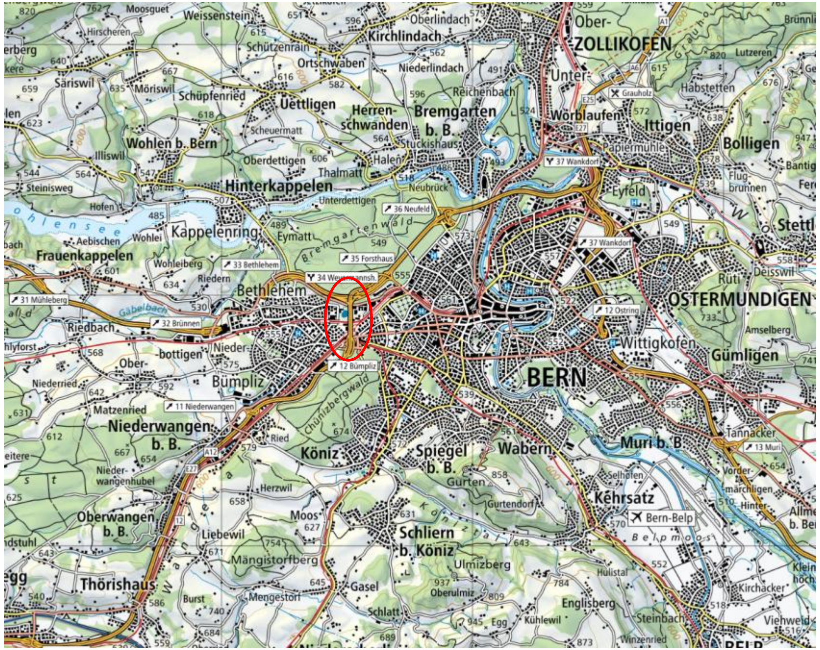
Excavation at Weyermannshausviadukt

ZSoil Symposium NUMERICS IN GEOTECHNICS & STRUCTURES 2026

Christoph Berger

Scope of project



Scope of project

- Railway part
  - Client: SBB
- Urban development part
  - Client: the city of Bern
    Tiefbauamt Stadt Bern

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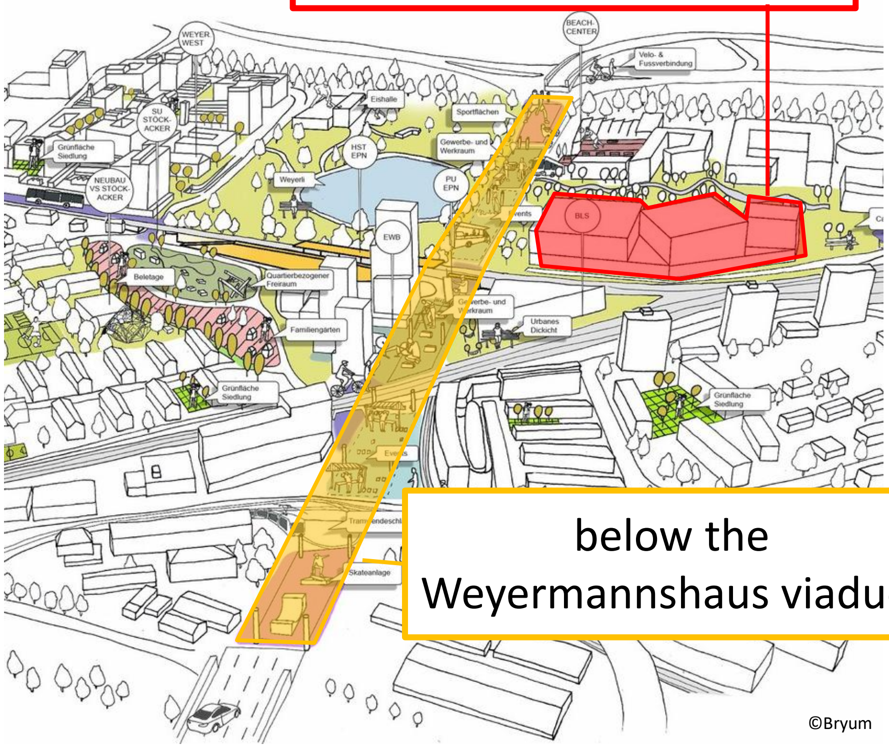
Urban development

- Area below the bridge
- New BFH campus

New campus
New system of sewers



below the
Weyermannshaus viaduct

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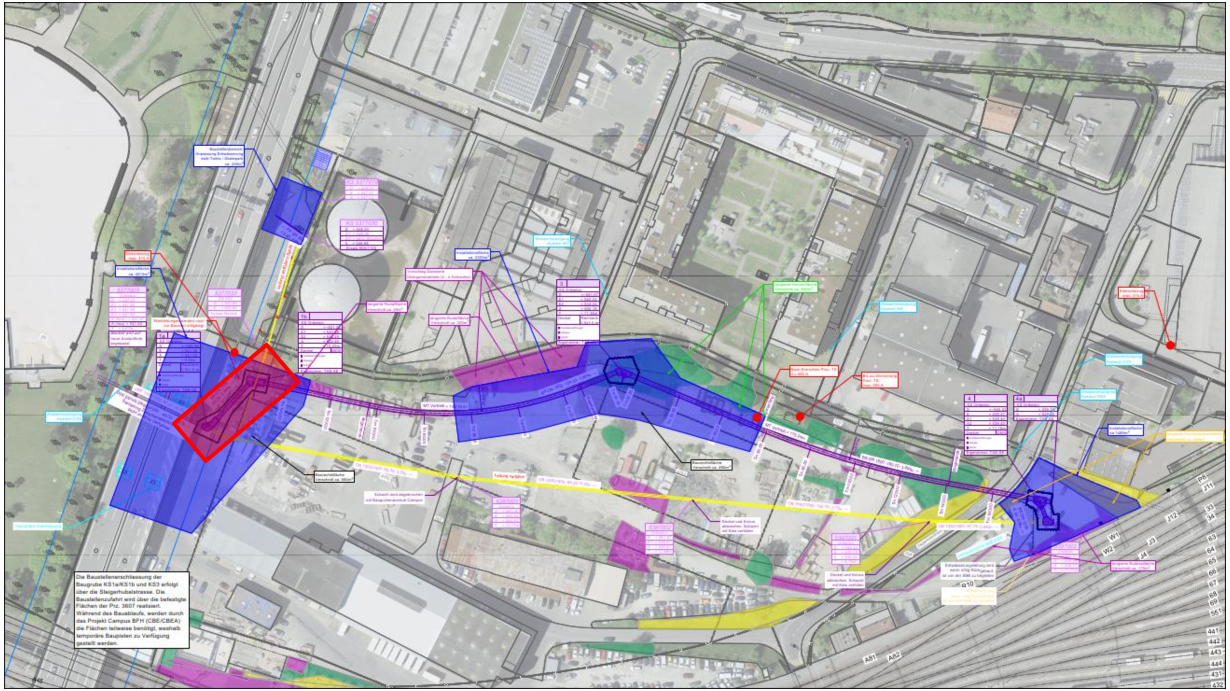
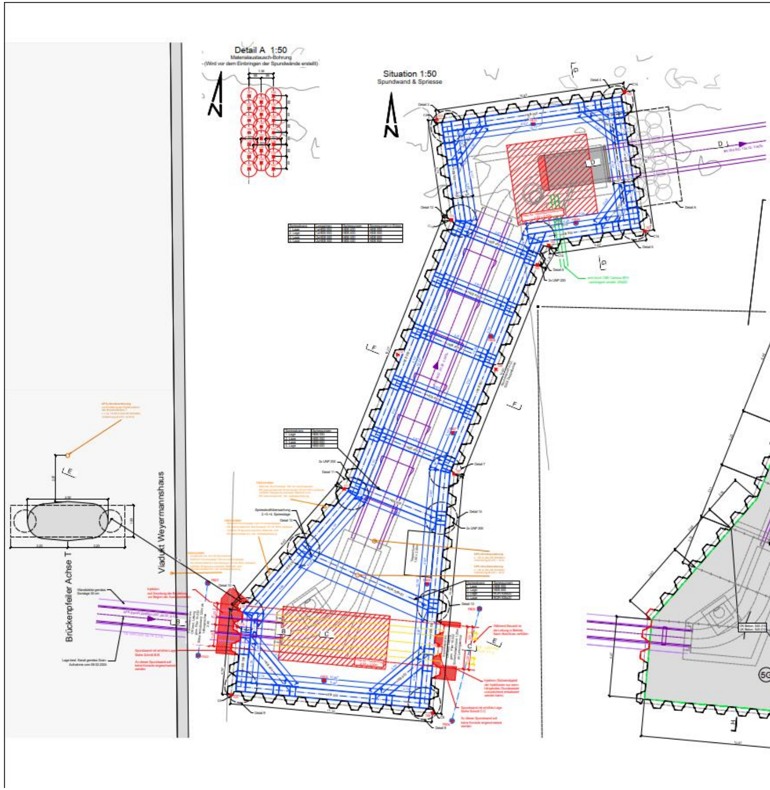
New system of sewers

- Excavation near the Weyermannshaus viaduct

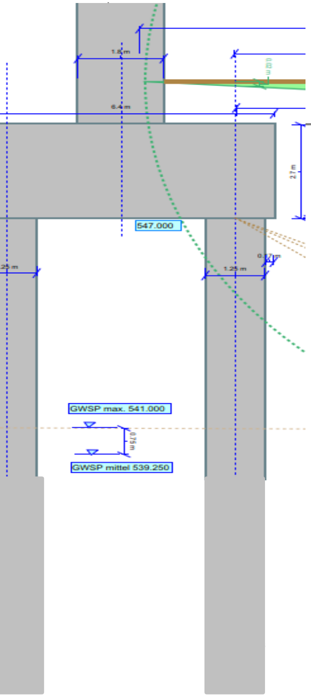


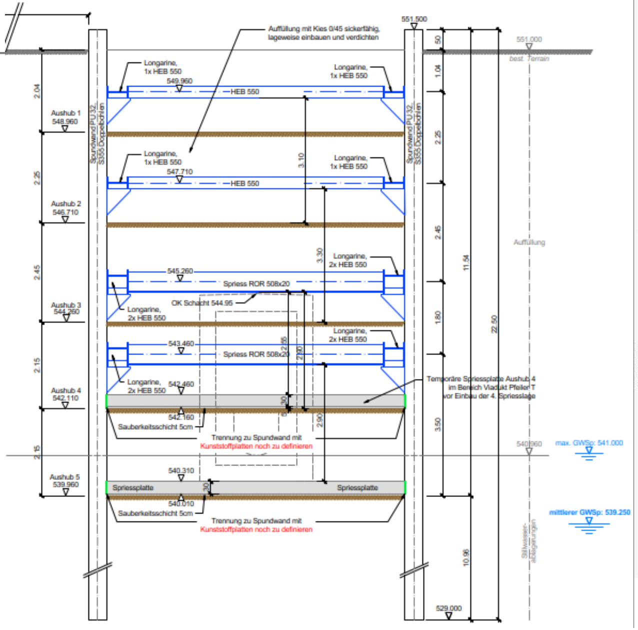
Excavation

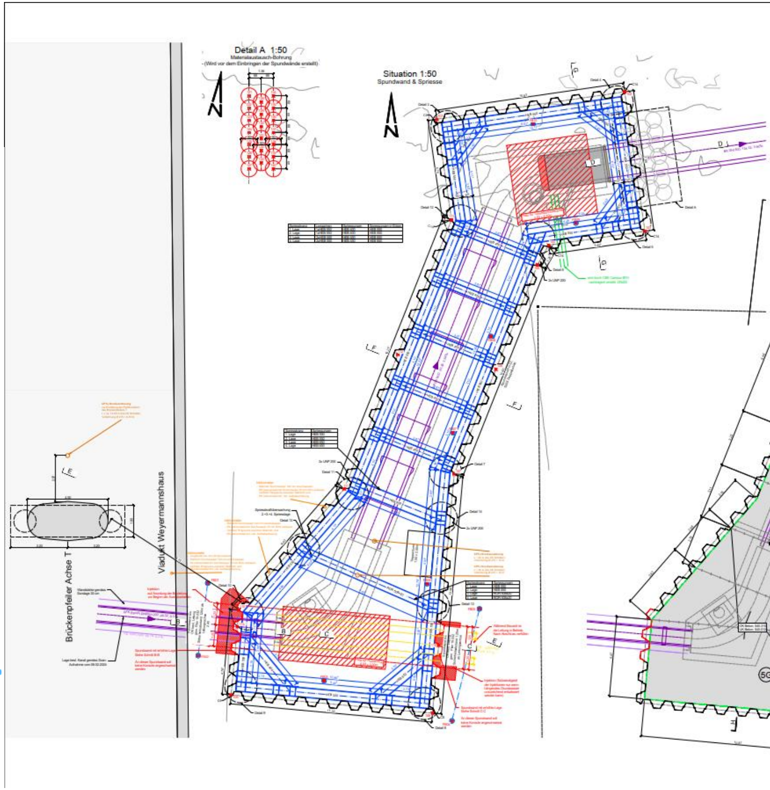
- Sheet pile wall
  - The cantonal water authority (AWA Bern) did not permit a bored pile wall due to groundwater flow concerns.
  - Long sheet piles of 22 m
- 11.5 m deep
- 4 struts
- 5th strut by bottom slab



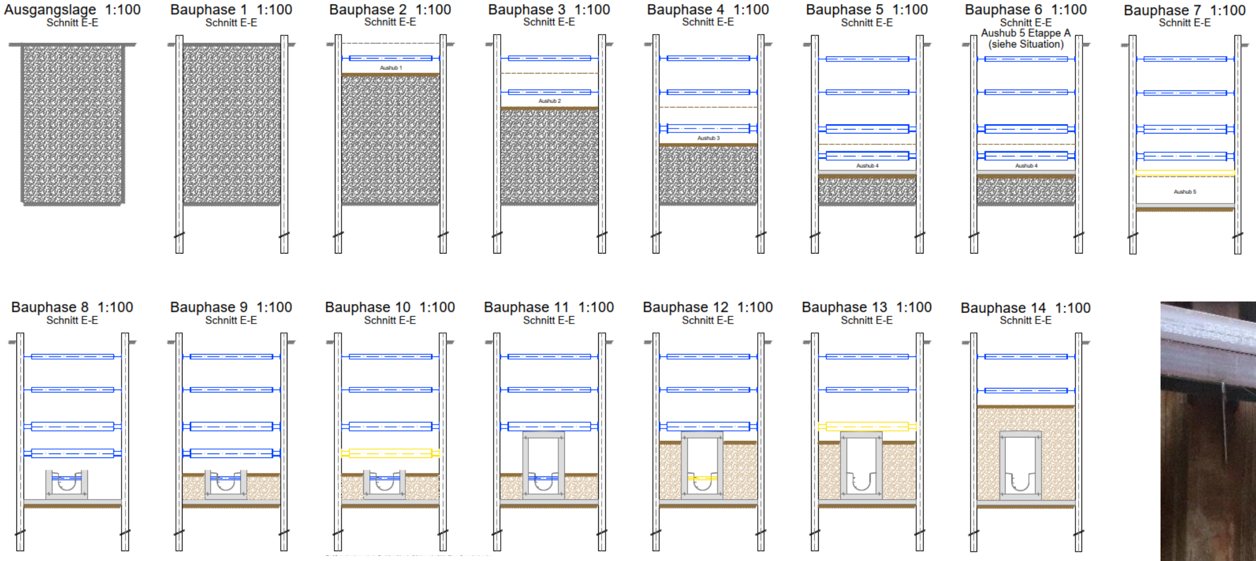
Excavation


1.6 m
6.4 m
2.7 m
547.000
1.25 m
GWSP max. 541.000
GWSP mittel 539.250


Auffüllung mit Kies 0/45 sickerfähig, lageweise einbauen und verdichten
551.500
551.000
best. Terrain
Longarine, 1x HEB 550
549.960
HEB 550
Aushub 1 548.960
Spundwand PU32, S355 Doppelbohlen
Longarine, 1x HEB 550
547.710
Aushub 2 546.710
545.260
Spriess ROR 508x20
Longarine, 2x HEB 550
OK Schacht 544.95
Aushub 3 544.260
543.460
Aushub 4 542.110
542.460
542.160
Sauberkeitsschicht 5cm
Trennung zu Spundwand mit
Kunststoffplatten noch zu definieren
Temporäre Spriessplatte Aushub 4 im Bereich Viadukt Pfeiler T vor Einbau der 4. Spriesslage
Auffüllung
540.960
max. GWSp: 541.000
mittlerer GWSp: 539.250
540.310
Aushub 5 539.960
Spriessplatte
540.010
529.000


Detail A 1:50
Situation 1:50
Spundwand & Spriesse
Viadukt Weyermannshaus
Brückenpfeiler Achse T

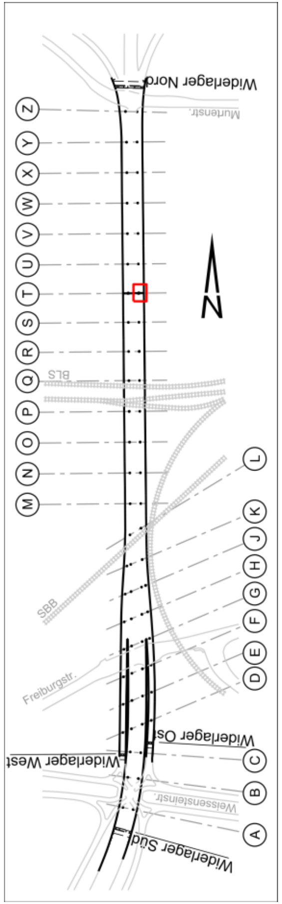
Excavation


Ausgangslage 1:100
Schnitt E-E
Bauphase 1 1:100
Schnitt E-E
Bauphase 2 1:100
Schnitt E-E
Bauphase 3 1:100
Schnitt E-E
Bauphase 4 1:100
Schnitt E-E
Bauphase 5 1:100
Schnitt E-E
Bauphase 6 1:100
Schnitt E-E
Aushub 5 Etappe A
(siehe Situation)
Bauphase 7 1:100
Schnitt E-E
Bauphase 8 1:100
Schnitt E-E
Bauphase 9 1:100
Schnitt E-E
Bauphase 10 1:100
Schnitt E-E
Bauphase 11 1:100
Schnitt E-E
Bauphase 12 1:100
Schnitt E-E
Bauphase 13 1:100
Schnitt E-E
Bauphase 14 1:100
Schnitt E-E


6540
63°

Excavation

– Close to pillar T of the bridge



Geology

- Still-water deposit (slackwater deposit)
  - post-glacial, no overconsolidation
  - loose packing is possible
  - thick layers up to 16 m possible

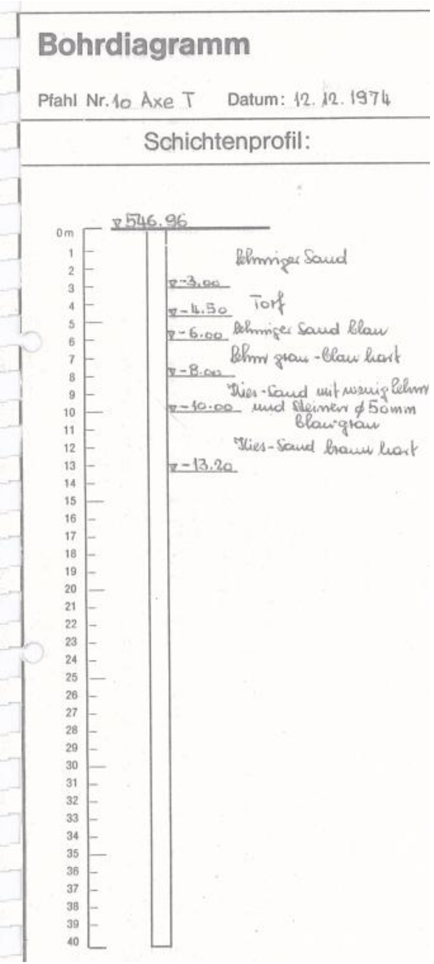
- Gravel/rubble
  - very heterogeneous
  - „not great either“

C Stillwasserabla-gerungen	2 - 4	**Ton**, siltig, leicht sandig	• mässig Tragfähigkeit • Setzungsempfindlich • Wenn aufgelockert nur be-schränkt verdichtbar • Baggerbar bis klebend • Zur Wiederverwendung nicht ge-eignet	Locker bis mitteldicht	CL	stark	S1

	Raumgewicht γ_m [kN/m³]	Reibungswinkel φ'_m [°]	Kohäsion c'_m [kN/m²]	M_E-Wert [MN/m²]	SPT [N_{30}]
Verlandungsbildungen / Stillwasserablagerungen	**18** (17 – 19)	**28** (26 – 30)	**0** (0 – 5)	**45** (25 - 80)	**20** (8 - 37)
Rückzugsschotter	**21** (20 – 22)	**35** (31 – 37)	**0**	**45** (20 - 120)	**25** (6 - 51)
Rückzugsschotter (unter-halb Grundwasserspiegel)				**30** (15 - 45)	**10** (5 - 20)

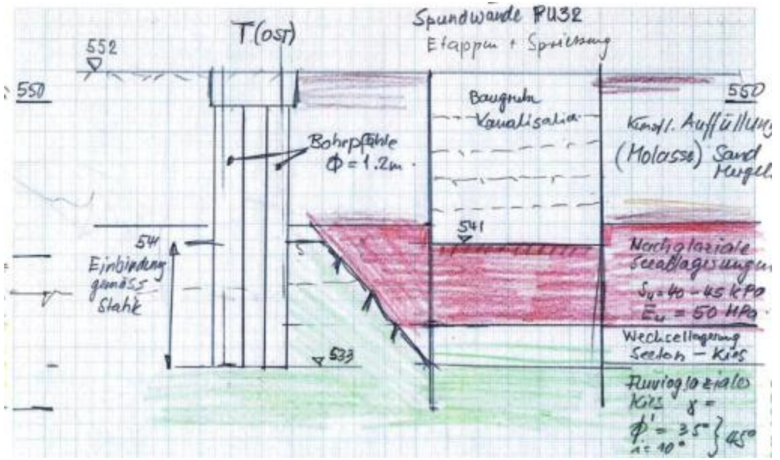
Geology

- Optimistic investigations 1974
- Reality very complex
- Two layers of concern:
  - gravel/Rubble
  - still-water deposit
    (slackwater deposit,
    the finest of the fine particles)



Geology

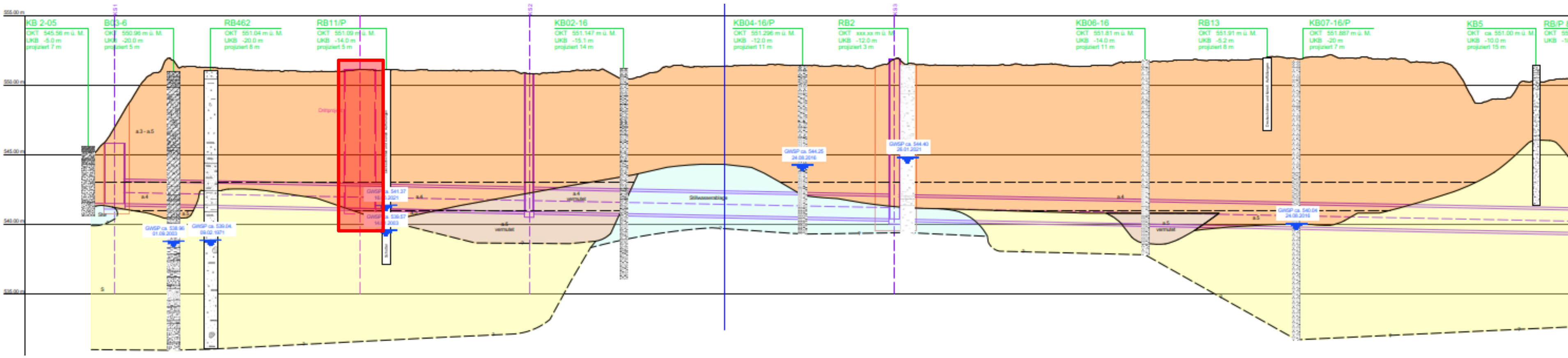
- Coarse topology rubble/gravel layer
- Possibly / locally interlayered
- Thick layers possible
- Steep slopes possible



LEGENDE

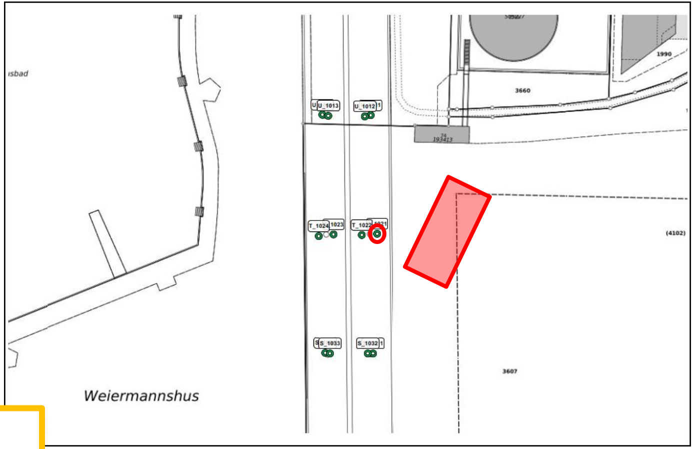
Schichten

- Auffüllung
- Auffüllung vermutet
- Schotter
- Stillwasserablagerungen

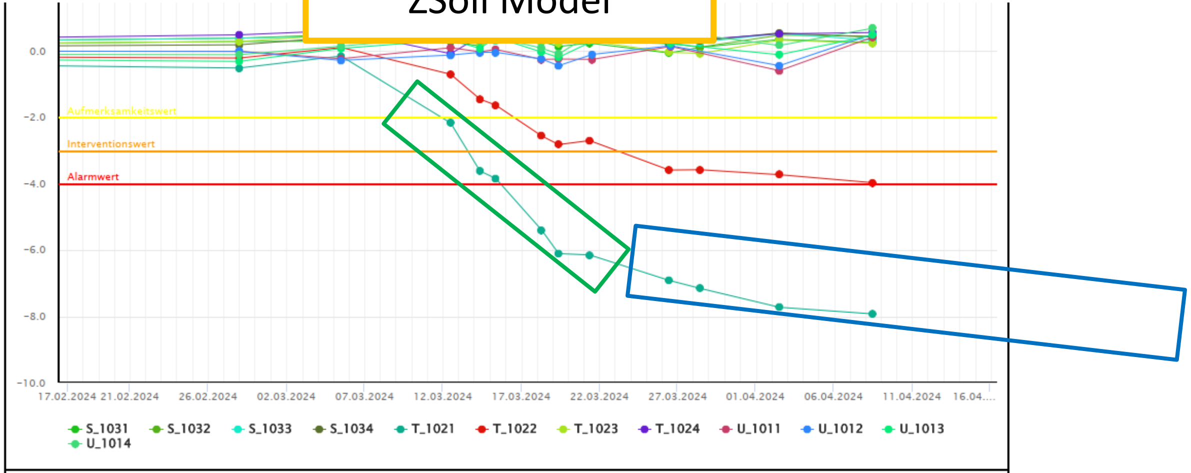


„Canon Moment“ of the project

- The monitoring triggered alarm:
  - triggered by vibrations of the sheet piling
  - significant settlements
  - st a high rate
  - no sign of stopping

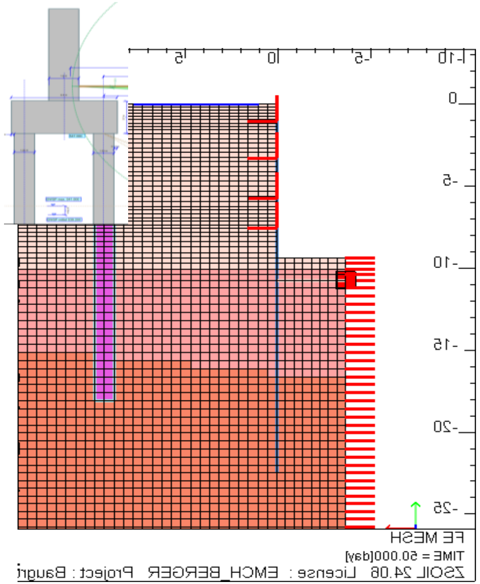


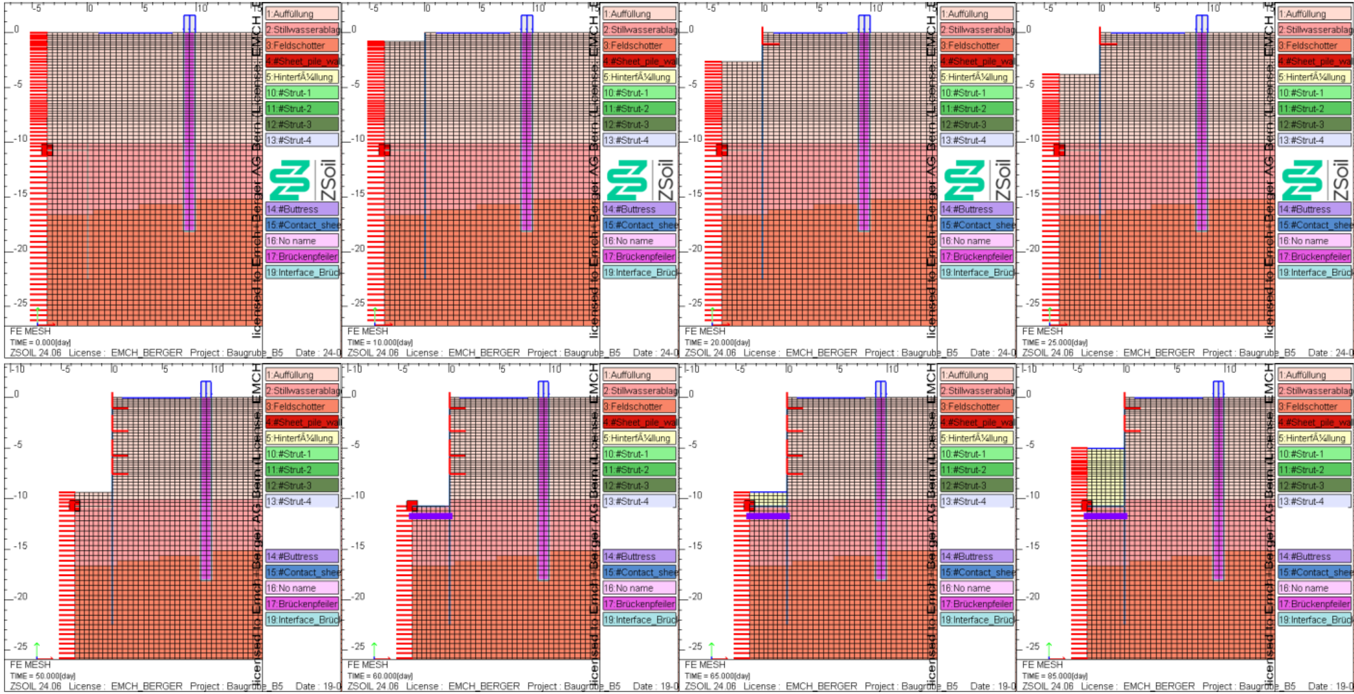
Countermeasure:
ZSoil Model



ZSoil Model

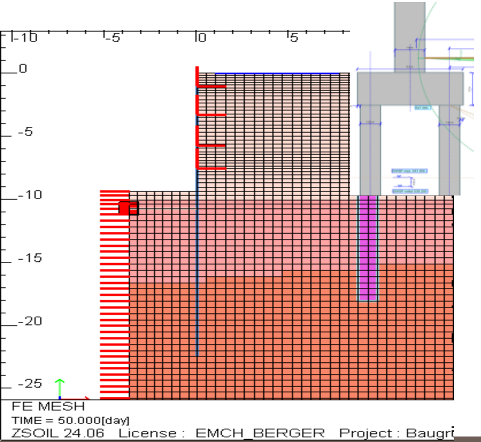
- Sheet pile wall template
- Focus: deformation

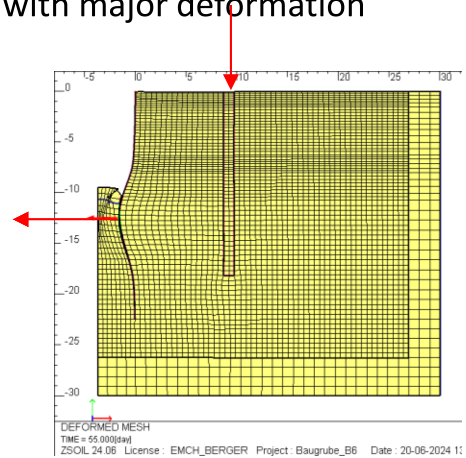


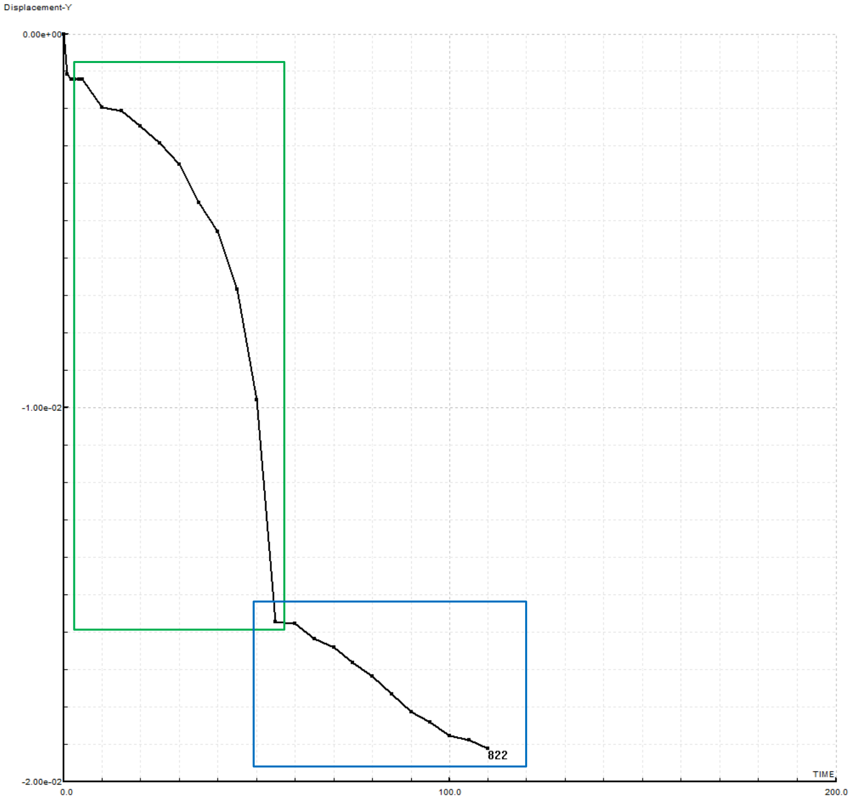


ZSoil Model

- Focus: deformation
- Excavation **16 mm**
- Backfill additional **3 mm (total 19mm)**
  - strut removal
  - compaction of the backfill
- Last two excavation steps with major deformation

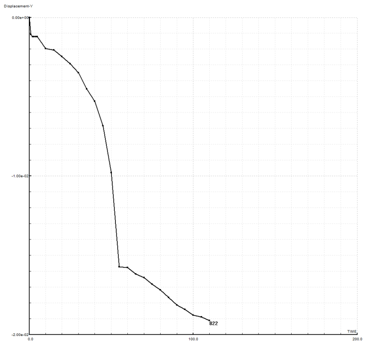


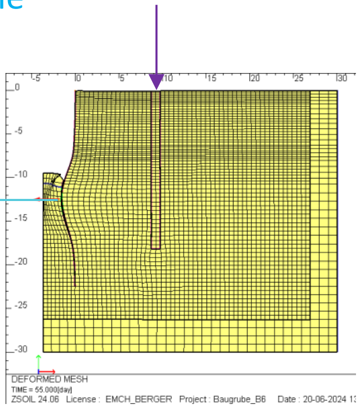


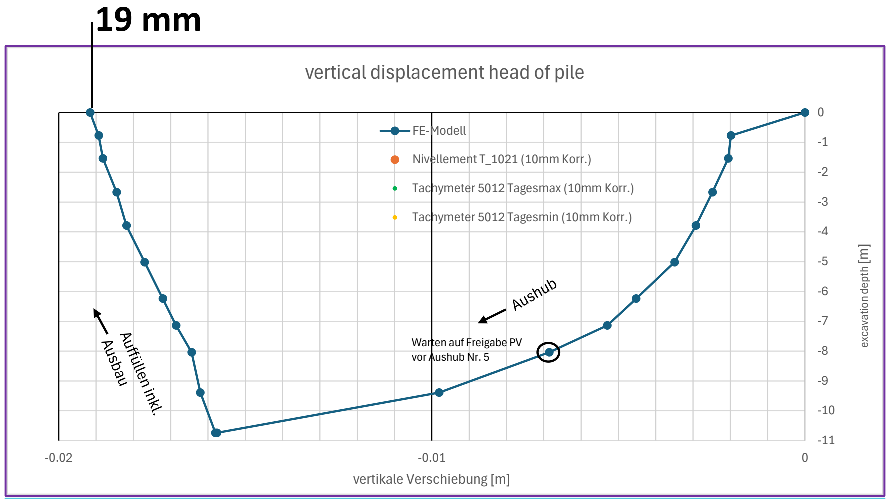


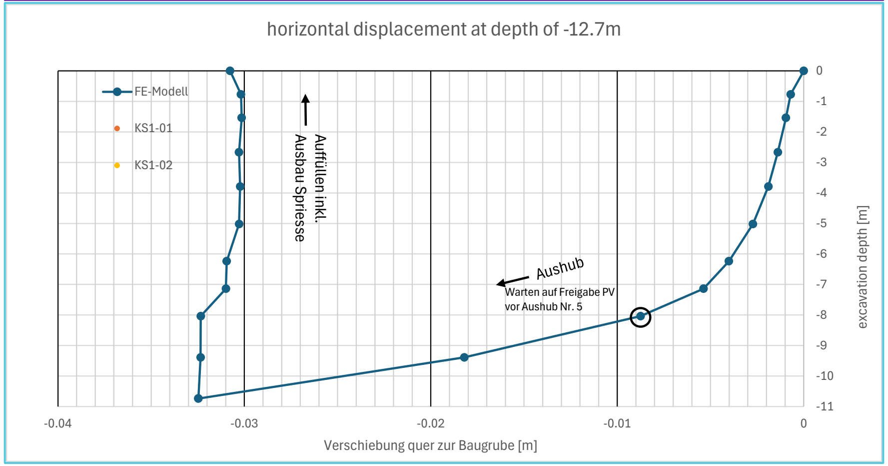
ZSoil Model

- Excavation **16 mm**
- Backfill additional **3 mm (total 19mm)**
  - strut removal
  - compaction of the backfill
- Last two excavations steps with major deformation
- Vertical settlement head of pile and horizontal displacement sheet pile



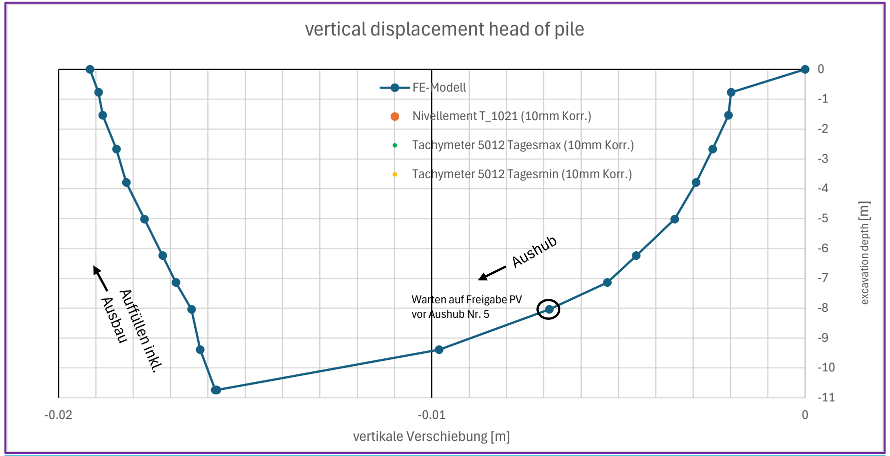


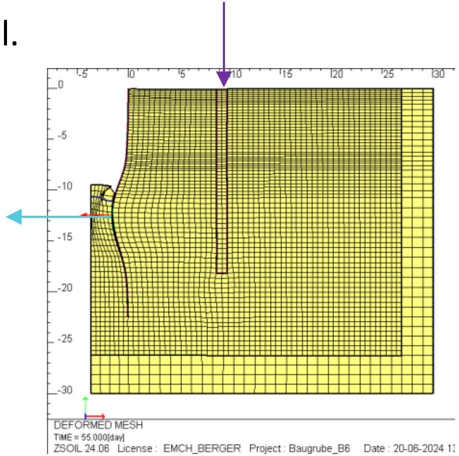


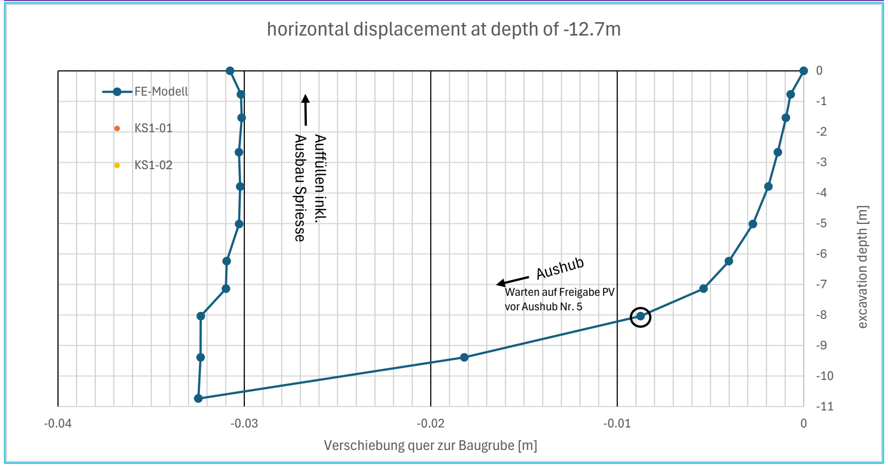


ZSoil Model

- Monitoring:
  - settlements of point T_1021 by leveling
  - settlements of point 5012 by automatic tachymeter
  - horizontal displacement by inclinometer KS1-01 and KS0-02
- Graph as a function of the excavation stage.
- Comparison to ZSoil model.



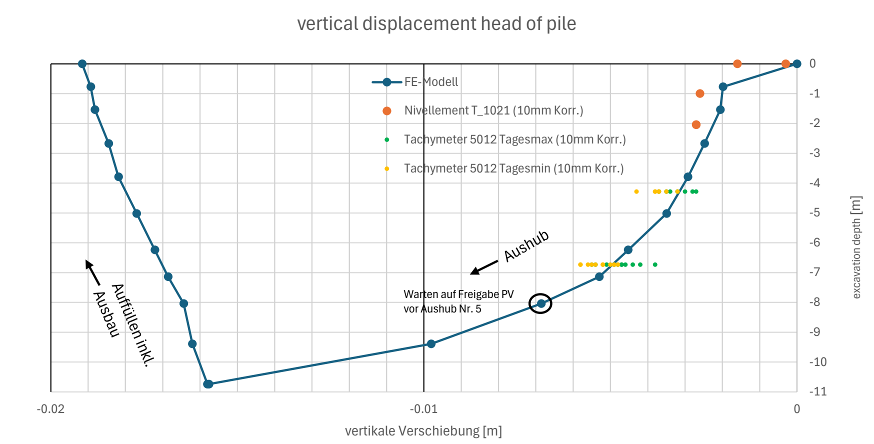


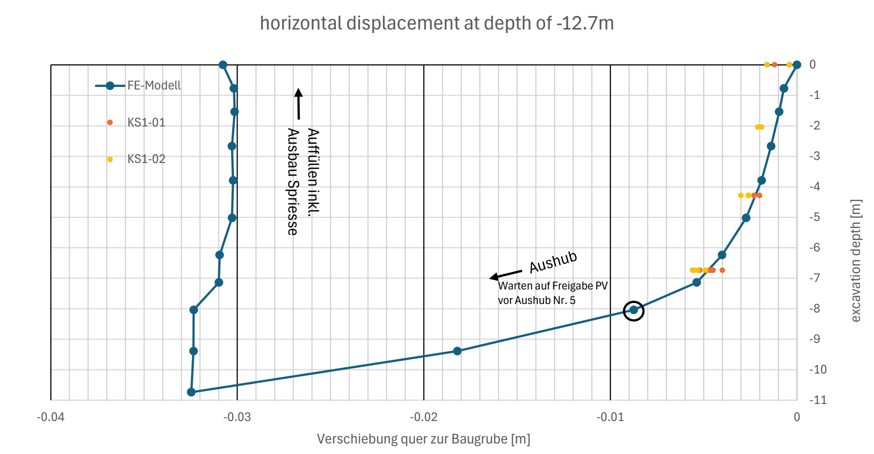


ZSoil Model

- Monitoring:
  - settlements of point T_1021 by leveling
  - settlements of point 5012 by automatic tachymeter
  - horizontal displacement by inclinometer KS1-01 and KS0-02
- Checkpoint before excavation step #5. Evaluation of settlements.
  - Go / No go.
  - countermeasures?

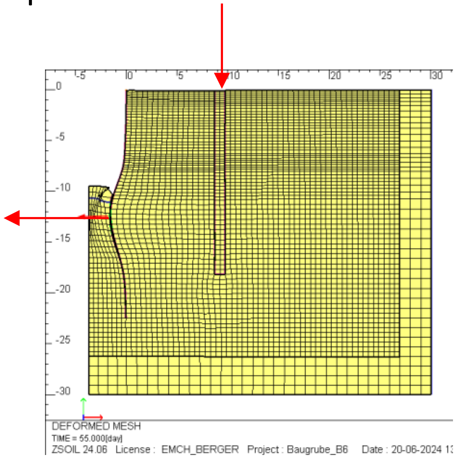
- Countermeasure at bridge

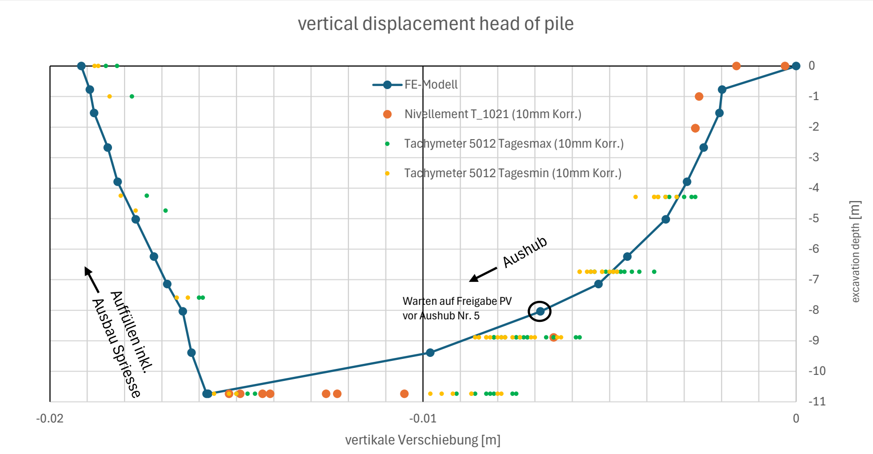


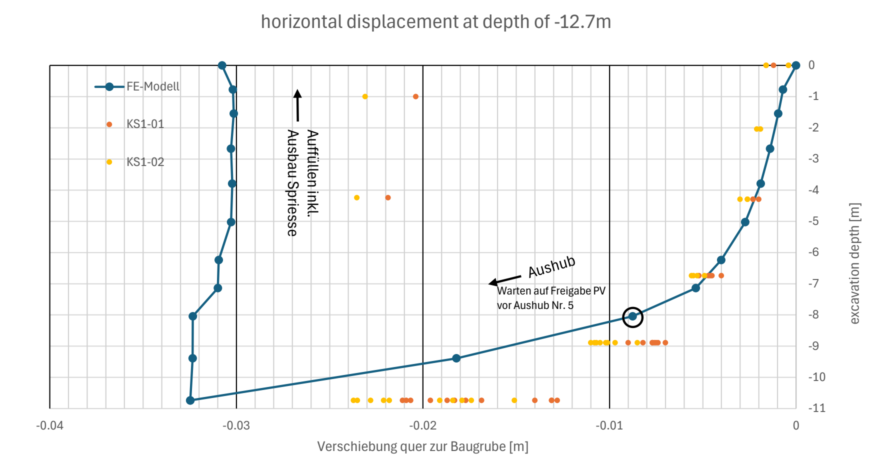


ZSoil Model

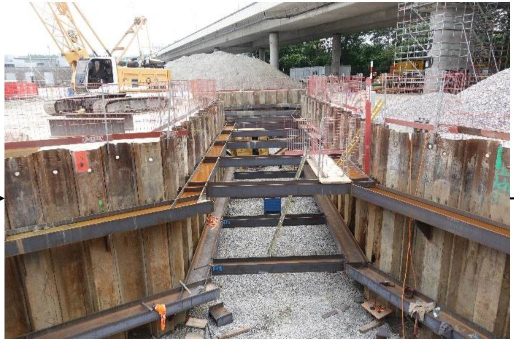
- Very (suspiciously) good agreement between monitoring and model
- Backfill and removal of struts
  - →additional settlements
  - see vertical displacements
- Backfill and pressure of compaction
  - → pushing back into soil
  - see inclinometers







Impressions



ZSoil Material

- Still-water deposit
  - HS-small strain
  - Friction angle ϕ = 22°,
  - Dilatany angle ψ = 0°
  - Cohesion c = 5 kPa
  - M1 = 4’000 kPa = E_ref_50
  - M2 = 10’000 kPa = E_UR
  - «M0» = 47’000 kPa = E_ref_0

- Permeability
  - K_hor 5e-6 m/s
  - K_vert 5e-7 m/s
  - Later 100x smaller for «undrained» effects
  - Personal observations after excavation:
    close to clay
  - Max eff. suction according to Bishop 14 kPa (1.4m)
  - (for the backfill material 10 kPa (1.0m))

ZSoil Material

– Gravel/rubble
  – HS-small strain
  – Friction angle ϕ = 35°
  – Dilatany angle ψ = 5°
  – Cohesion c = 0 kPa
  – M1 = 35’000 kPa = E_ref_50
  – M2 = 105’000 kPa = E_UR
  – «M0» = 205’000 kPa = E_ref_0

– Permeability
  – K_hor 4e-4 m/s
  – K_vert 4e-5 m/s

ZSoil Drivers

- B3 and B5
  - Quasi-undrained; **consolidation** (and 1/100x permeability)

Equations générales des écoulements souterrains

On procède à un changement de variable en définissant, le coefficient d'emmagasinement spécifique S_s (m^{-1}) :

$$S_s = \rho \cdot g \cdot (\alpha + n \cdot \beta) \qquad (3\text{-}18)$$

Il est composé de deux termes :

- $\rho.g.\alpha$: emmagasinement dû à la variation de volume du squelette solide ou à la quantité d'eau expulsée à cause de la dilatance
- $\rho \cdot g \cdot n \cdot \beta$: emmagasinement dû à la compressibilité du fluide

Alors l'équation (3-17) devient :

$$\nabla^2 h = \frac{S_s}{K} \cdot \frac{\partial h}{\partial t} \qquad (3\text{-}19)$$

C'est la **loi de perte de charge** qui régit l'écoulement souterrain.

Coupled total stress analysis (CTS) in **Deformation+Flow** mode

Governing equations for two-phase fully or partially saturated medium

- Overall equilibrium: $\sigma^{tot}_{ij,j} + f_i = 0$
- Effective stress principle by Bishop: $\sigma^{tot}_{ij} = \sigma'_{ij} + S\, p\, \delta_{ij}$
- Fluid flow continuity: $S\, \dot{\varepsilon}_{kk} + v^F_{k,k} - c\, \dot{p} = 0$
- Body load: $f_i = (\gamma^{DRY} + S\, n\, \gamma^F)\ b_i$

Remark

The initial void ratio e_o (to be set at the material level) plays an important role especially in the CTS analyses

- B4 and B6
  - Drained; **driven loads – steady state**

Un écoulement permanent est caractérisé par le fait que la charge ne varie pas avec le temps, c'est à dire :

$$\frac{\partial h}{\partial t} = 0 \qquad (3\text{-}20)$$

L'équation (3-19)donne alors :

$$\nabla^2 h = \Delta h = \frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} + \frac{\partial^2 h}{\partial z^2} = 0 \qquad (3\text{-}21)$$

Remarque : cette loi régissant l'écoulement en régime permanent est indépendante de la perméabilité *K*.

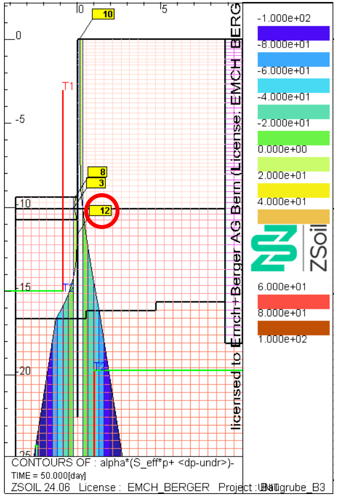
Uncoupled total stress analysis (UTS) in **Deformation+Flow** mode

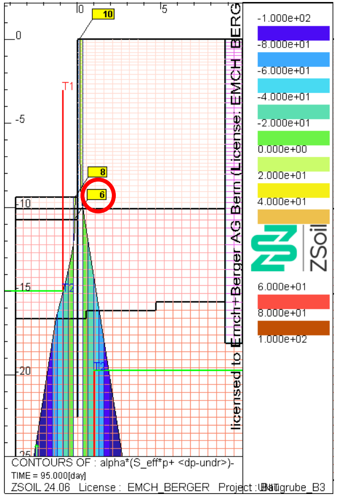
Governing equations for two-phase fully or partially saturated medium

- Overall equilibrium: $\sigma^{tot}_{ij,j} + f_i = 0$
- Effective stress principle by Bishop: $\sigma^{tot}_{ij} = \sigma'_{ij} + S\, p\, \delta_{ij}$
- Fluid flow continuity (steady state): $v^F_{k,k} = 0$
- Body load: $f_i = (\gamma^{DRY} + S\, n\, \gamma^F)\ b_i$
- In this case each computational step consists of two:
  1. Steady state fluid flow; it yields current pressure state $p(t_{N+1})$
  2. Evaluation of mechanical state $(u_{N+1}, \boldsymbol{\sigma}_{N+1})$ with the explicit pore pressures state $p(t_{N+1})$

Pore pressure by Bishop

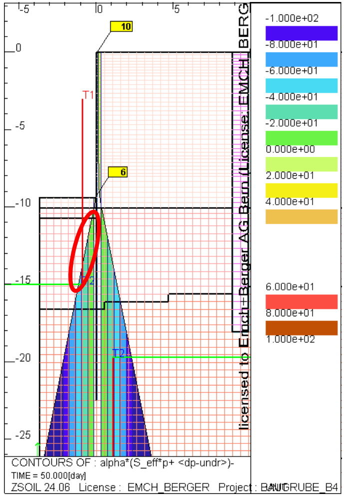
– Quasi-undrained; **consolidation**

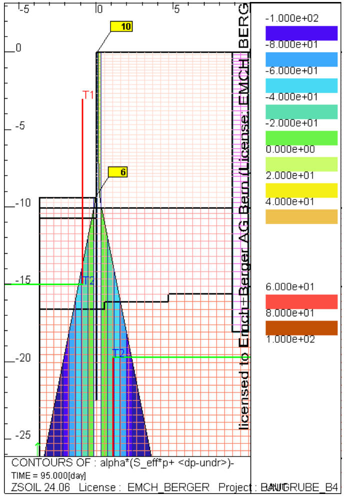




– The suction due to the excavation reduces from 12 kPa to 6 kPa.
(pore pressure increases)

– Drained; **driven loads – steady state**



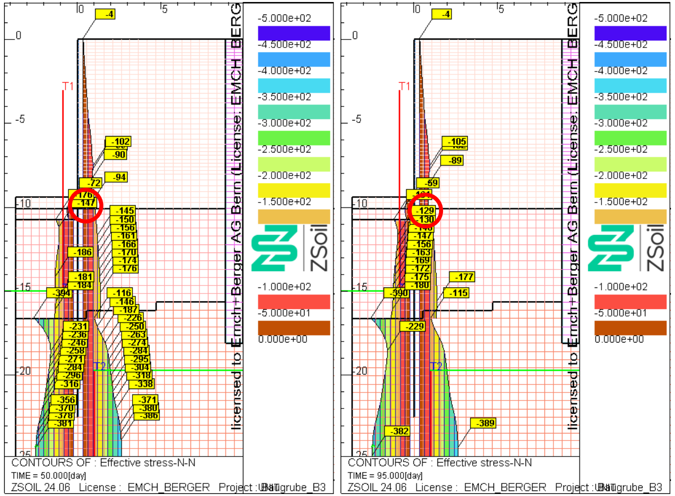


– There is no suction below the water table.

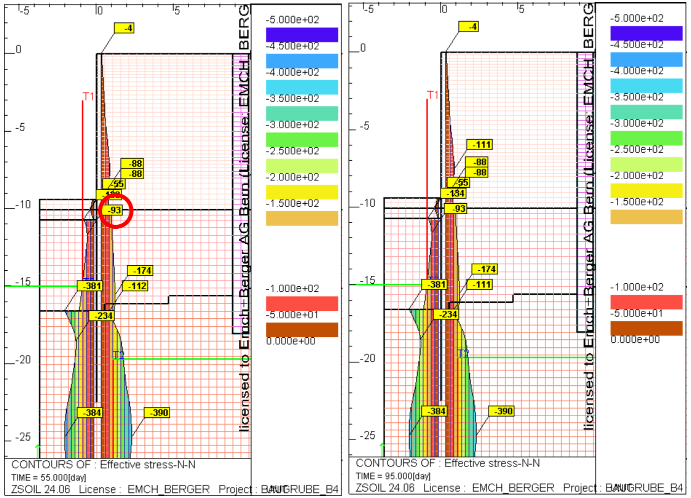
– No change in time

Effective stress σ’

– Quasi-undrained; **consolidation**



– Drained; **driven loads – steady state**



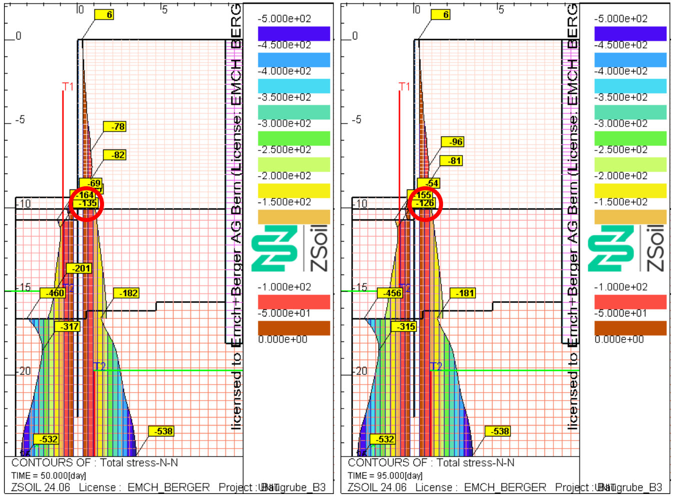
– Effective stress decreases in magnitude from -147 kPa to -129 kPa.

– Effective stress -93 kPa

– No change in time

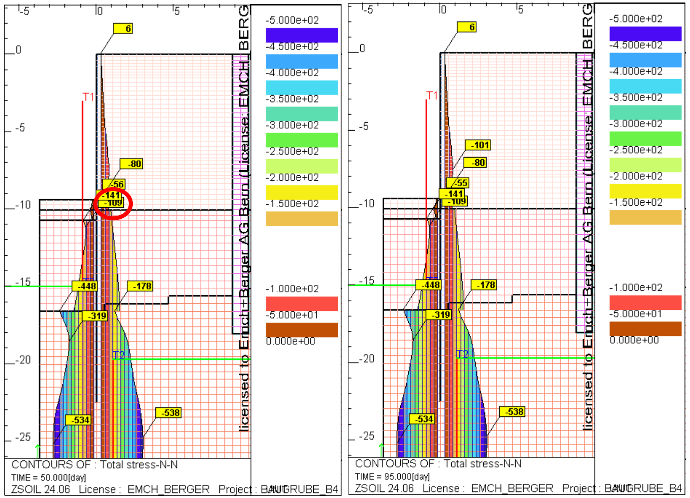
Total stress σ

– Quasi-undrained; **consolidation**



– Total stress decreases in magnitude from -135 kPa to -126 kPa.

– Drained; **driven loads – steady state**

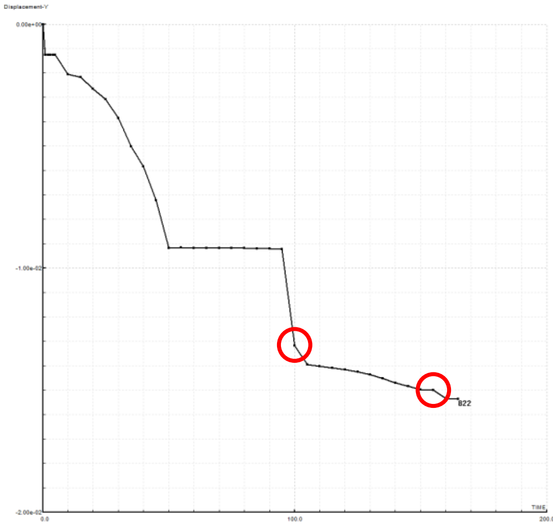


– Total stress -109 kPa

– No change in time

Deformation

– Quasi-undrained; **consolidation**

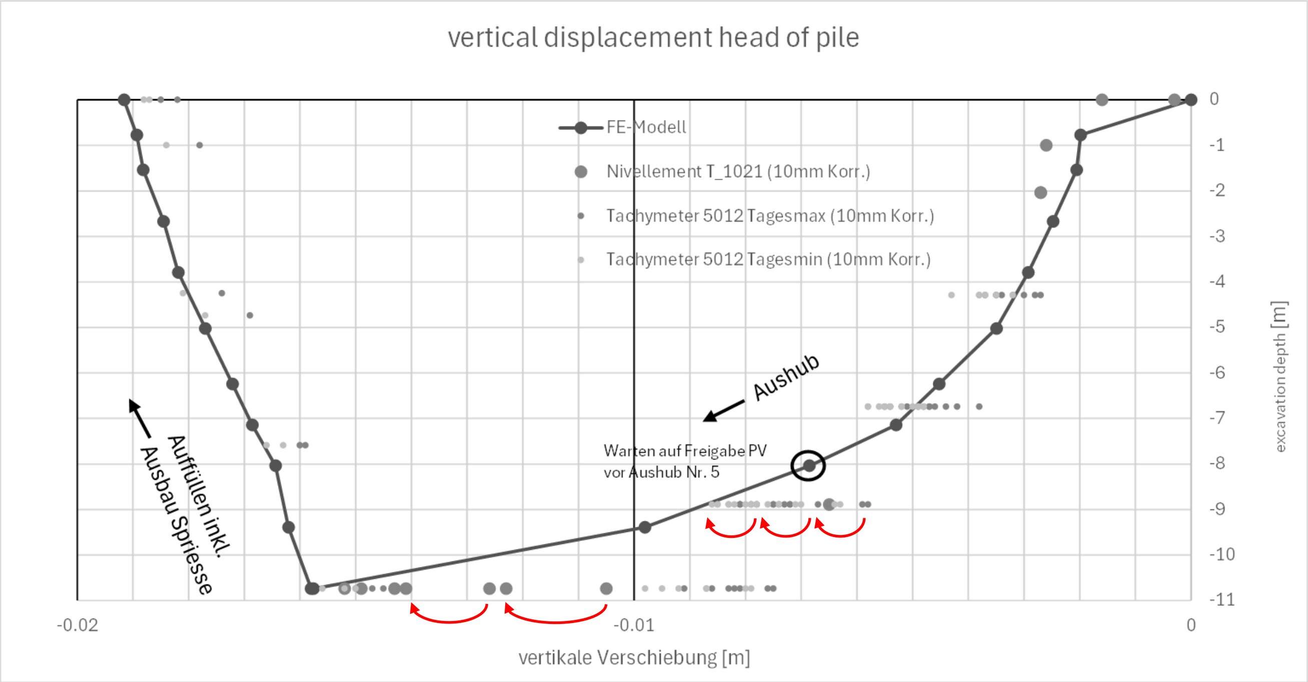


– Deformation from -13 mm to -15 mm

– Drained; **driven loads – steady state**

– Deformation -16 mm

Deformation



– Deformation increases over time

Thank you for your attention!

Picture by

Dr. Walter Steiner / B+S