SUPPLEMENTARY JET GROUTING AT METRO VIENNA LOT U1-10

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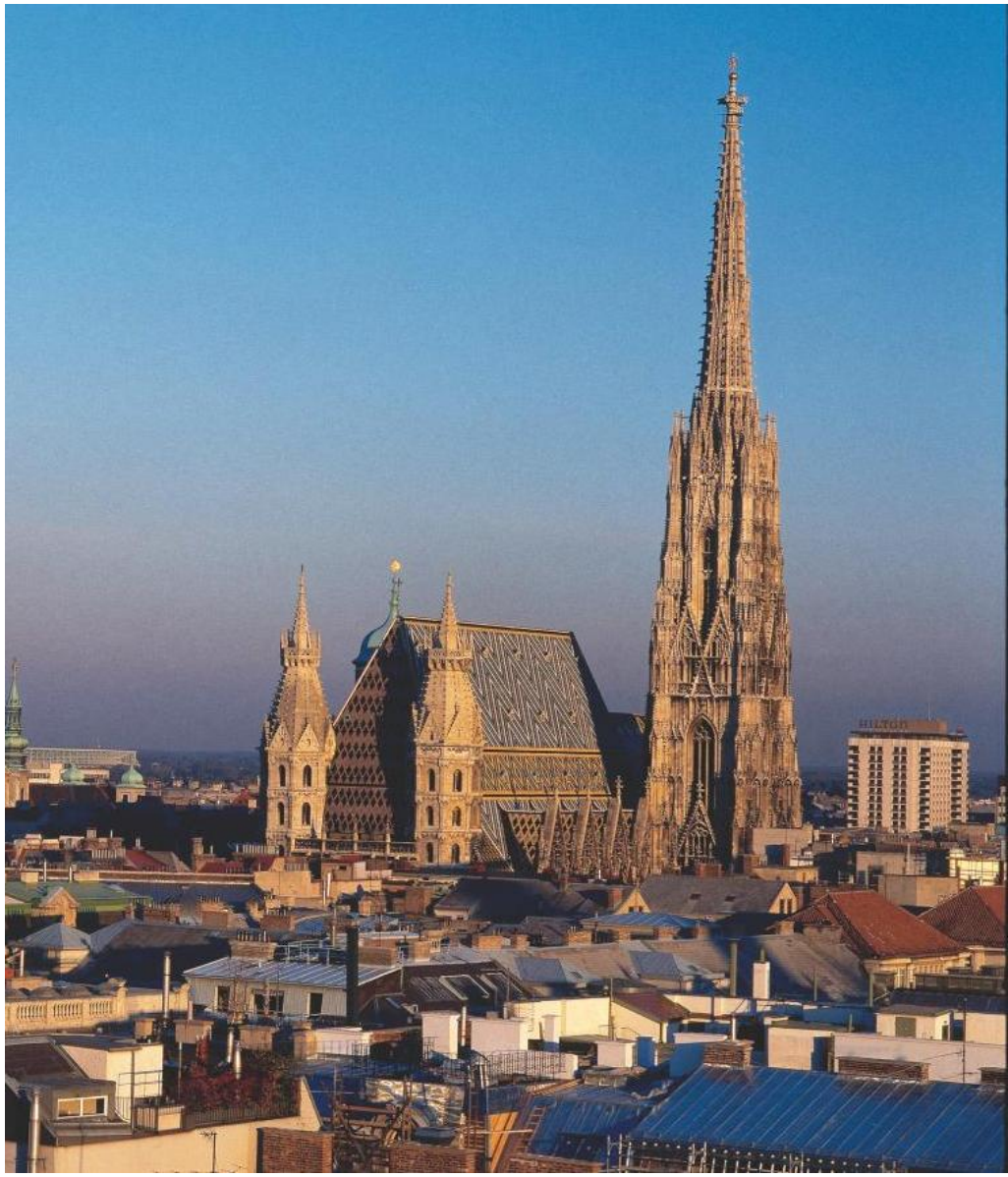
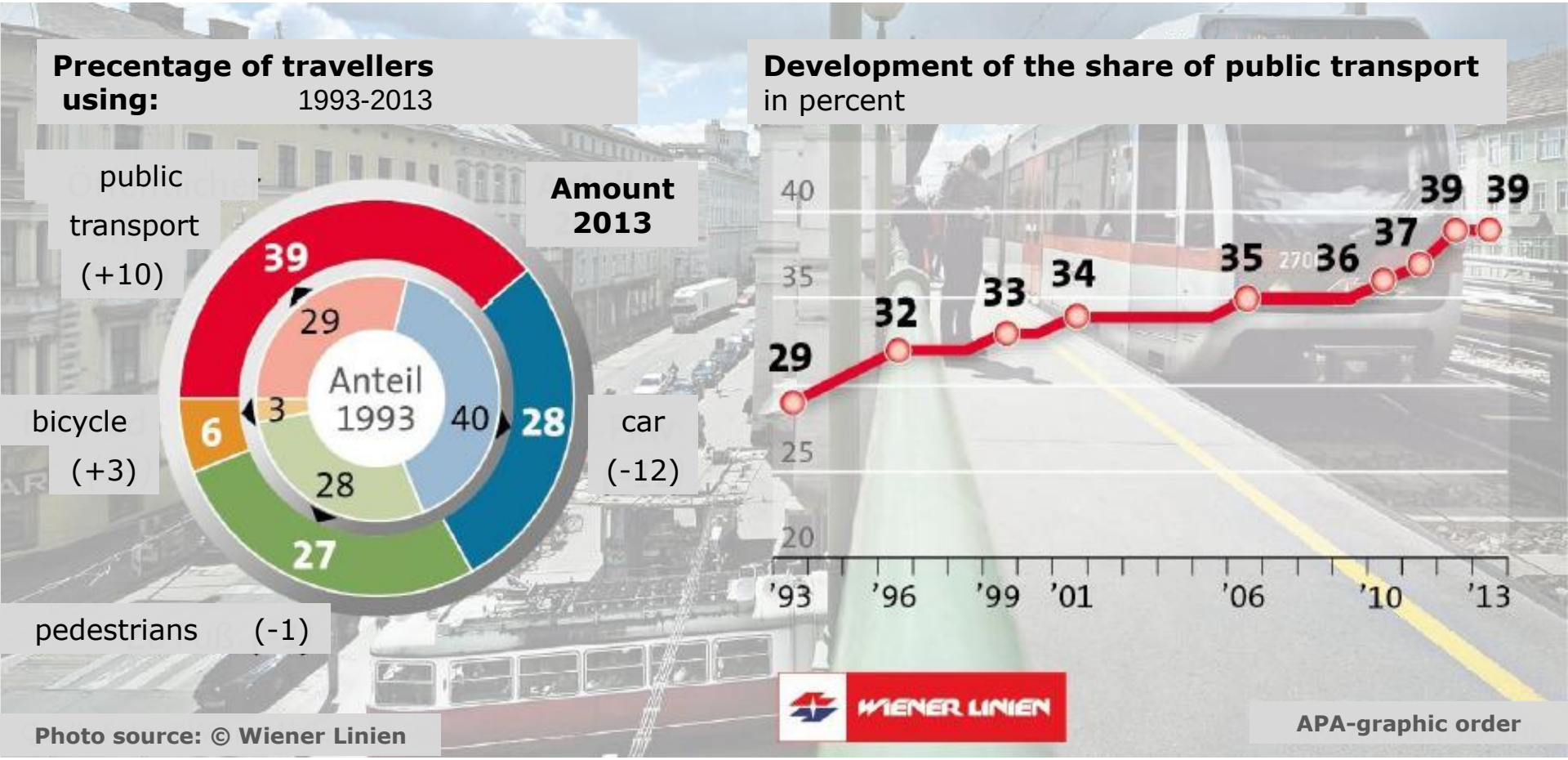
Vienna

- Currently 1.7 mio inhabitants
- 5 metro lines in operation
- various tramway and bus lines
- fastest growing city of Austria

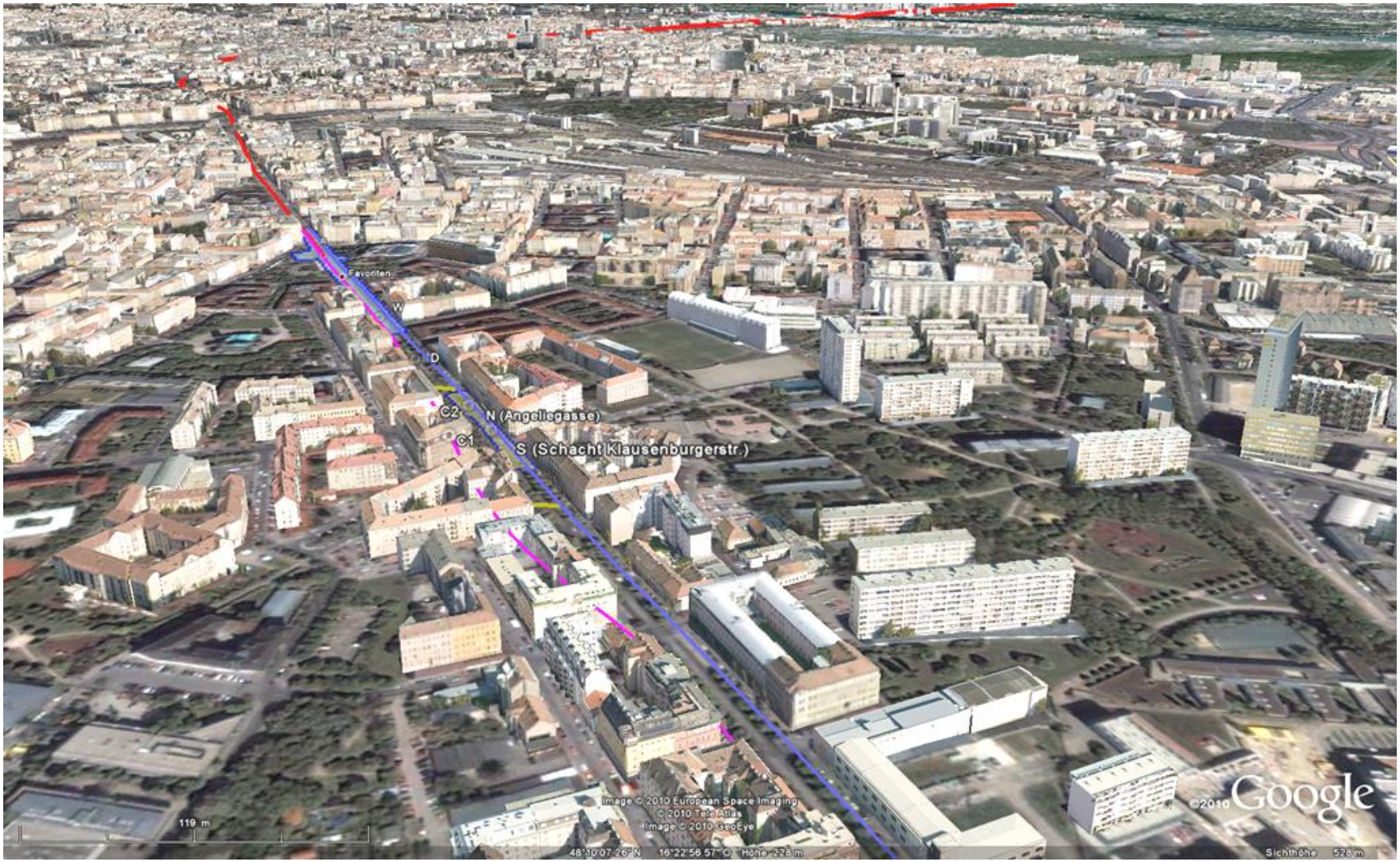


Modal Split – Wiener Linien

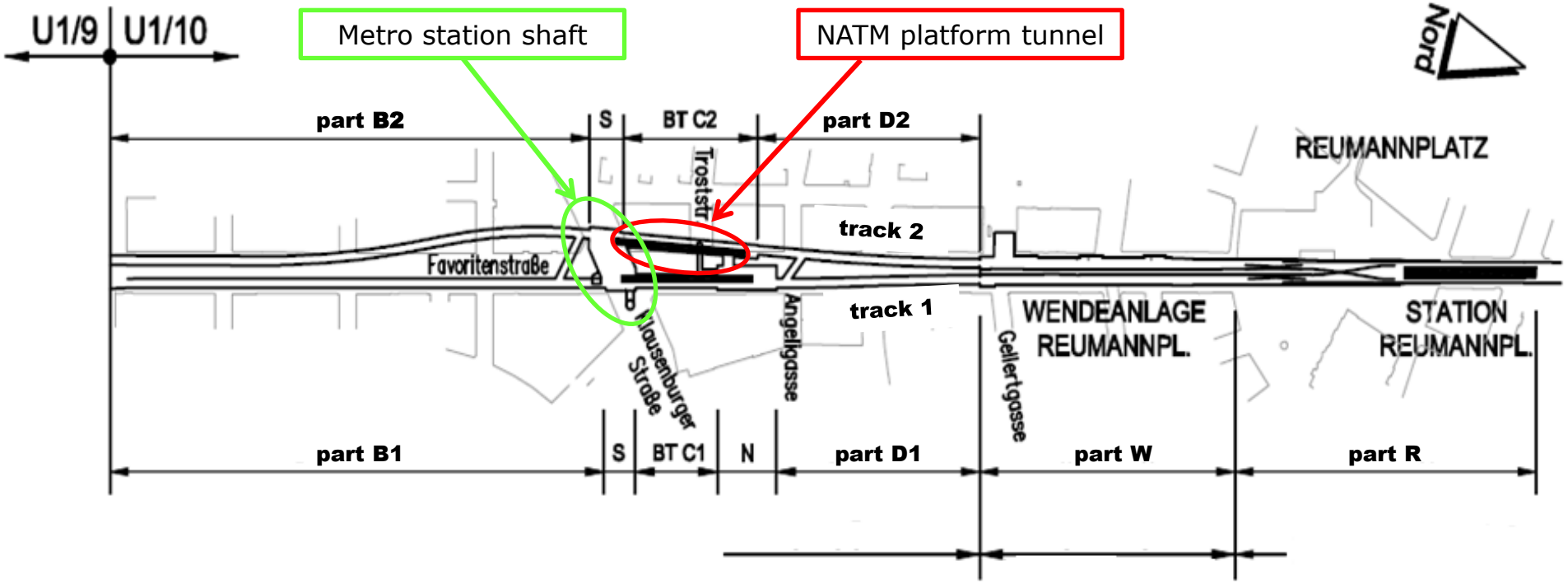


- 900 million passengers
- 600.000 sold annual season-tickets

Vienna Metro Line U1 South Extension
Construction Lot U1/10 Troststraße

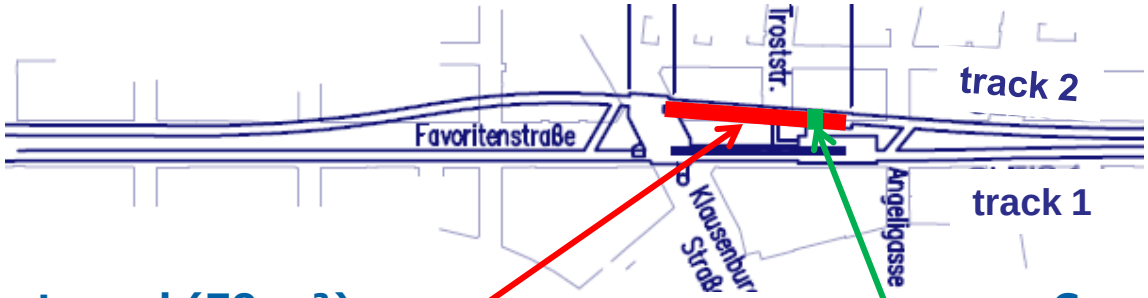


General lay out



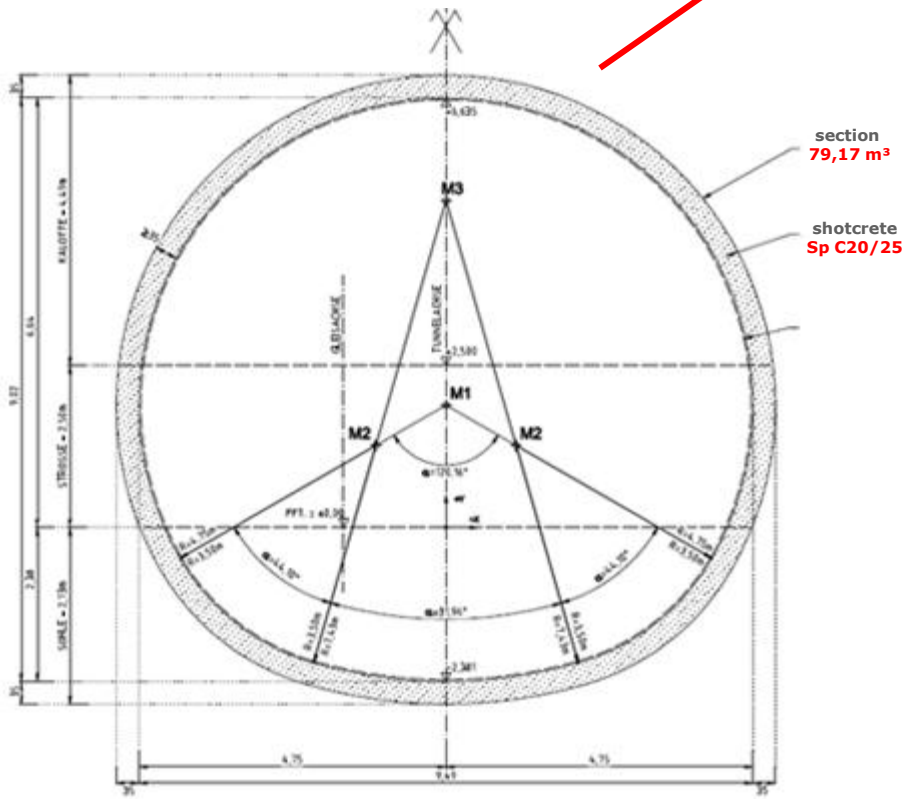
U1 south extension	Adaption exist. bifurcation	Adaption existing station

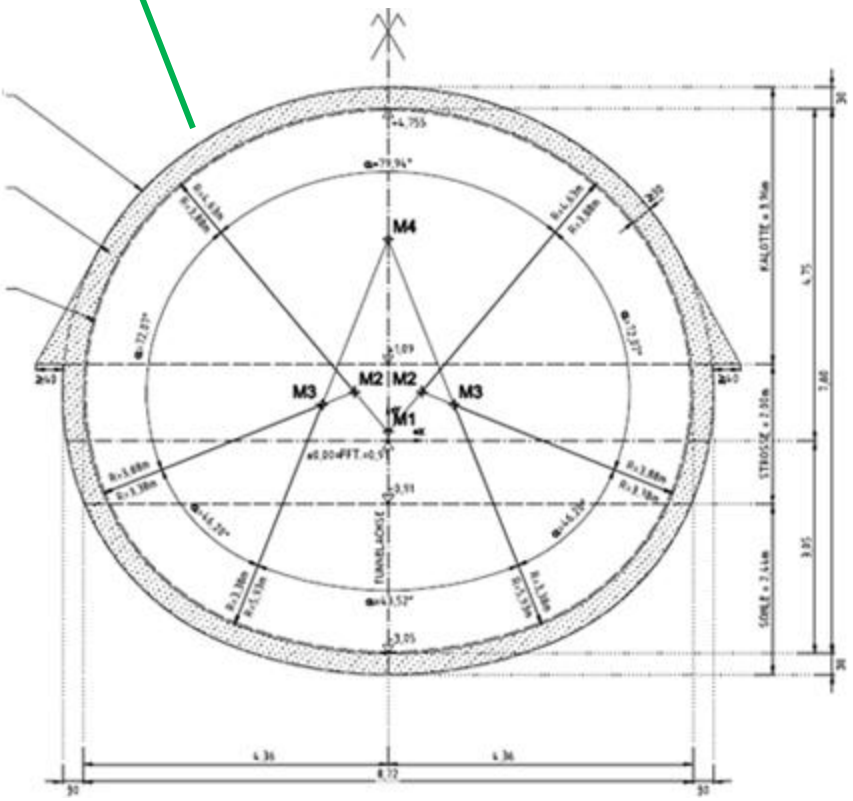
Cross sections



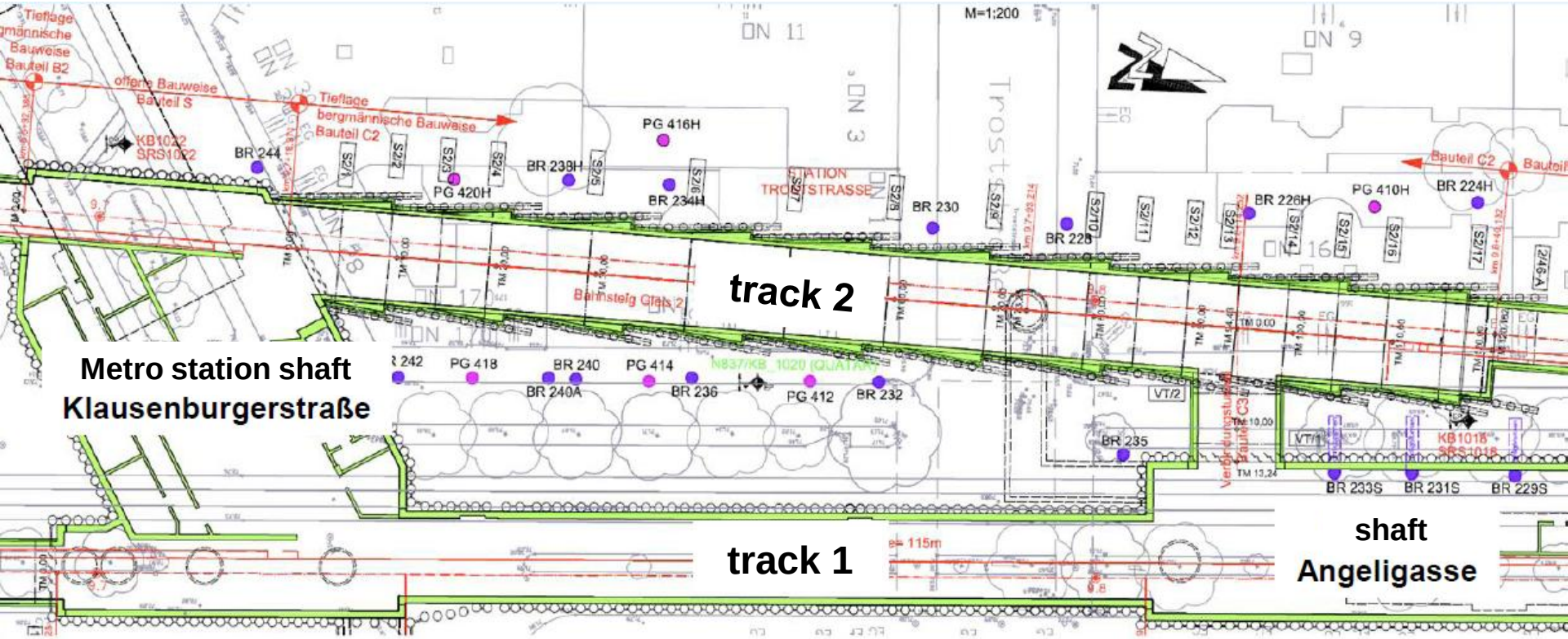
Platform tunnel (79 m²)

Cross passage



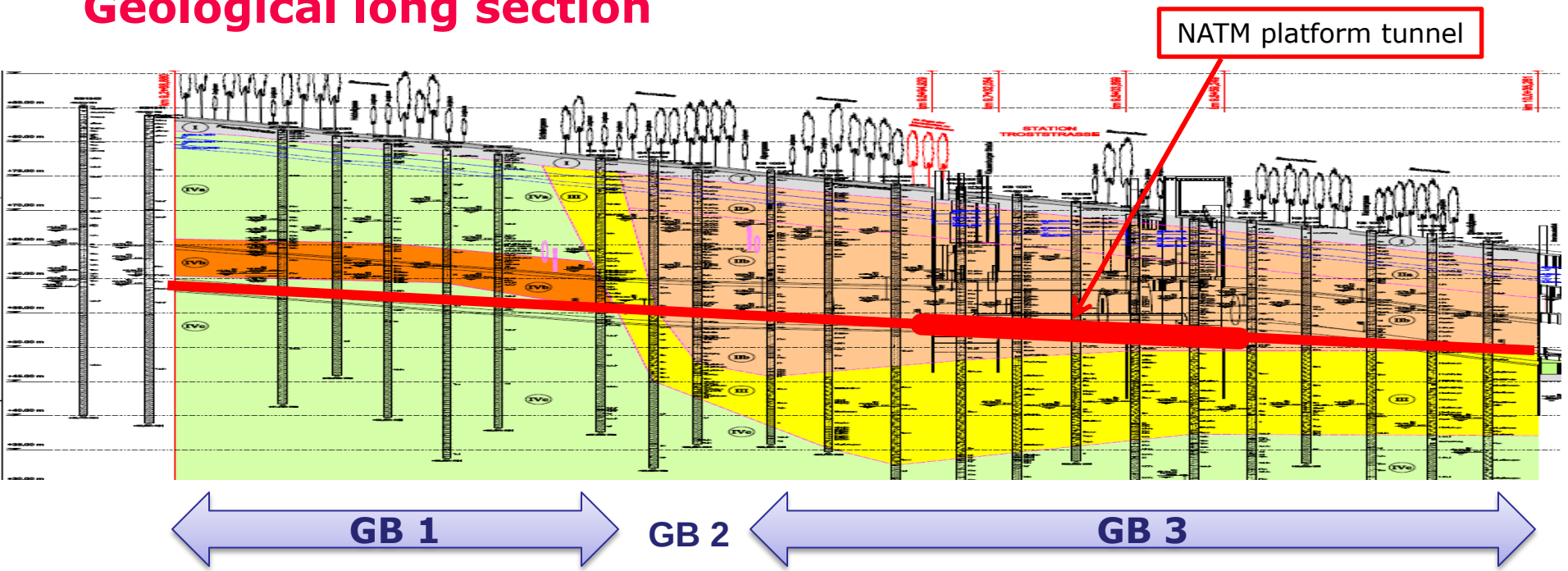


Station Troststraße



- station tunnel track 1: open cut & cover tunnel with bored piles
- station tunnel track 2: mined tunnel with jet grouting-umbrella

Geological long section



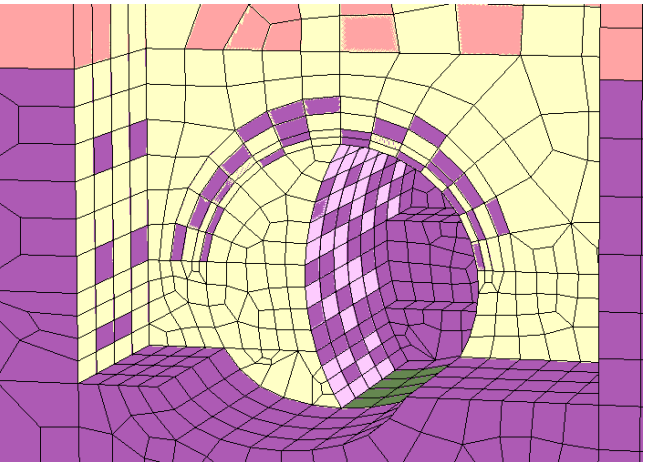
GB	Length ~[m]	Angle of friction	Cohesion	E-Modulus
1 *Silt*	242	23°	0,05 MPa	50 MPa
2 *Gravel*	30	35°	0 MPa	100 MPa
3 *Loess*	495	25°	0,02 MPa	25 MPa

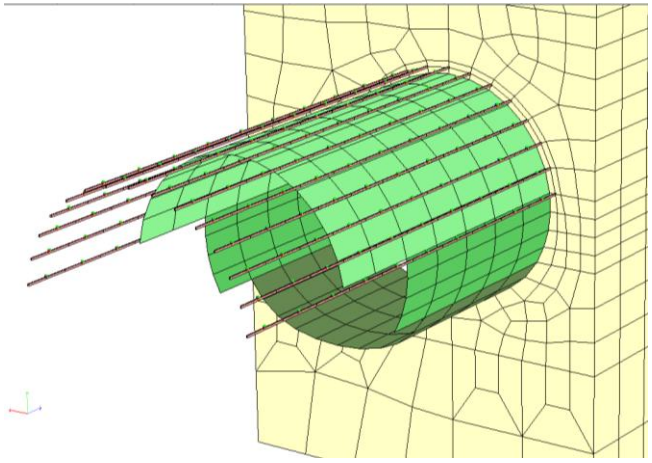
Alternating strata loess/loessic loam

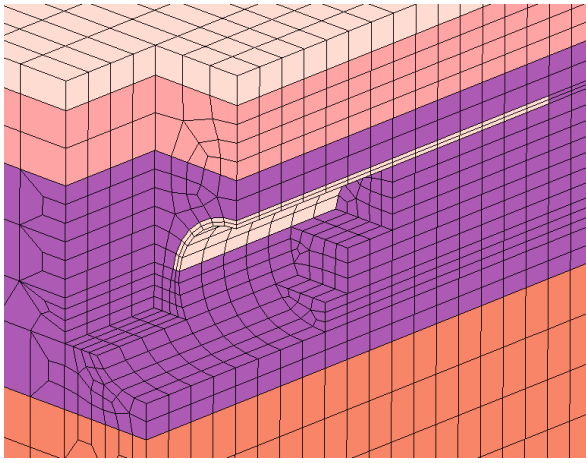
Geotechnical design of Troststraße metro station

- standard tunnel heading could not satisfy the settlement trough criteria (max. tangent slope 1:750)

- The following scenarios for the excavation of the mined station tunnel were simulated:
  - sidewall drift
  - pipe roof umbrella
  - Jet grouting umbrella







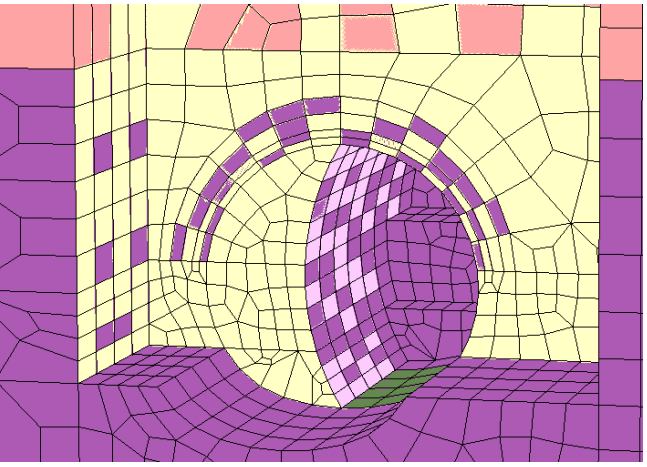
Geotechnical design of Troststraße metro station

- standard tunnel heading could not satisfy the settlement trough criteria (max. tangent slope 1:750)

- The following scenarios for the excavation of the mined station tunnel were simulated:

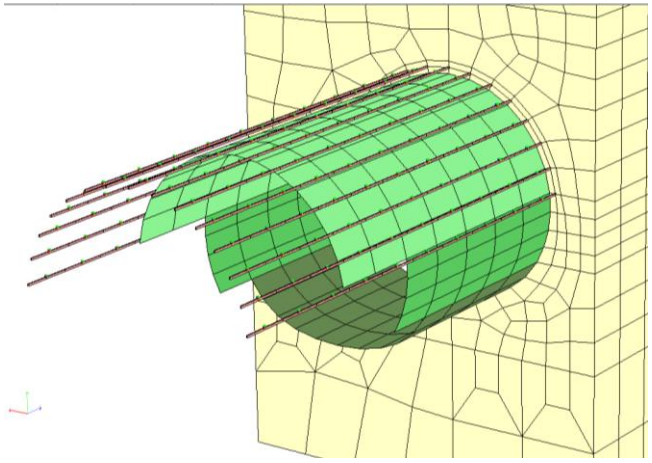
~~sidewall drift~~

max. settlement ~45mm, 1:450



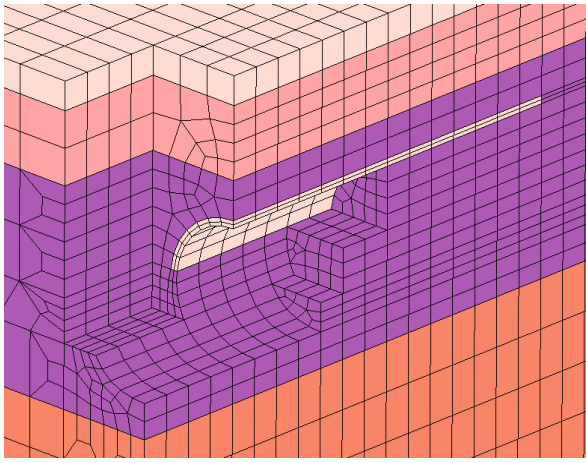
~~pipe roof umbrella~~

max. settlement ~50 mm, ~1:400



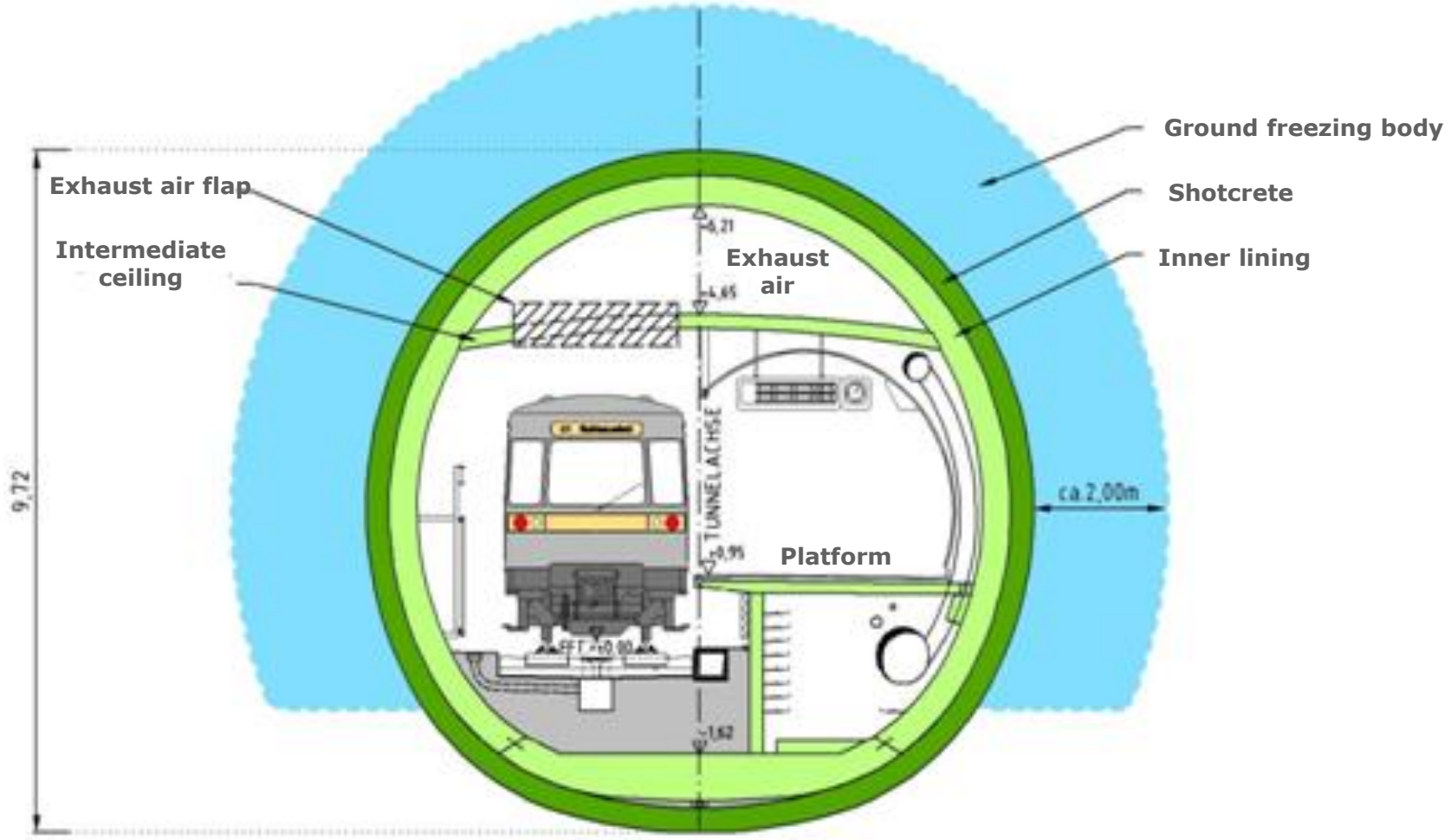
~~Jet grouting umbrella~~

max. settlement ~42mm, ~1:500



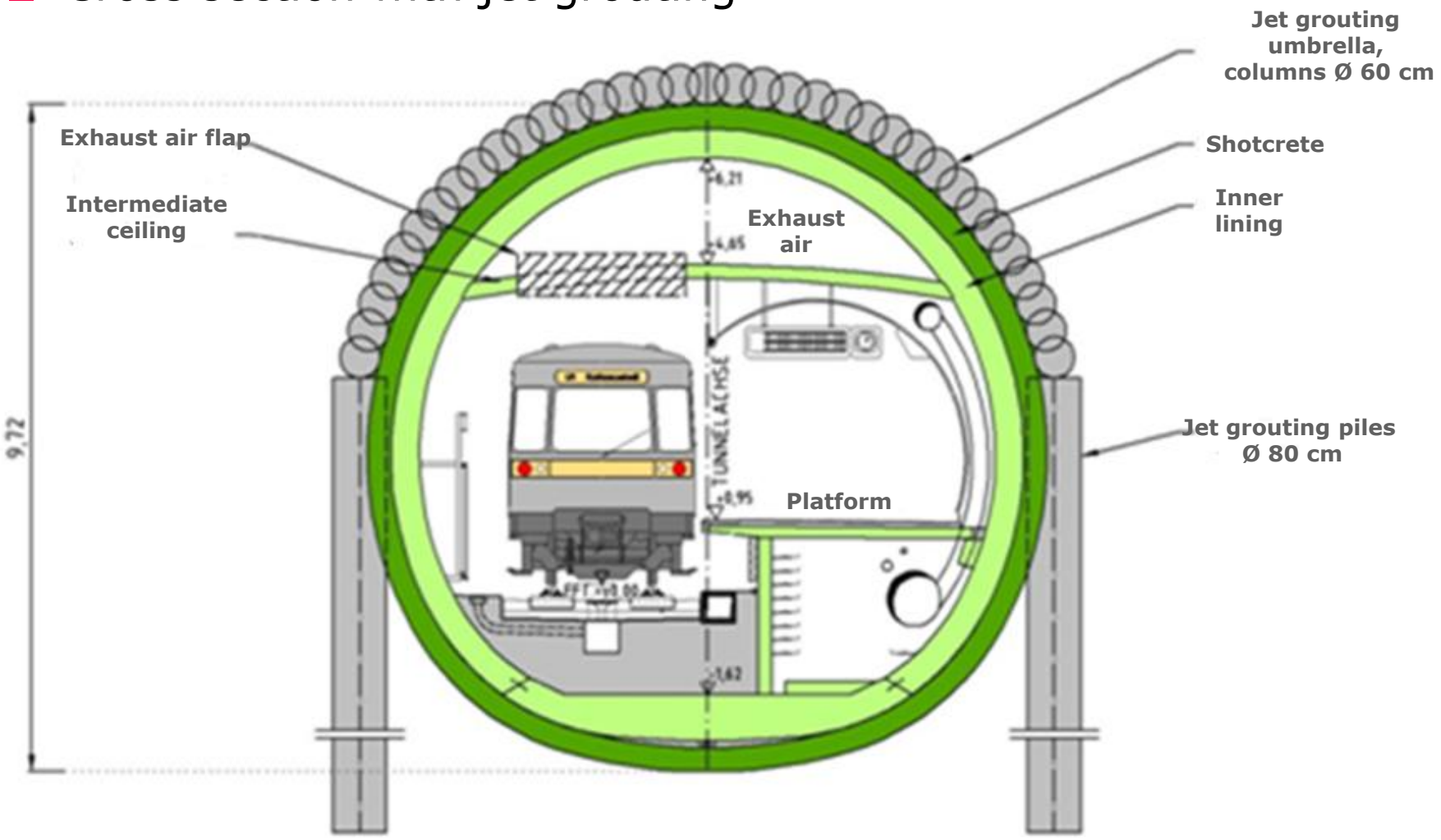
Artificial ground freezing

- Cross section with freezing

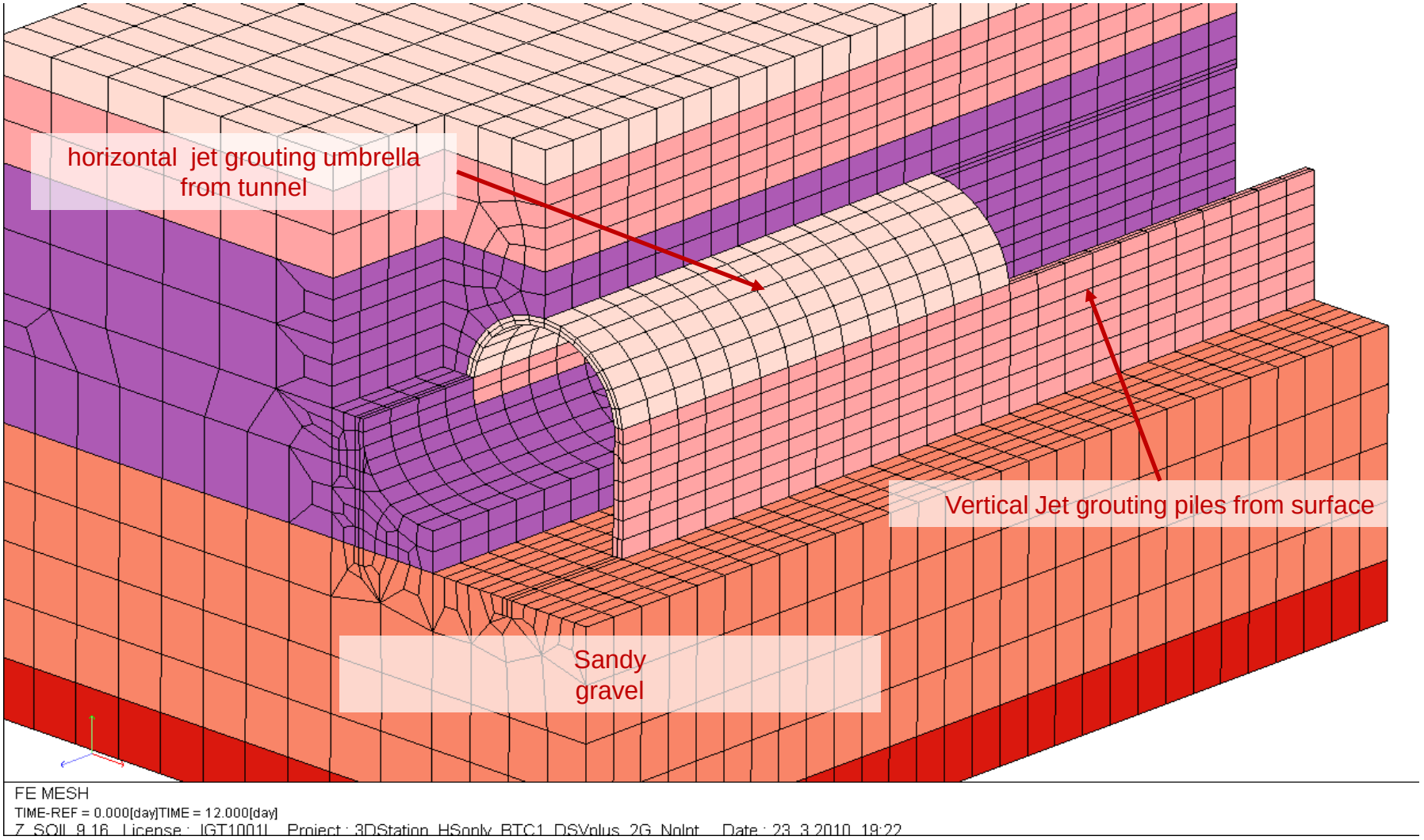


Horizontal jet grouting umbrella on vertical jet grouting piles

- Cross section with jet grouting

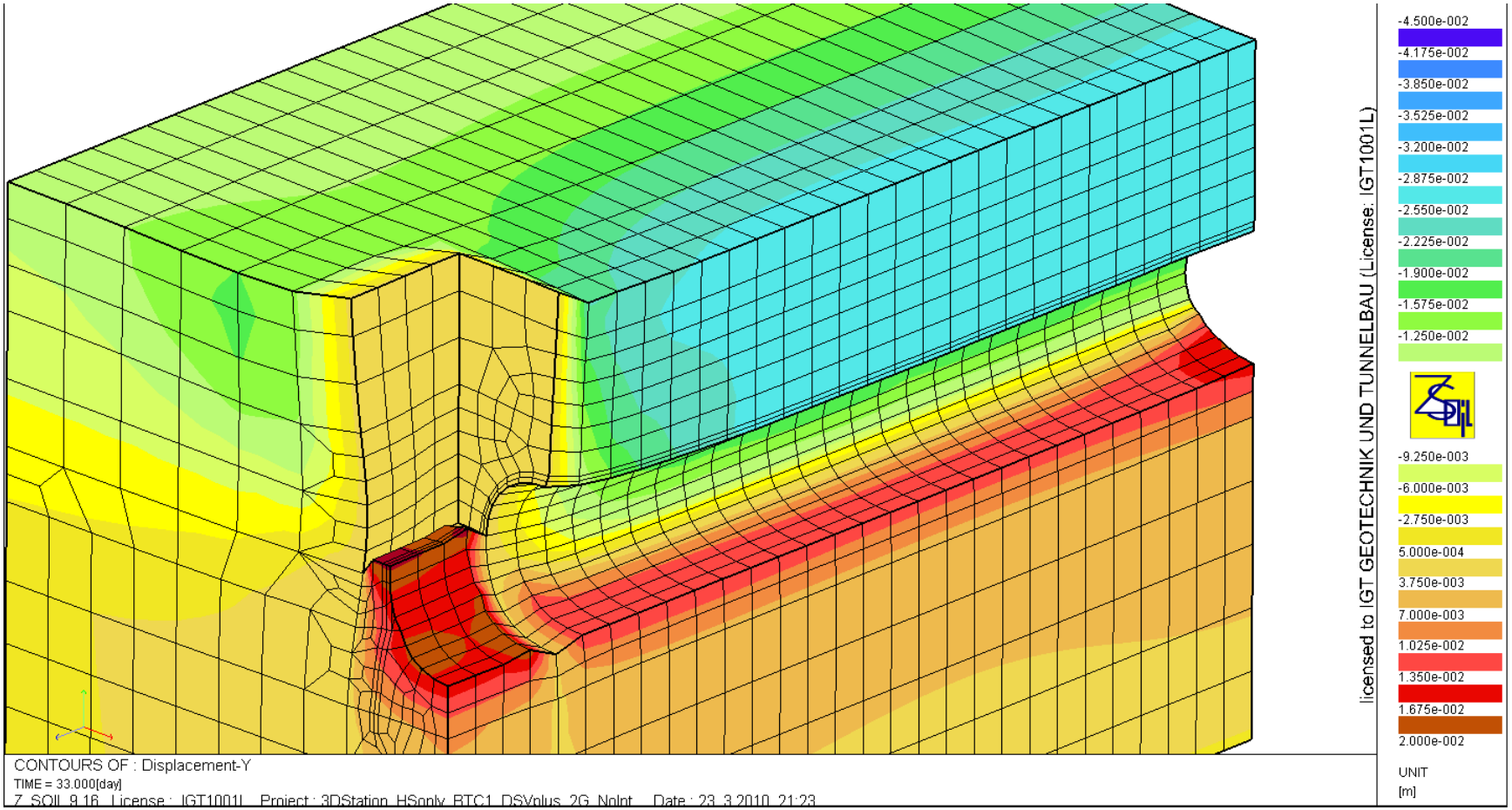


Platform tunnel 3D FE analysis with HS model for loess

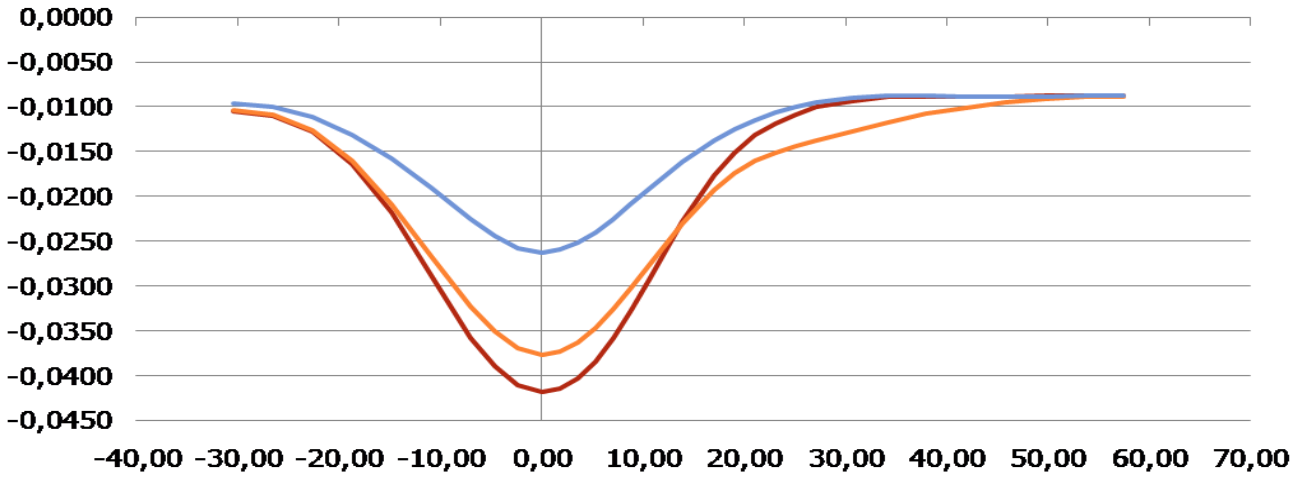


Results from 3D FE

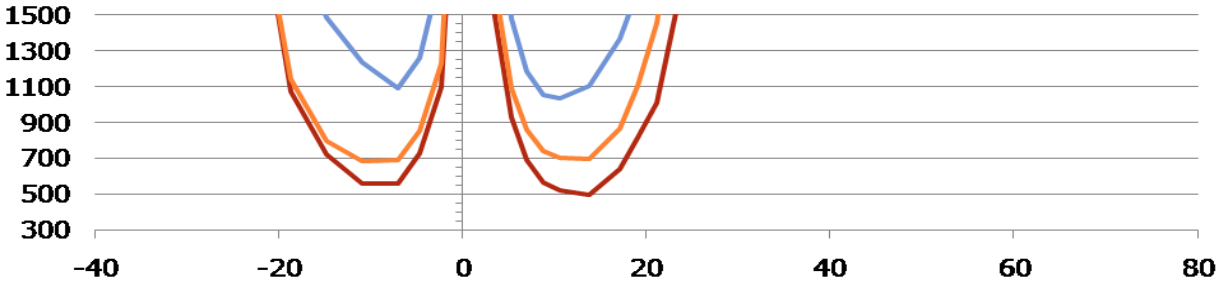
- Inclination for horizontal and vertical jet grouting < 1:750 + max. settlements < 3 cm



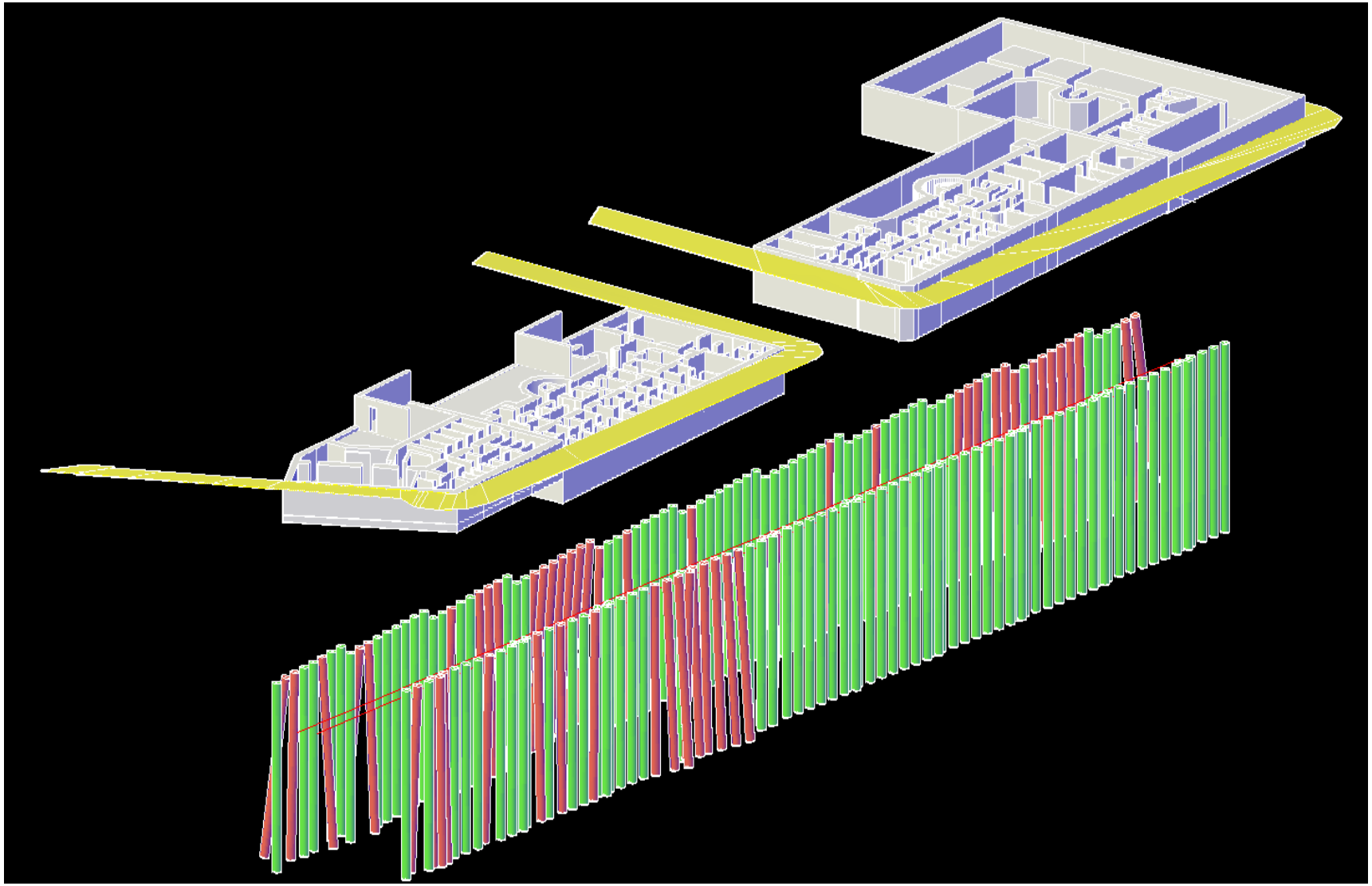
- Settlement trough on surface



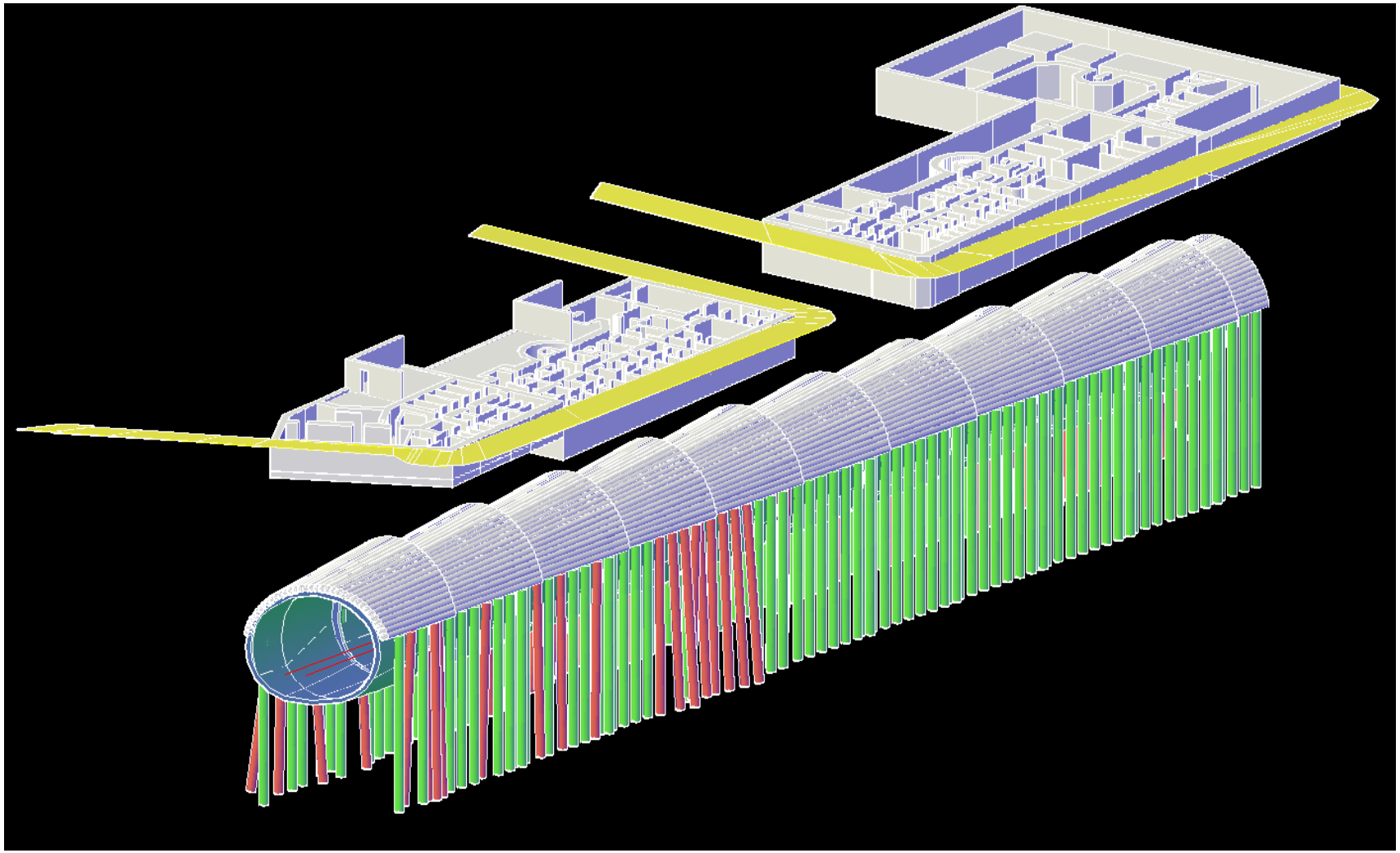
- Inclination on surface **1:x**



3D view of vertical jet grout piles

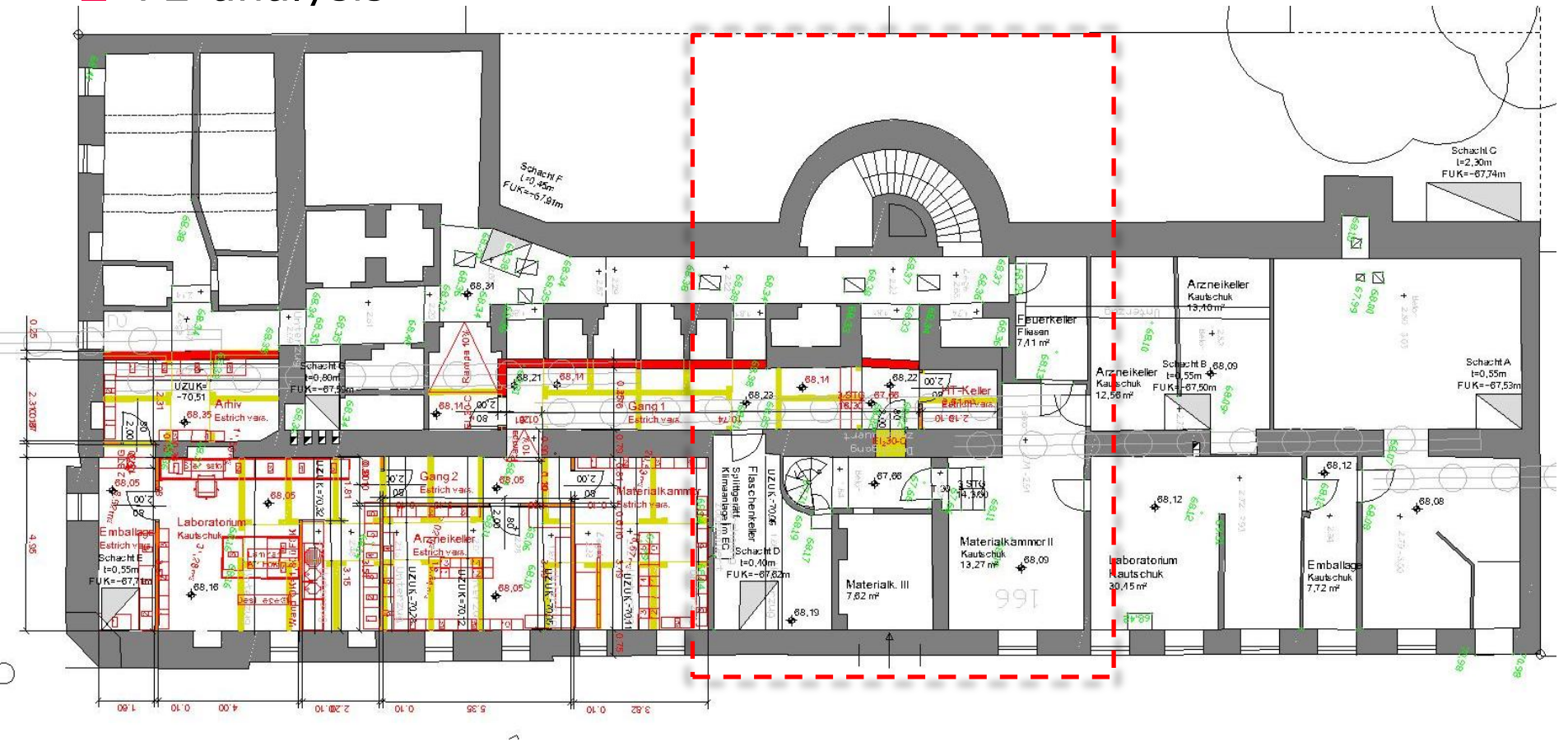


3D view of lateral and vertical jet grouting



Detailed Building Assessment

- Building inspections
- FE-analysis



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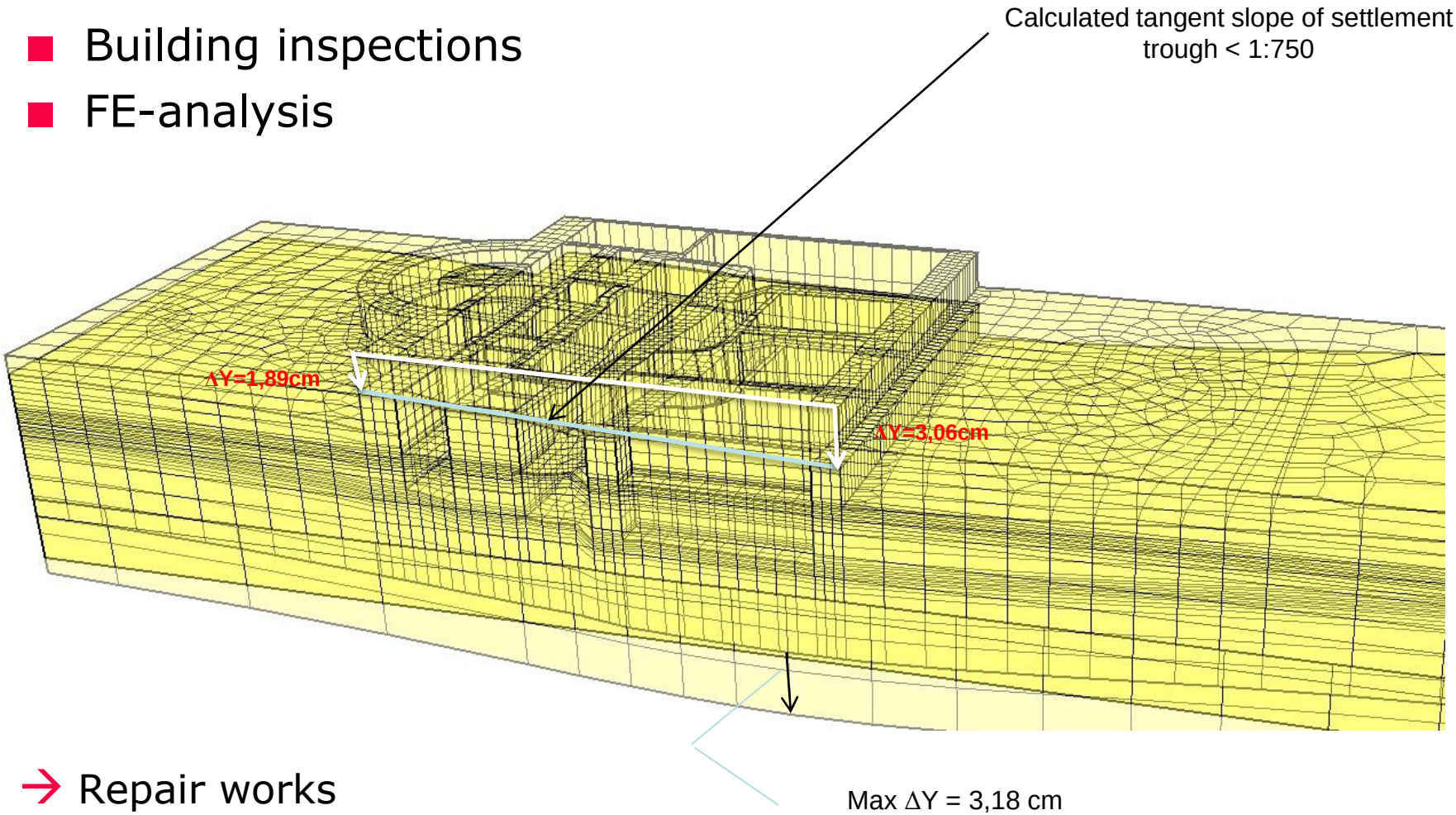


→ Repair works

→ Improvement of building foundations

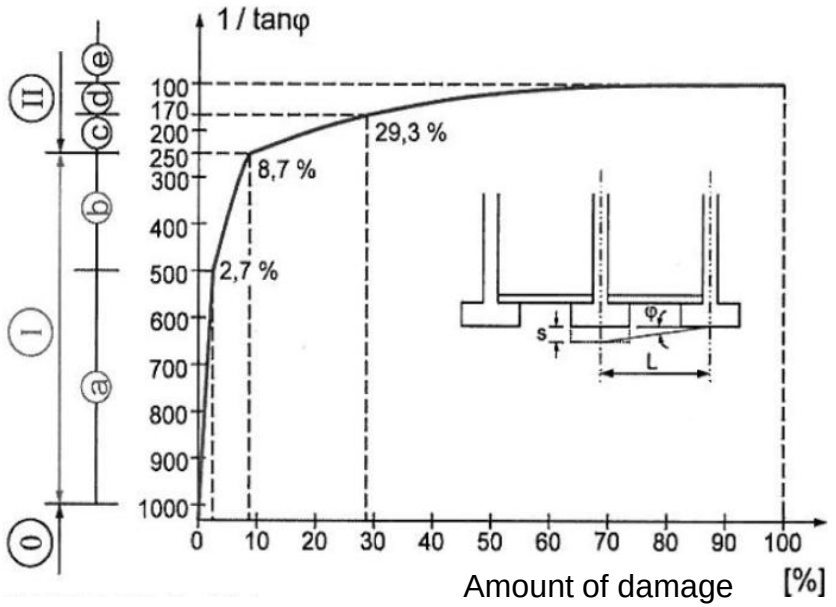
Alert and alarm criteria

Tunnel

Alert Level	Indicator
S0	System behaviour within the tolerances of the expected behaviour according to the design
S1	Deviation from the expected behaviour; phase of reaction
S2	Dangerous conditions; risk limited to the construction site, crisis situation
S3	Dangerous conditions, risk not limited to the construction site and public involved; crisis situation

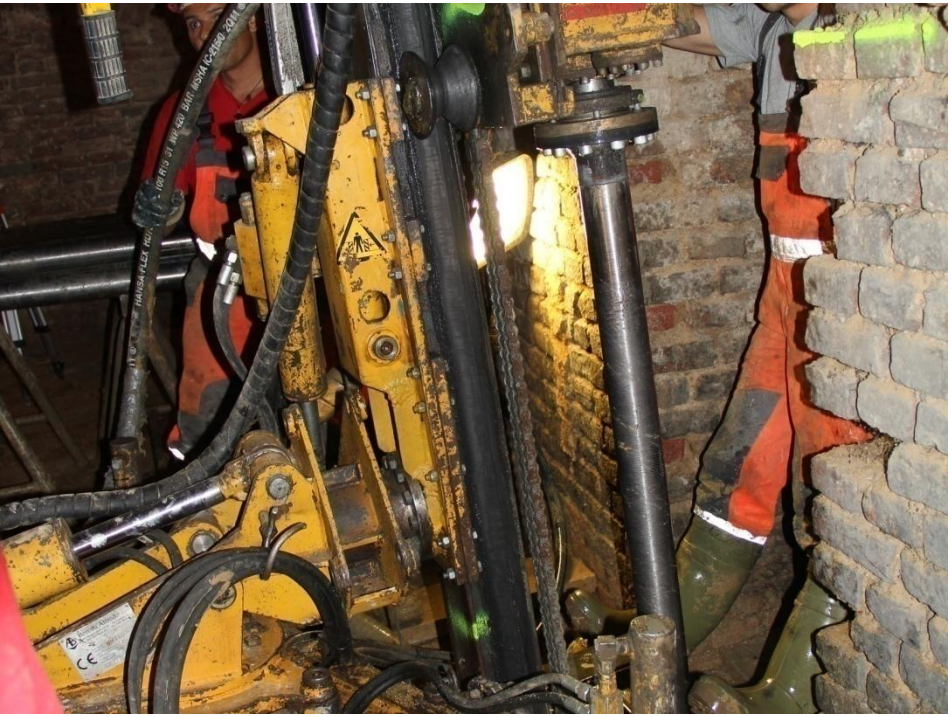
Buildings (damage classification according to Kramer)

Level	Kind of demage	Class	Demages
0	No damages	G 0	No damages
I	Architectural damages	G Ia	Light architectural damages
		G Ib	Medium to heavy archtitectural damages
II	Construction damages	G IIc	Light to medium damages on construction
		G IId	Heavy damages on construction
		G IIe	Collapse or removal of construction



Vertical jet grouting

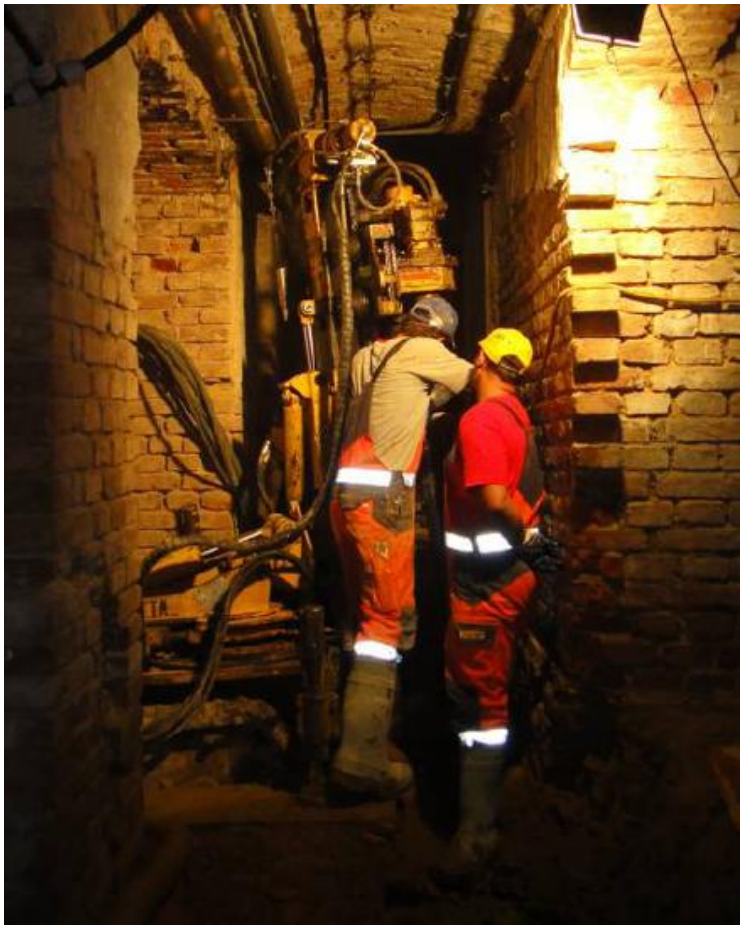
- From building basements



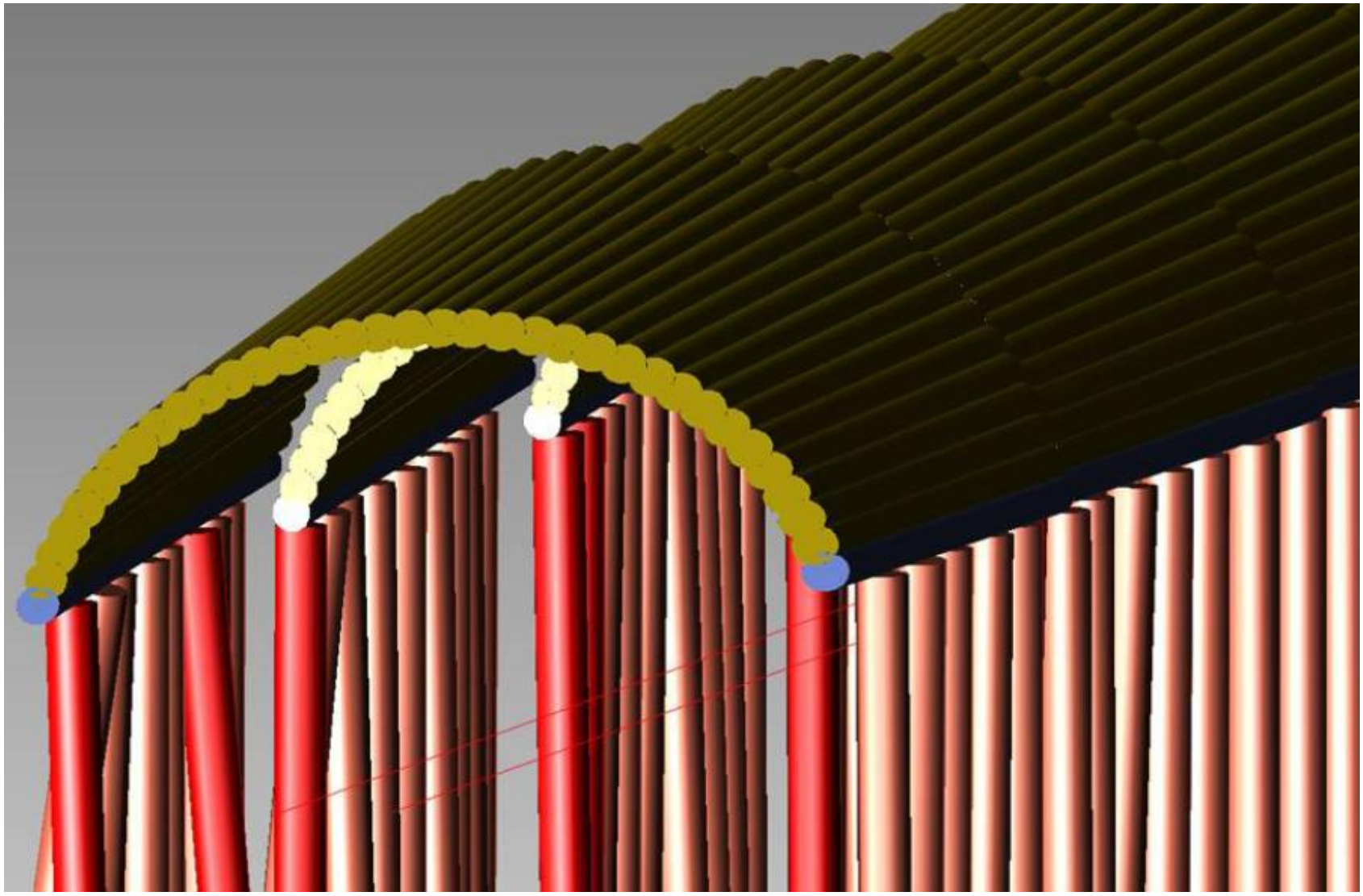
- From surface

Vertical jet grouting piles - construction

- Requirements:
  - pile-Ø 80 cm, minimum compressive strength 5 N/mm²
  - maximum 1% directional deviation, bore hole logging
  - Construction time: summer 2012, about 3 months duration
  - Total jet grouted piles
    - 184 piles
    - 4.200 m bore holes (max.depth22 m)
    - 1.900 m jet grouting



Actual position of jet grouting piles (logging)



Horizontal jet grouting umbrella

- Equipment:
  - horizontal drilling device Casagrande PG185 with carriage length of 22,5 m
  - high pressure pump
  - batching plant
  - silo
- Requirements:
  - space
  - noise (residents)
  - strength development of the columns
  - surveying work
  - monitoring work

Horizontal jet grouting umbrella

- Construction time: November 2013 to April 2014
- Scope of work:
  - 11 jet grouting umbrellas with 35 pieces of ⌀ 600 mm piles each pile 14,8 m long and 5,5° inclination
  - 6 test piles inside the excavation section (tunnel face)

Platform tunnel horizontal jet grouting

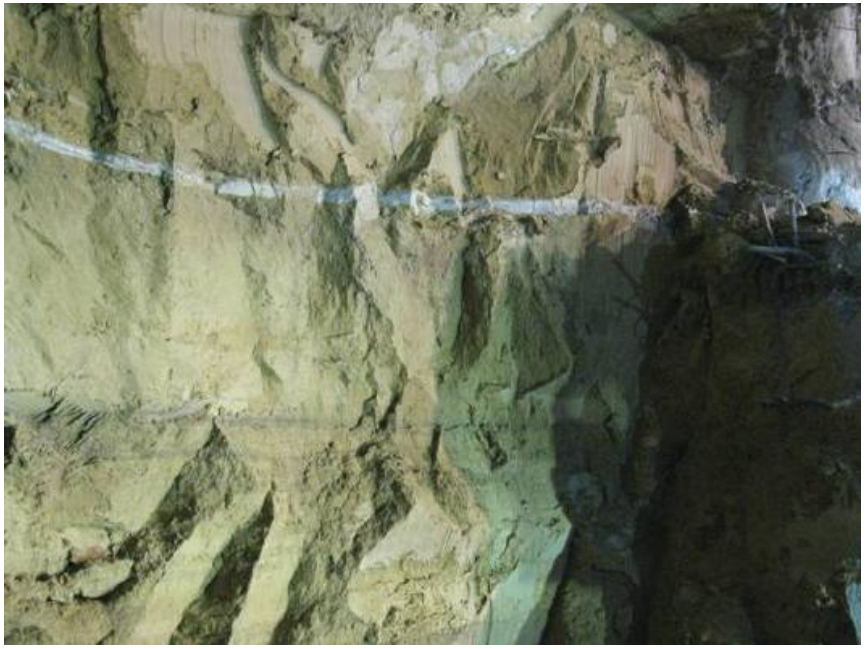
Jet grouting umbrella

- Drilling device during the calibration

- Tunnel face with relief drillings, before start of jet grouting works

Special challenges

- grout entries into basements
- Tearing of the soil: „fracks“
- heave up to max. 15 mm on the surface
- Displacement of face and cracking of face

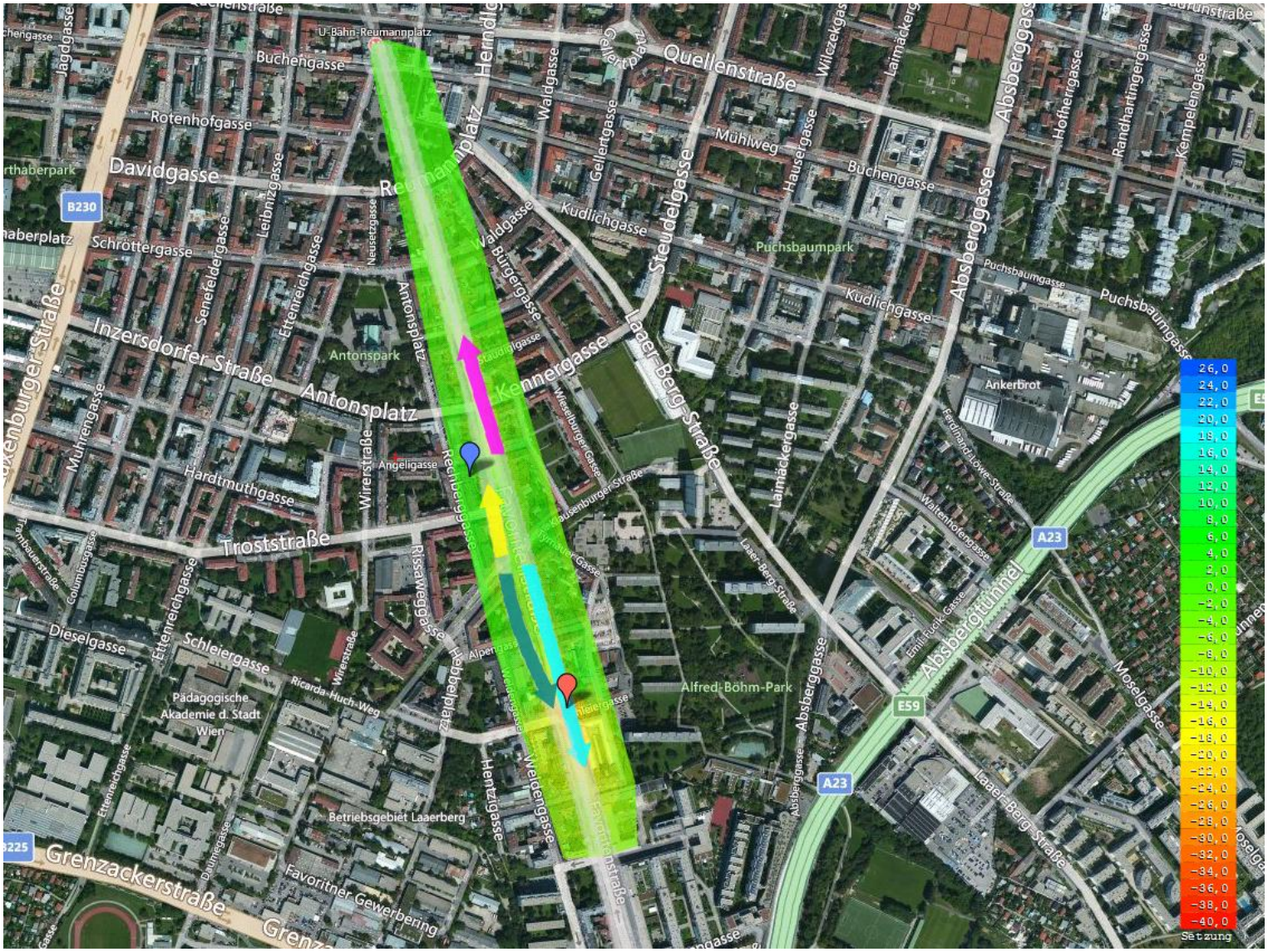


Special challenges – mitigation measures

- Increased intervals of monitoring
- Building inspections with designers and independent verifiers
- Supervision personnel in selected building basements during jetting
- Careful adaptation of alert and alarm criteria

- Adaption the jetting parameters
- Systematic relief drillings
  - in umbrella area
  - in tunnel face
- Shortening of the secondary jet grouting piles
- Use of face bolts instead of jet grouting piles in the face

Surface settlements - overview



Conclusion

- Horizontal jet grouting umbrella based on vertical jet grouting piles is an effective auxiliary method to limit settlement and max. tangent slopes for tunnelling in sensitive built-up areas
- Horizontal jet grouting in fine-grained soils requires:
  - a consistent alarm plan
  - an experienced team
  - a clear and open communication between all parties involved and quick decision-making
- Despite the aforementioned challenges, the jet grouting and tunnel heading works have successfully been completed without major problems or deviations from the design criteria.

Announcement:

The journal

„Geomechanics and Tunnelling“

publishes international articles about geomechanics and all aspects of tunnelling. Each issue of the journal has a special topic and is published in English and German.

- The topic of issue 3/16 (June 2016) will be

  „ **Tunnelling in Turkey** “

- Colleagues interested to publish an article are encouraged to contact either:

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till **20.July 2015** with an abstract in English or Turkish.