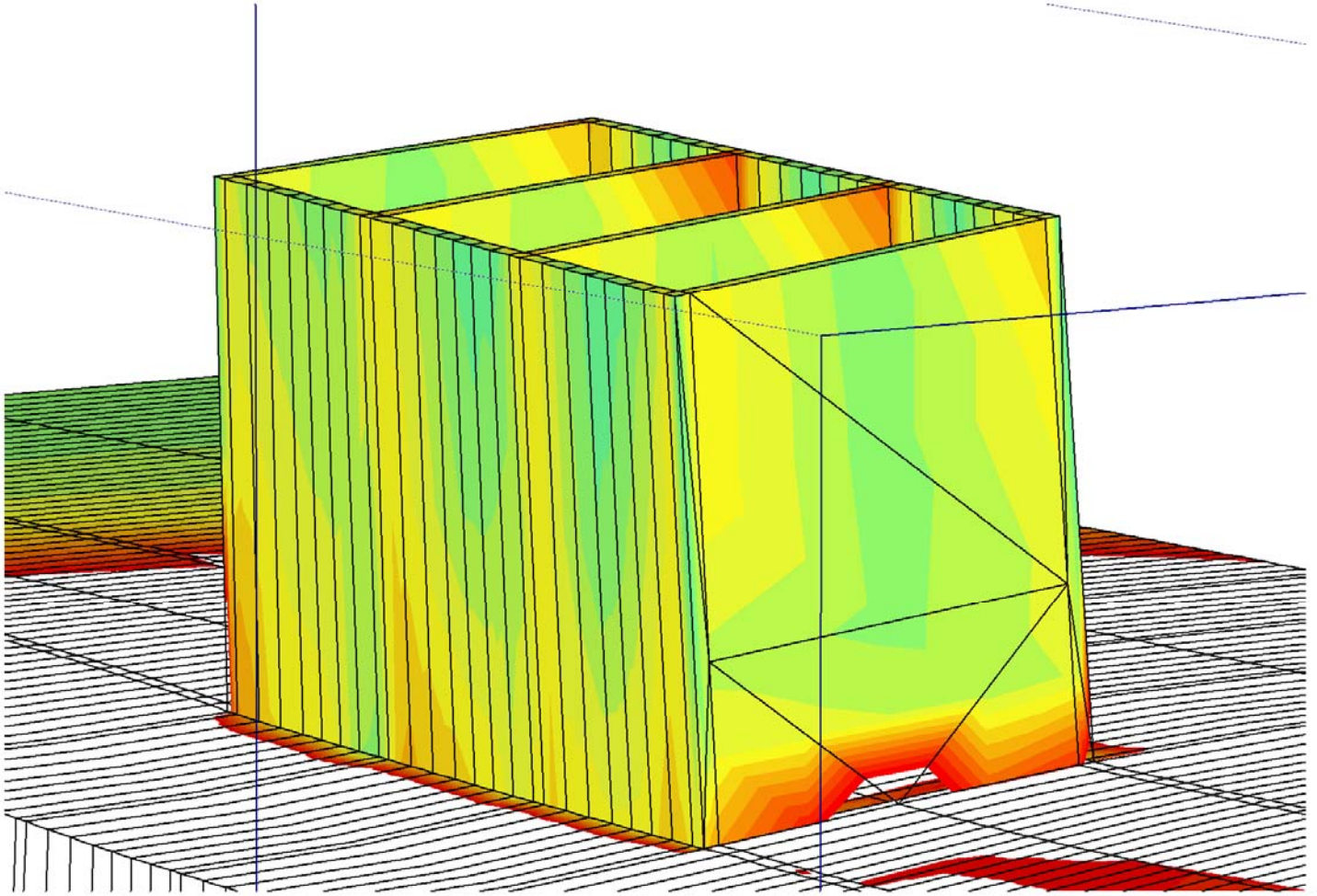
Phased simulation



Shaded deformations



Shear strains



Conclusions

- 3D calculations are time consuming, but become practically applicable.
- Perform 3D calculations only if really necessary
- Take care of the following aspects:
  - Choice of soil models and parameters
  - Mesh fineness (coarseness)
  - Calculation phases (construction stages)

β - Method

- Simulate spatial arching around tunnel
- NATM tunnelling

1. Generate initial conditions
2. Staged construction, using Σ-Mstage = 1-β
3. Activate lining, continue s.c. to Σ-Mstage = 1