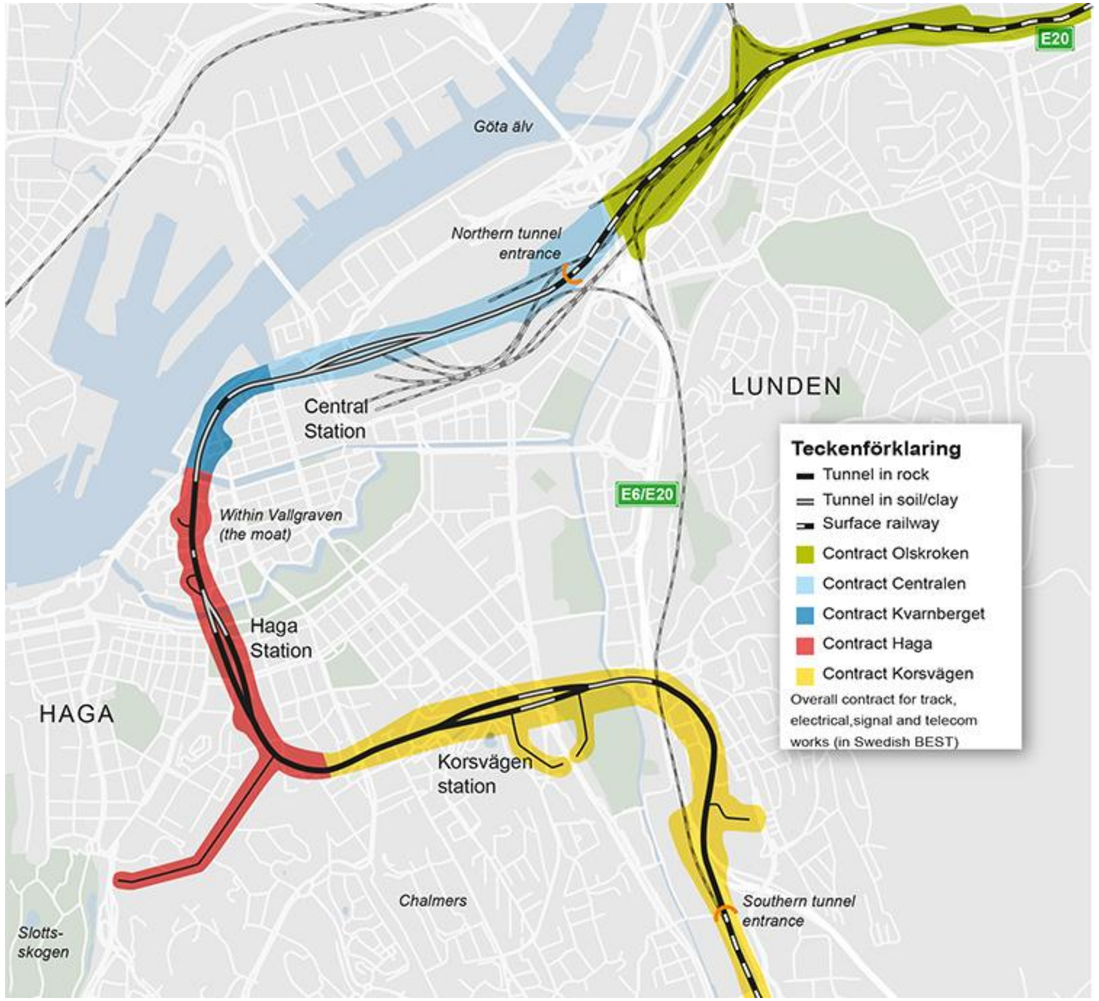
RD pile retaining walls Korsvägen station: Predictions versus monitoring

Thomas Kasper, COWI A/S, Denmark
Vinicius da Quinta Rodrigues, University of Porto, Portugal

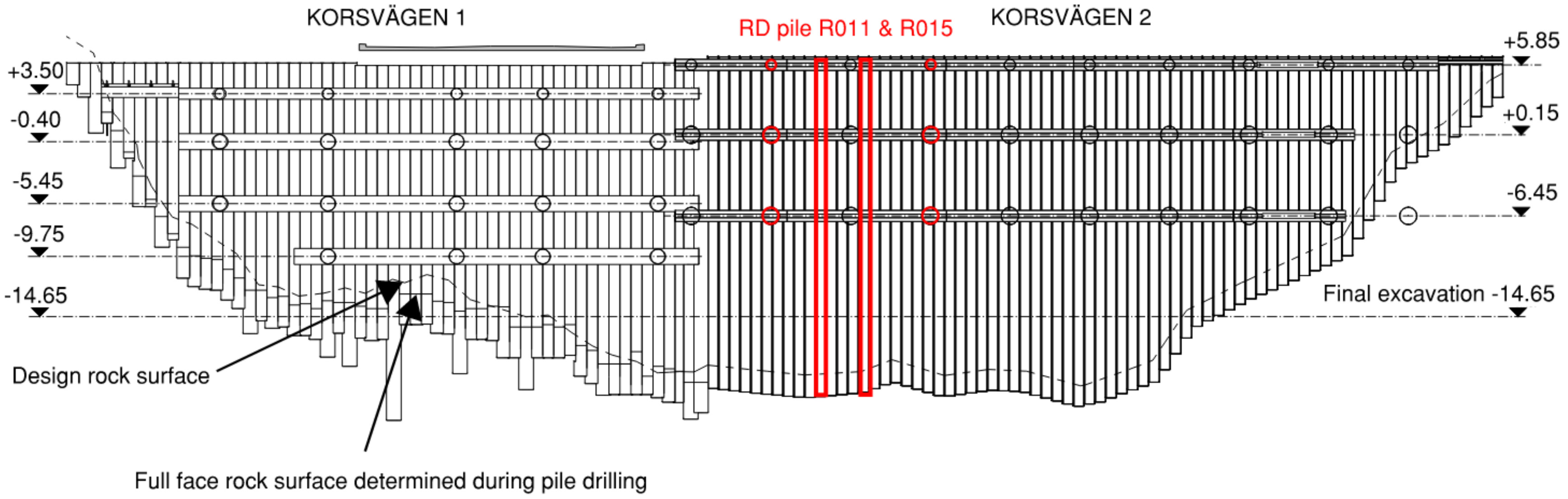
PÅLDAG 24

pålgrundläggning



Västlänken E05 Korsvägen design & build contract: NCC and Wayss & Freytag Ingenieurbau JV with COWI A/S as main designer

Reference: T. Kasper, M.B. Steffensen, C. Maier, J. Wächter (2023): Deep excavation design for Korsvägen underground railway station in challenging ground conditions. Forschung + Praxis, U-Verkehr und unterirdisches Bauen, Vol. 59, STUVA e.V.

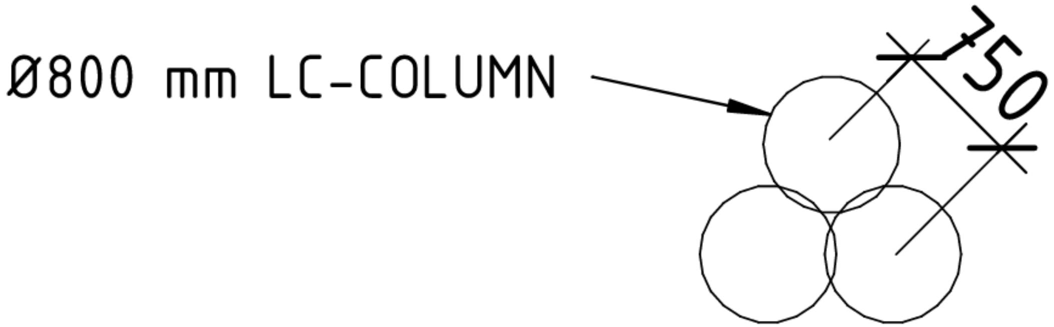


RD pile wall consists of ø813 mm/t = 20 mm piles with steel grade S355 and c-c spacing of 877 mm.

Deflection monitoring results in this presentation are average values of the two red marked piles
Strut force monitoring results in this presentation are average values of the two red marked strut rows

Lime cement (LC) block stabilization of the whole excavation volume:

- Increase passive resistance – reduce wall deflections and optimize retaining wall system
- Ease excavation and muck handling / transport
- 40 kg/m3 30/70 % lime/cement binder type for RD piles



Clay at Korsvägen station:		
	Sensitivity	20 -150
	$C_{u,active}$ (kPa)	25 – 33
	w_N (%)	75

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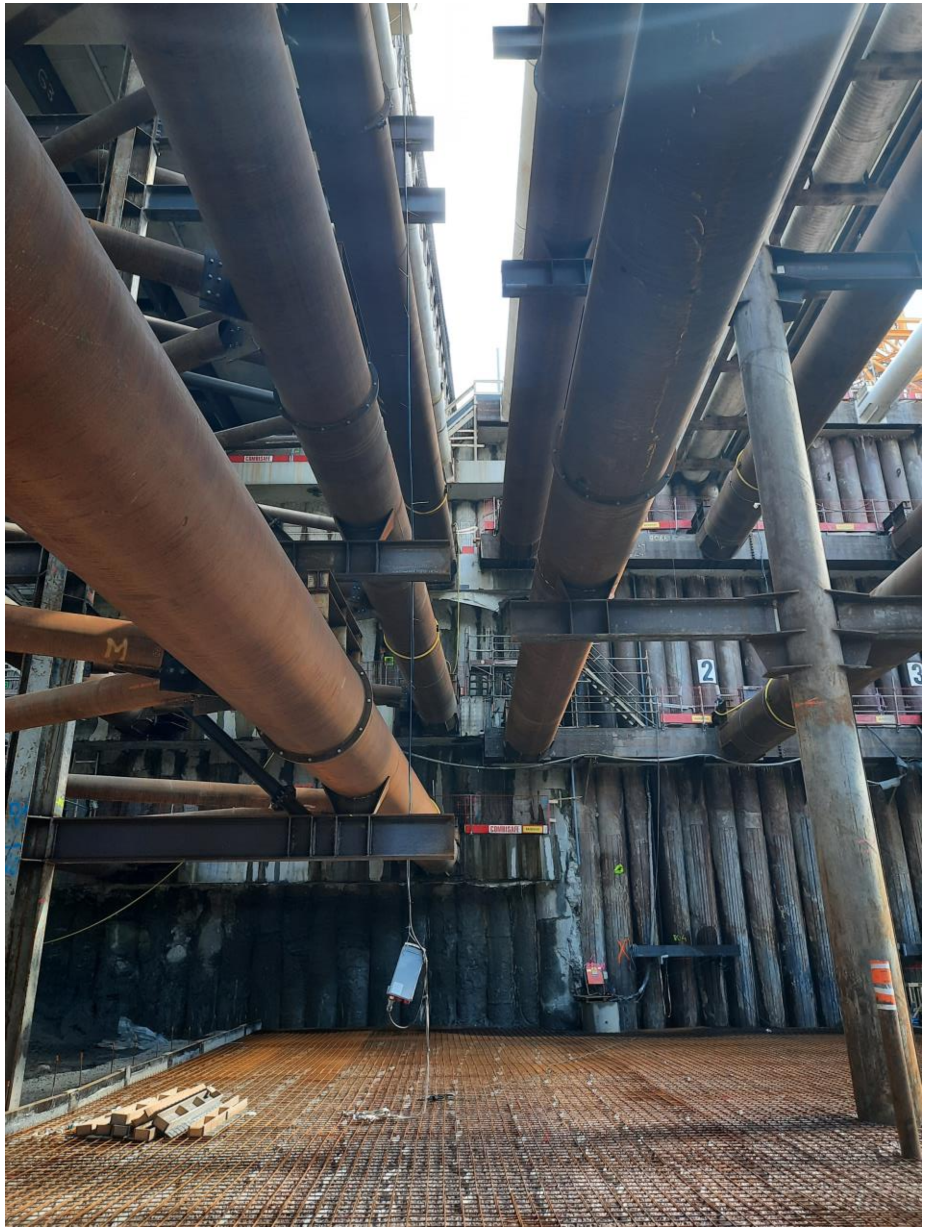
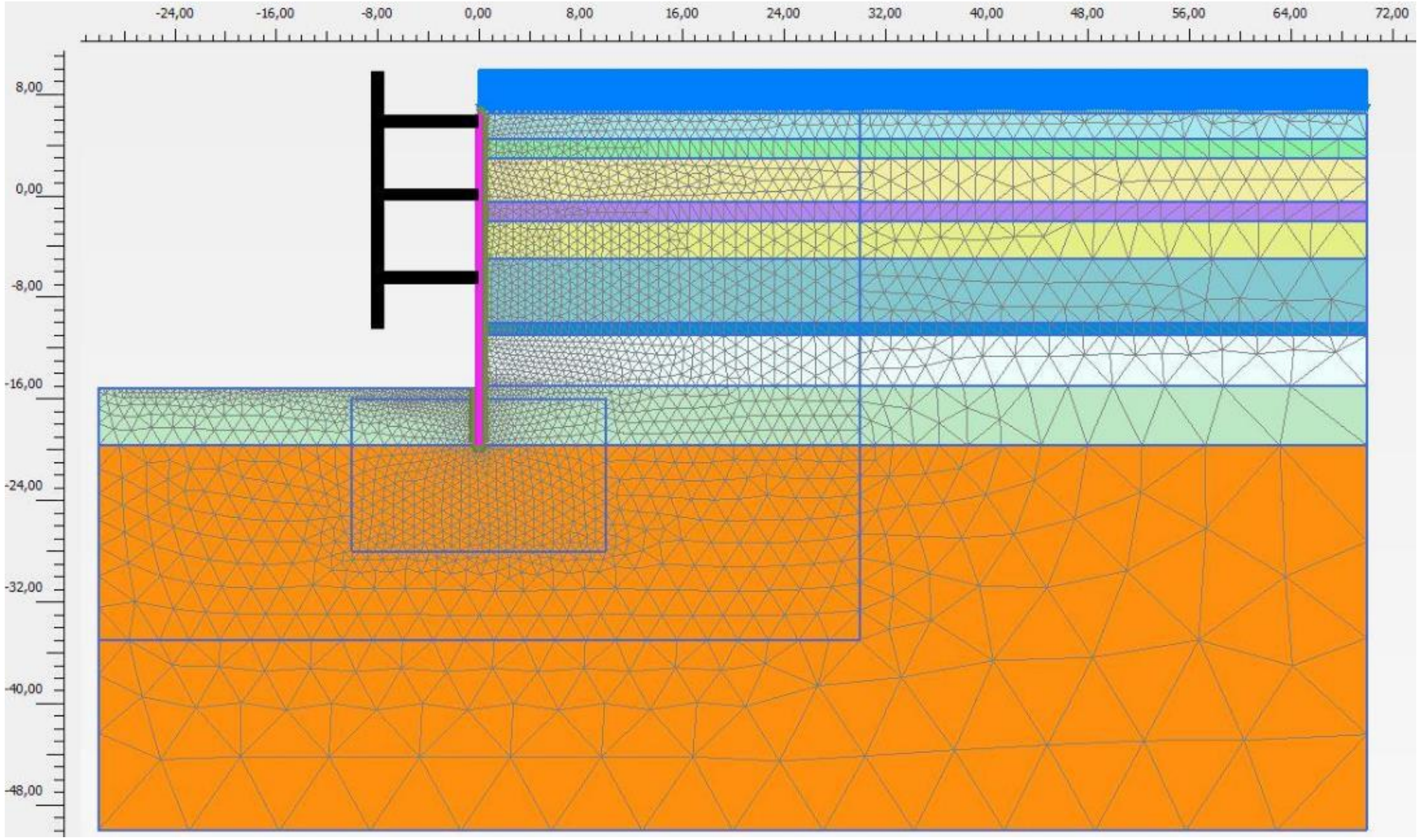
pålgrundläggning





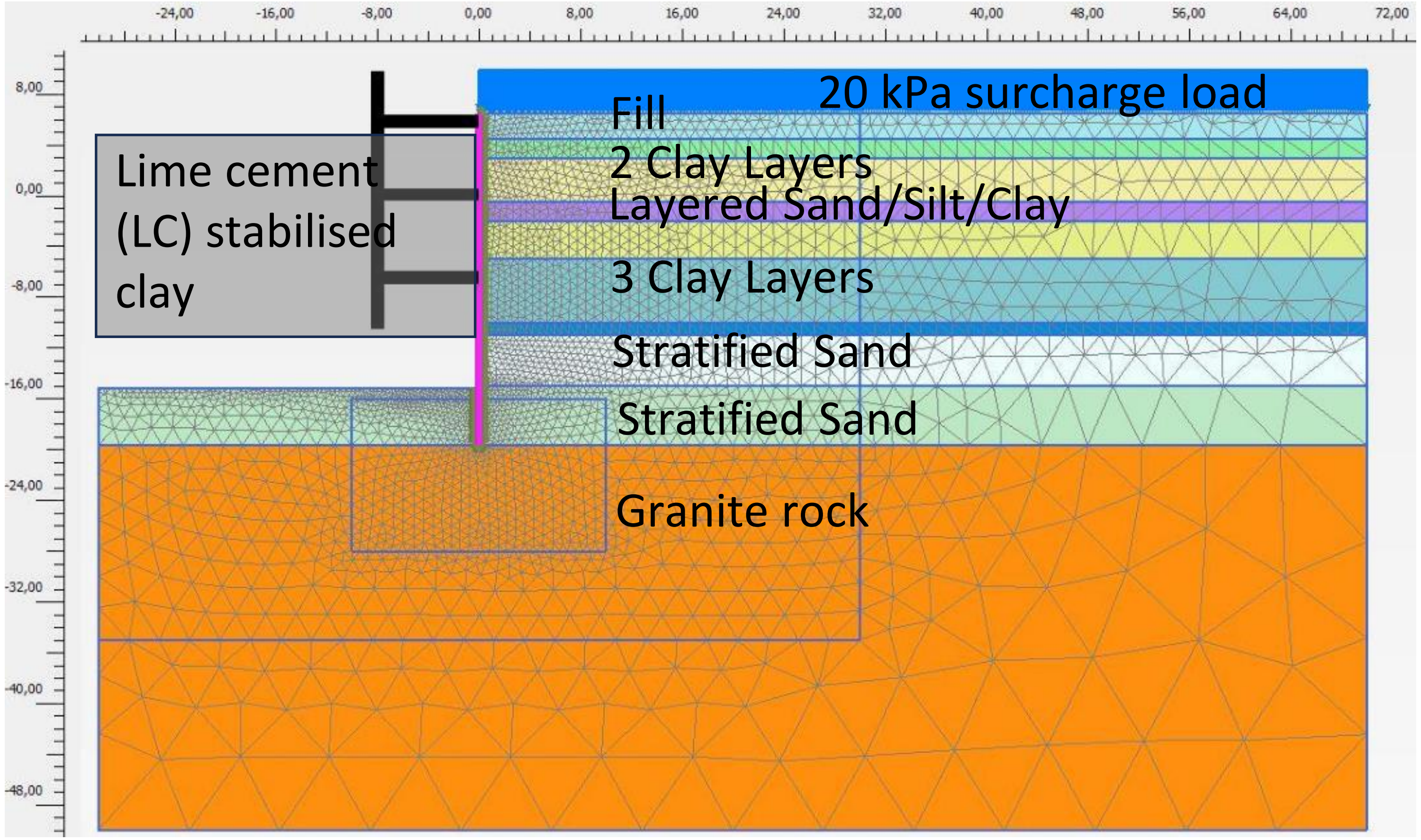
Plaxis model for RD pile R011

Mohr-Coulomb material model:

- Fill (Drained)
- Layered Sand/Silt/Clay (Drained)
- Stratified Sand (Drained)
- LC stabilised clay on passive side (Undrained (B), E = 40 MPa, c = 100 kPa, phi = 0 according to TK Geo)

NGI-ADP material model:
Clay layers on active side

Hoek-Brown material model:
Granite rock



Groundwater level at ground surface

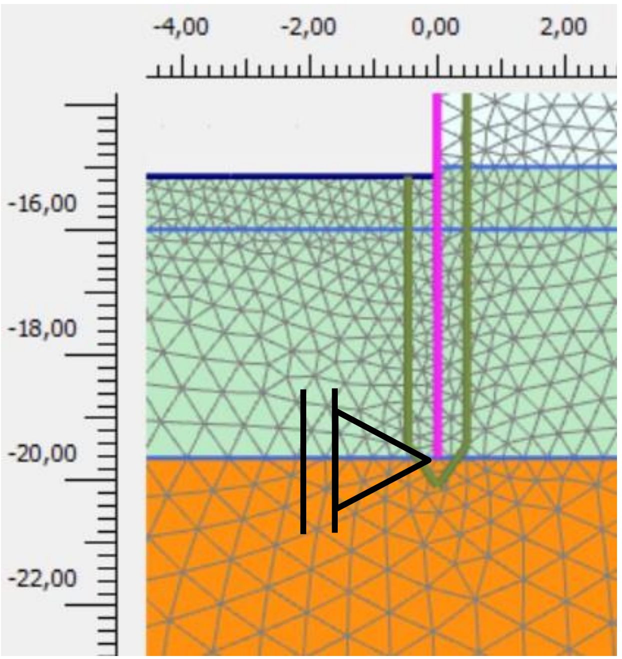
Toe support

SSAB's RD pile manual proposes low toe rotational stiffness for 3 diameter rock embedment length. 2 diameter embedment was chosen to minimise rock drilling.

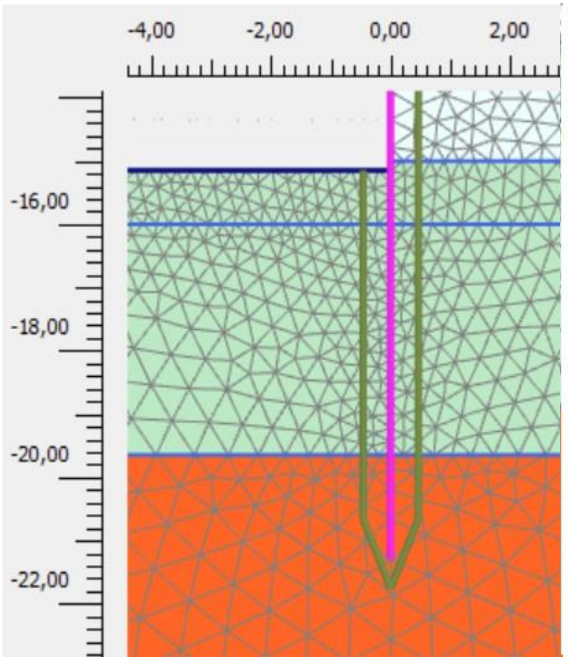
-> Design was therefore based on calculations both:

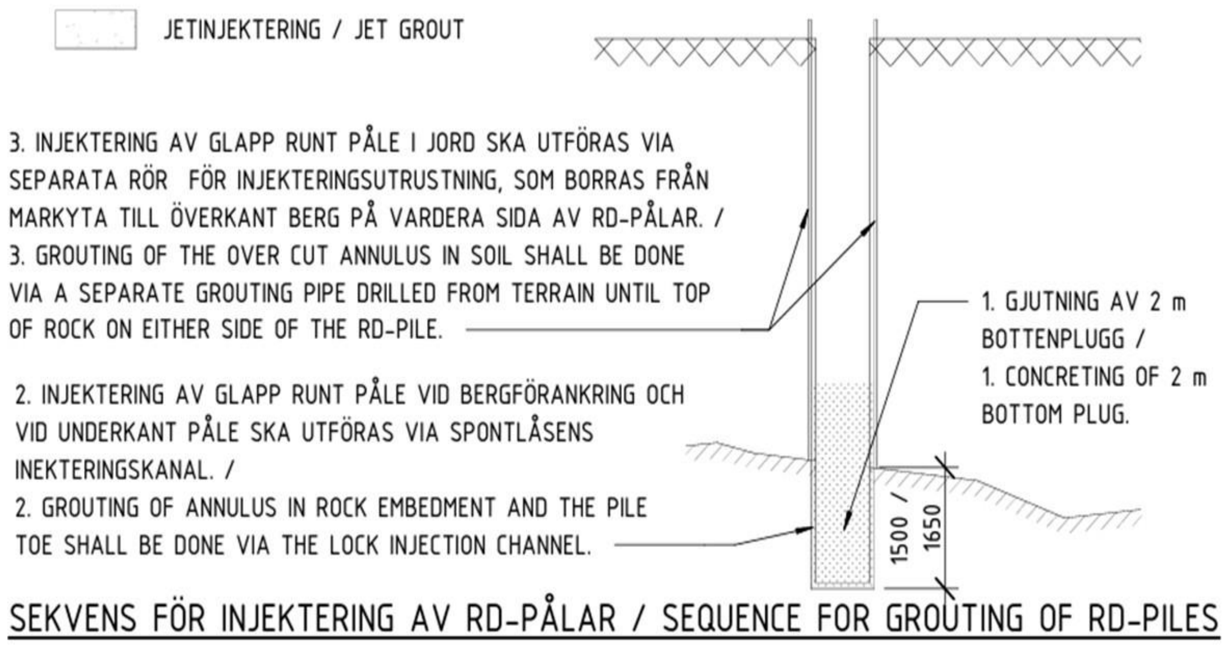
- Without toe rotational restraint (simple horizontal toe support)
- With toe rotational restraint (embedment modelling)

Without toe rotational restraint



With toe rotational restraint





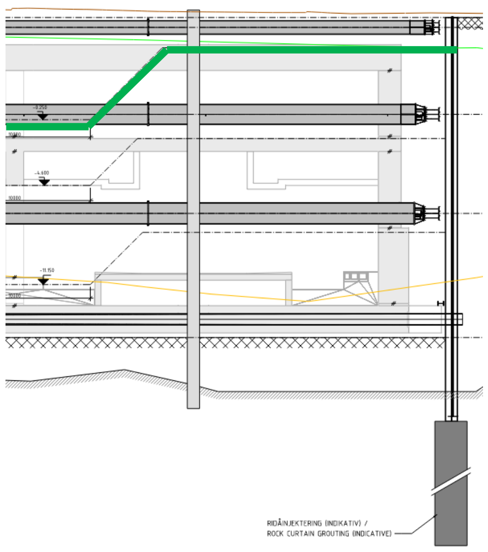
Results

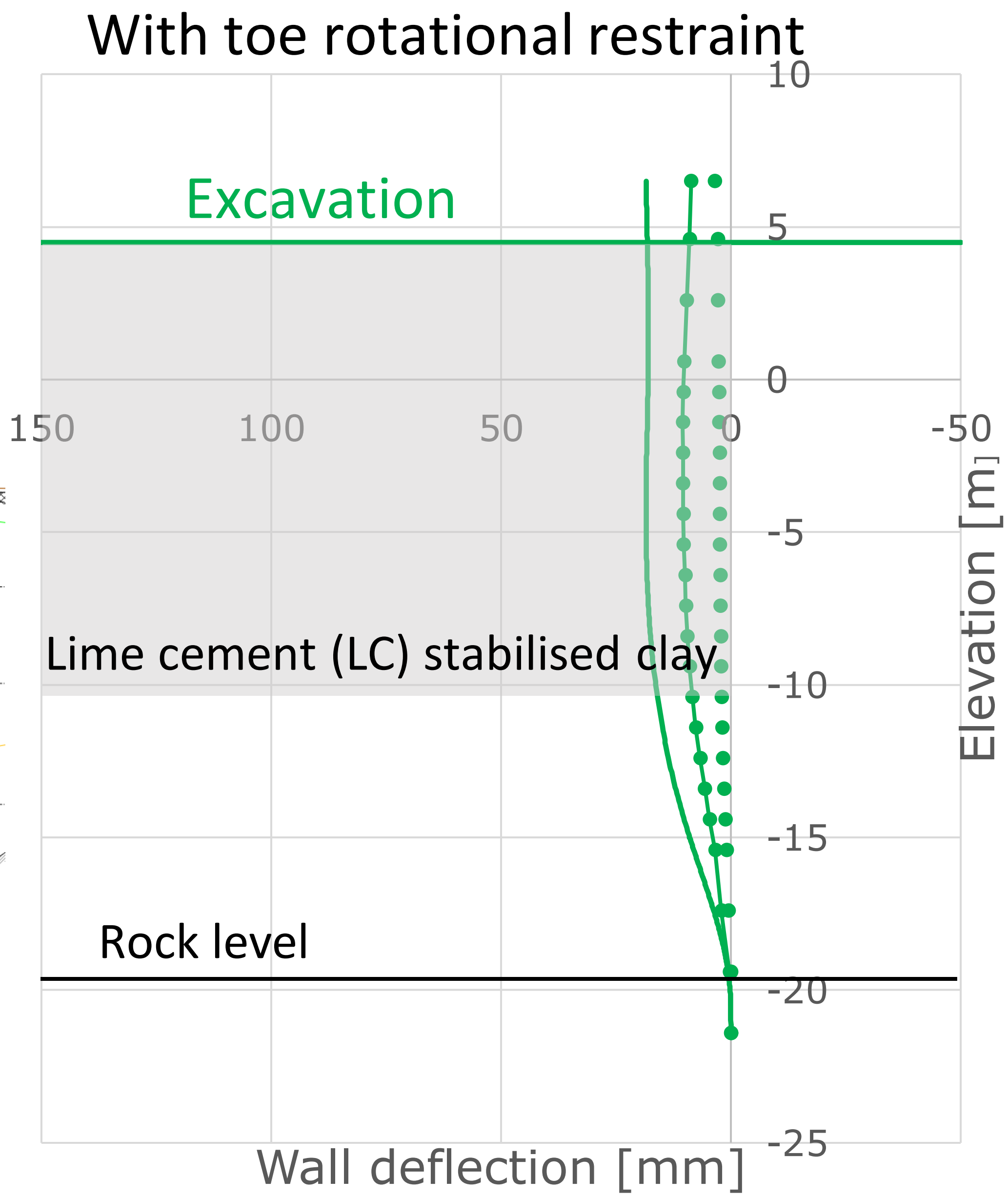
Design calculation:

No markers

Measured:

With markers





First excavation:

- 20 mm wall deflection (uniform compression of the LC block) calculated
- 3 mm deflection measured after excavation, increasing to 10 mm after strut installation

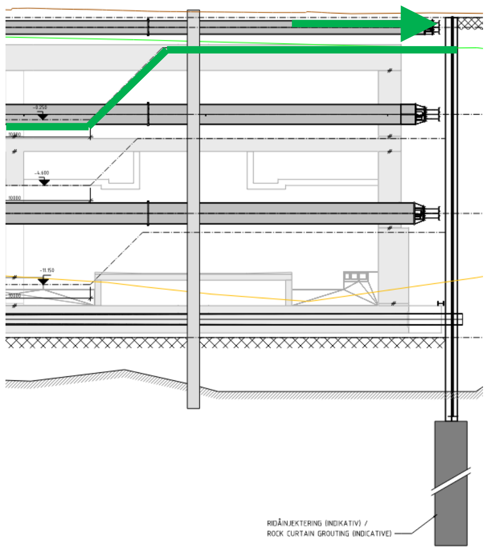
Results

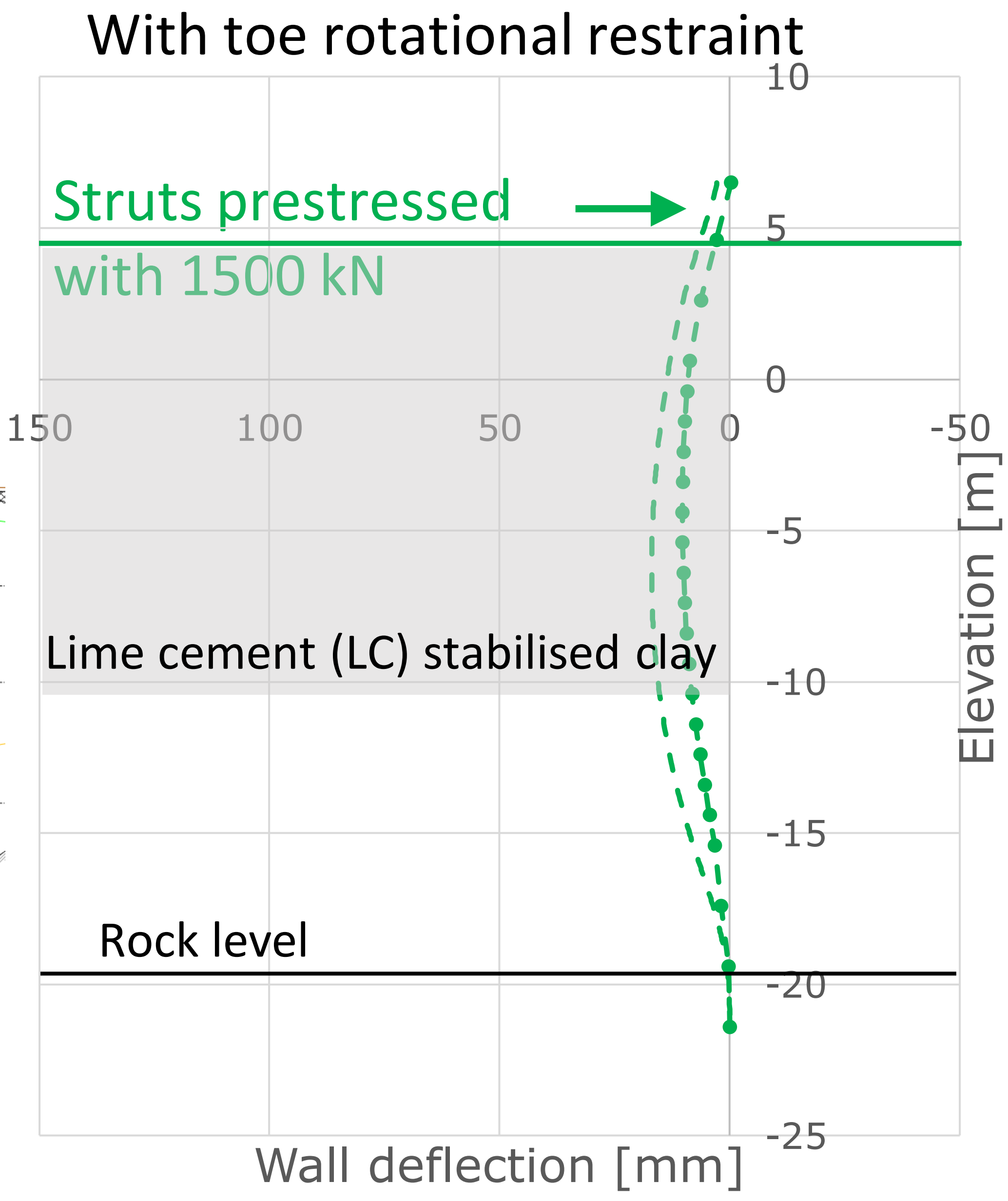
Design calculation:

No markers – –

Measured:

With markers •-•-•





Prestressing of first strut level:

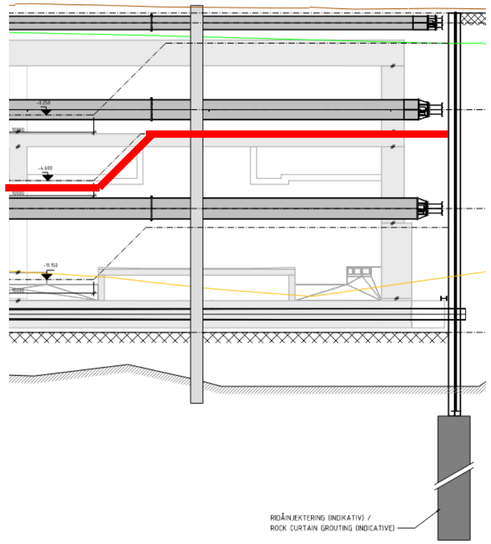
- Measured backwards deflection smaller than calculated -> soil stiffness higher than assumed

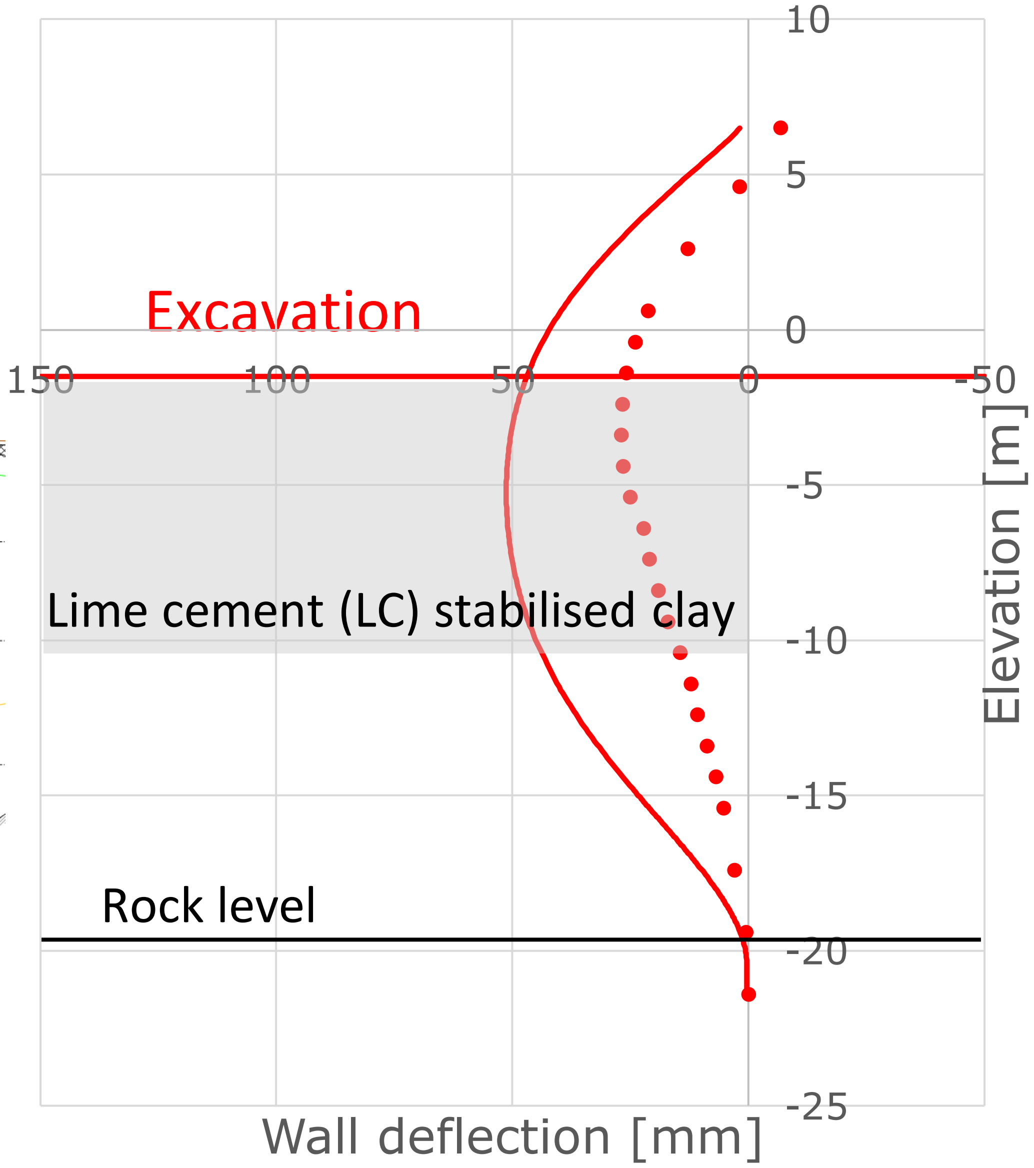
Results

Design calculation:
No markers

Measured:
With markers

With toe rotational restraint





Excavation to second strut level:

- 30 mm measured until end of excavation

Results

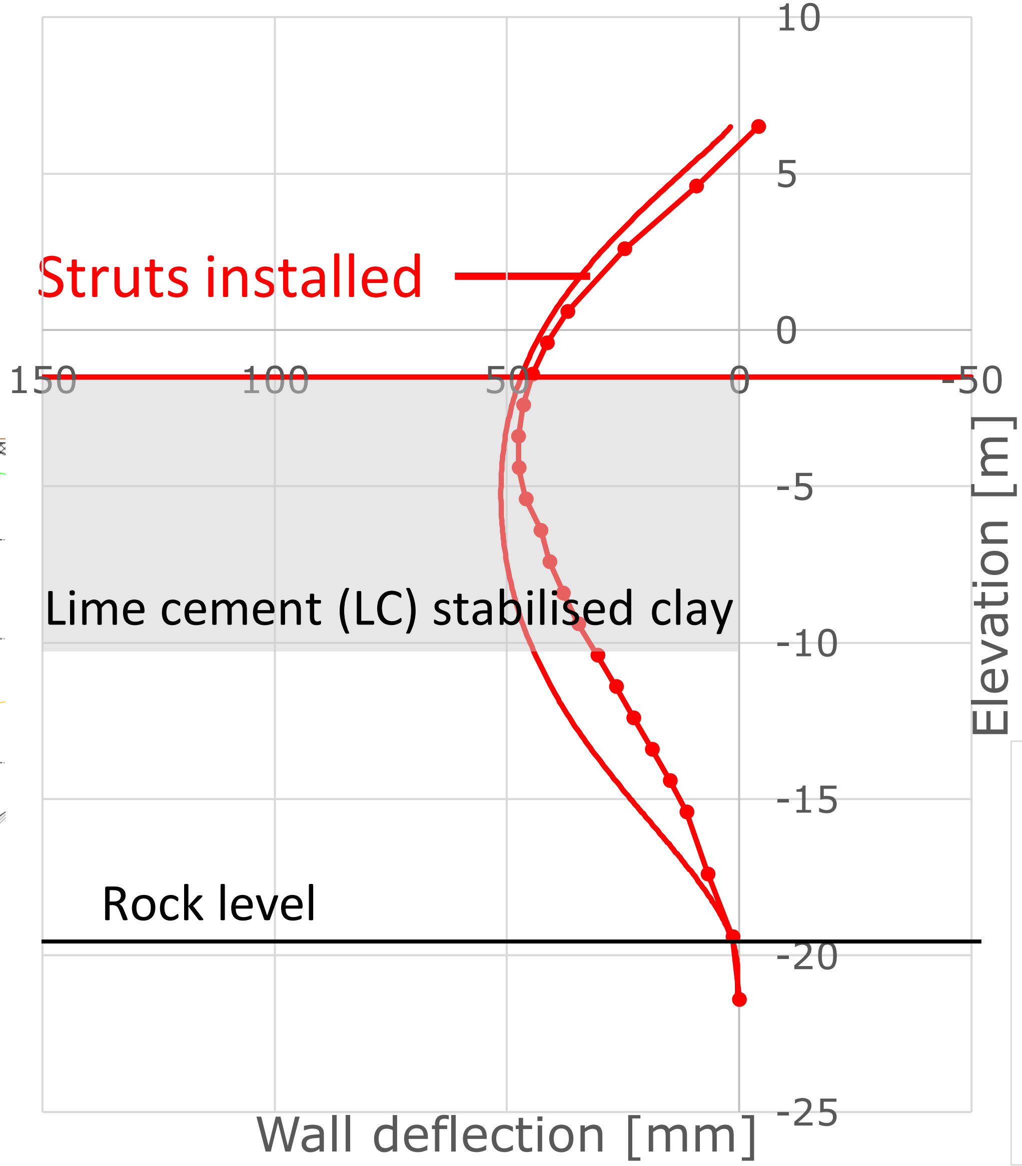
Design calculation:

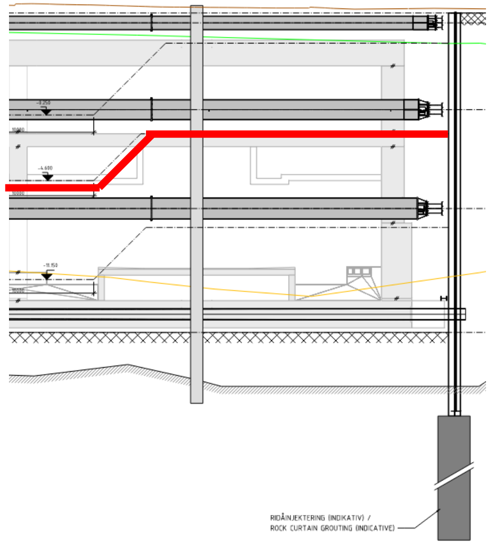
No markers

Measured:

With markers

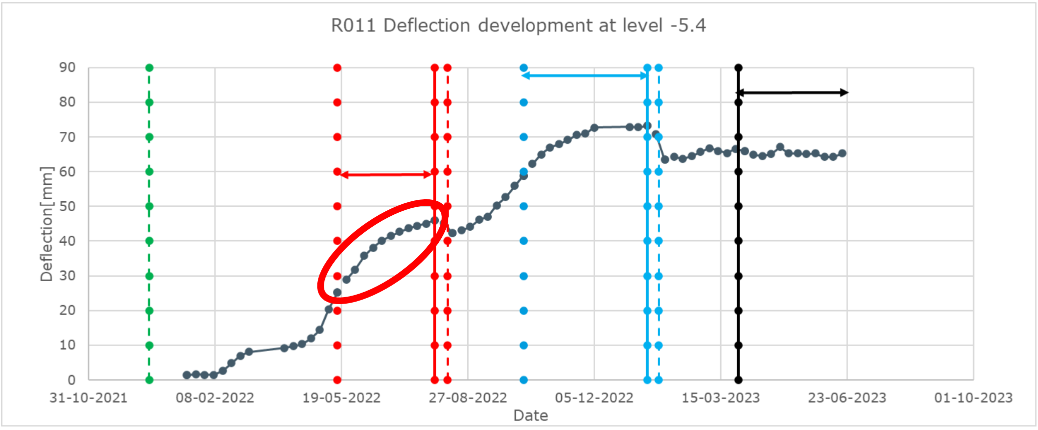
With toe rotational restraint





Second strut level installed over a 2.5 months period:

- 20 mm additional measured deflection due to LC stabilised clay consolidation



Results

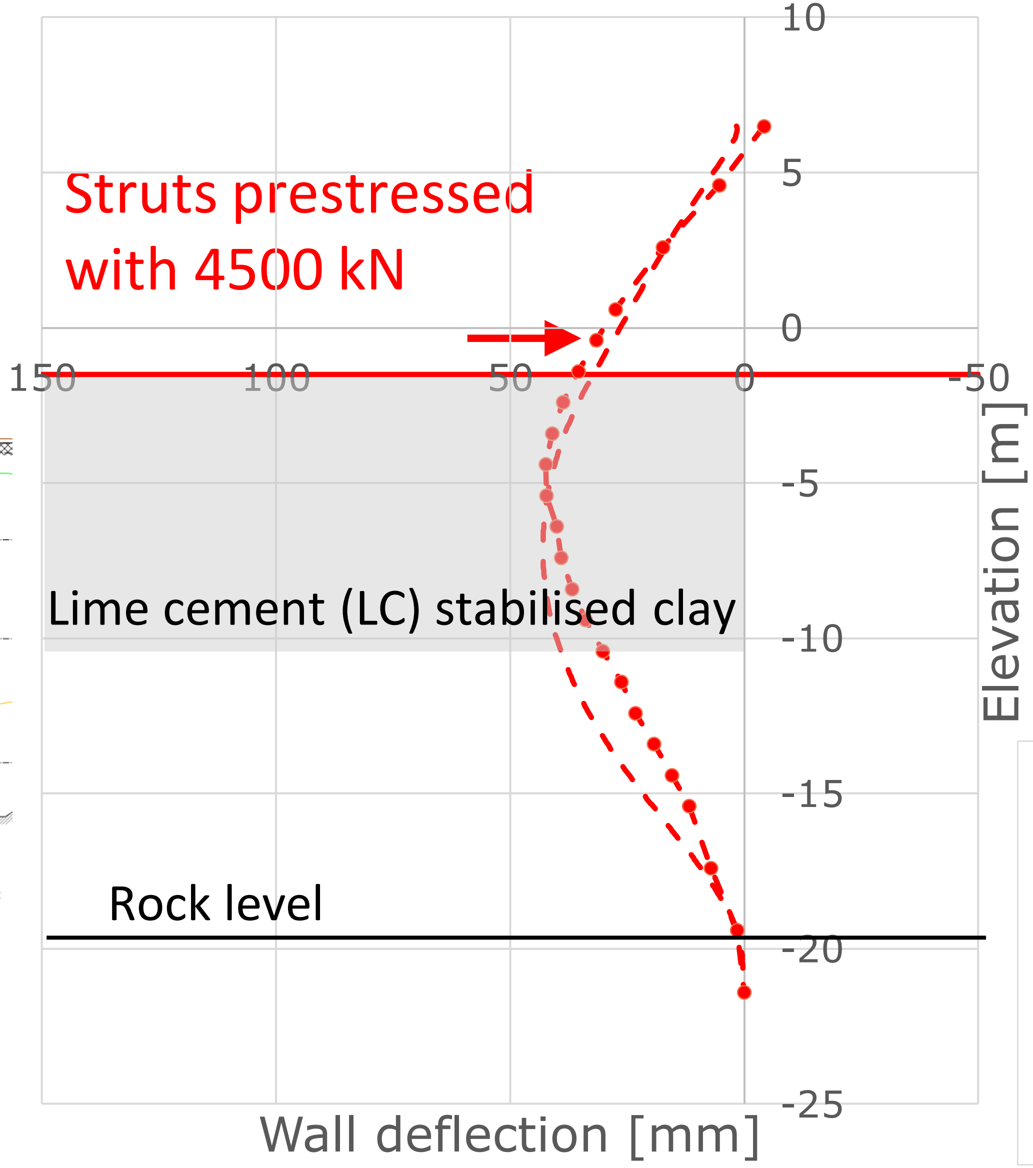
Design calculation:

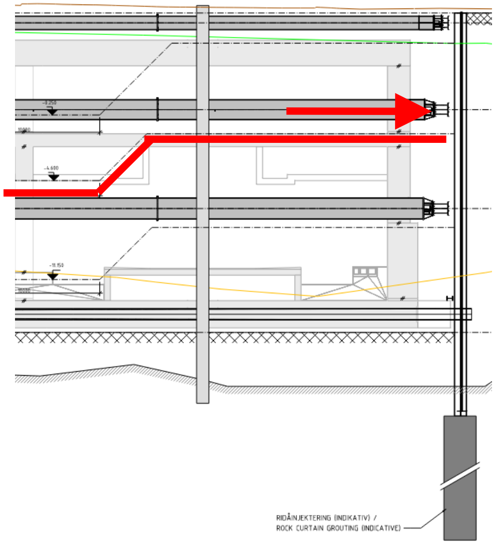
No markers

Measured:

With markers

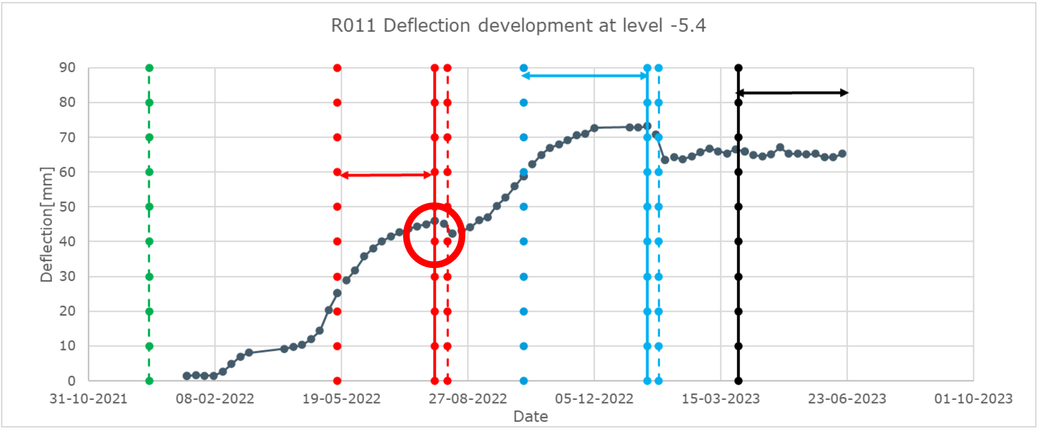
With toe rotational restraint





Second strut level prestressed:

- Measured backwards deflection smaller than calculated -> soil stiffness higher than assumed

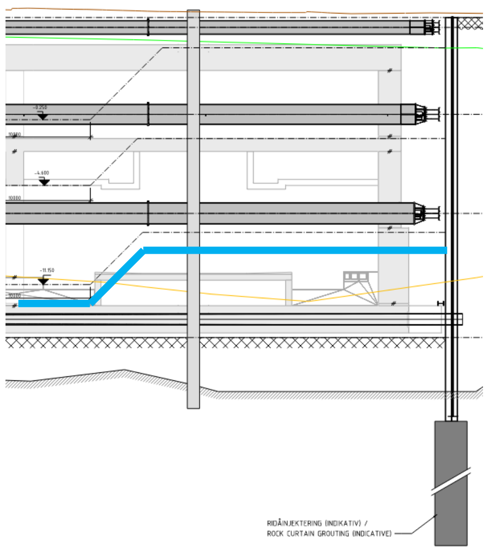


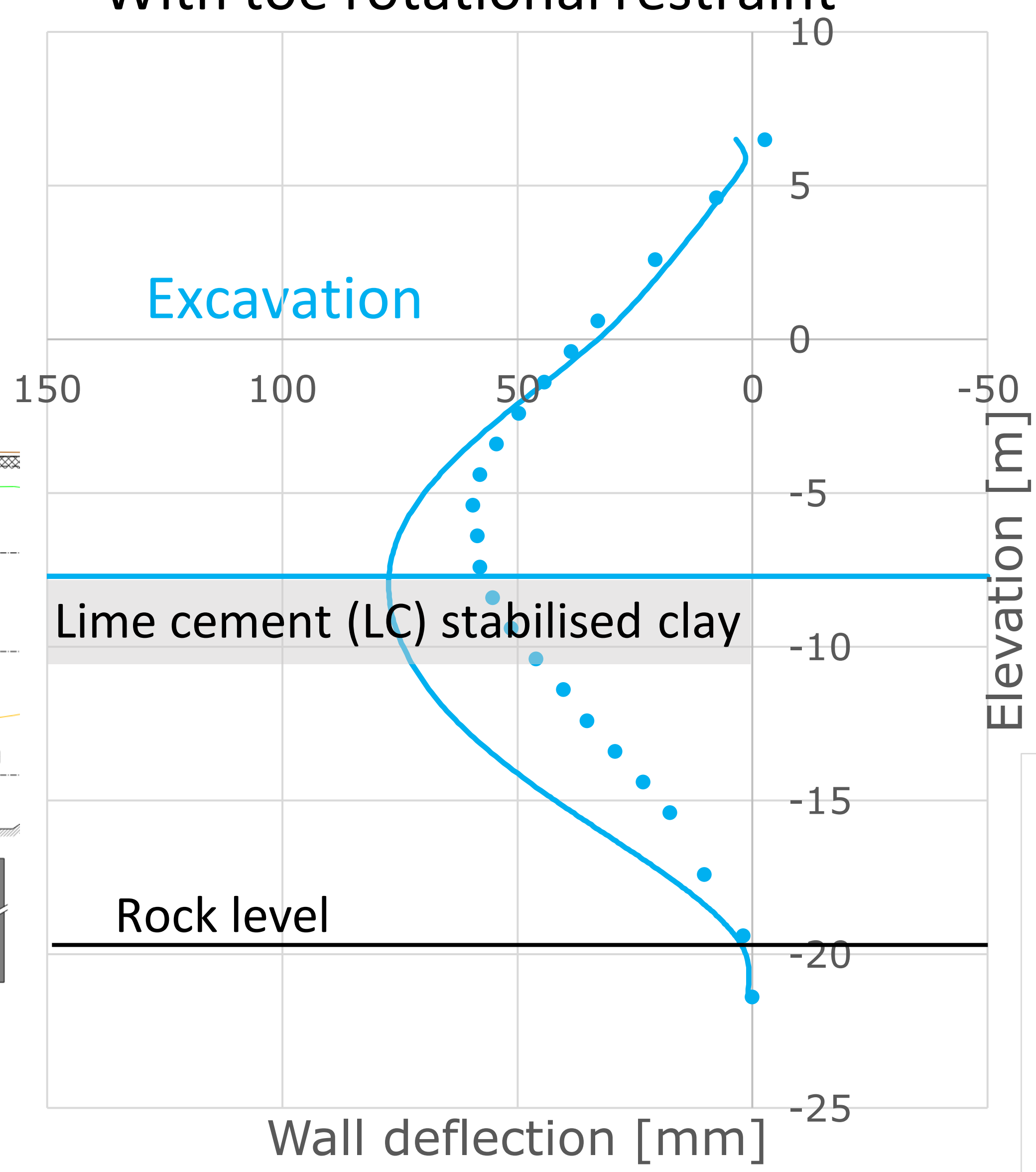
PÅLDAG 24 *pålgrundläggning*

Results

Design calculation:
No markers – –

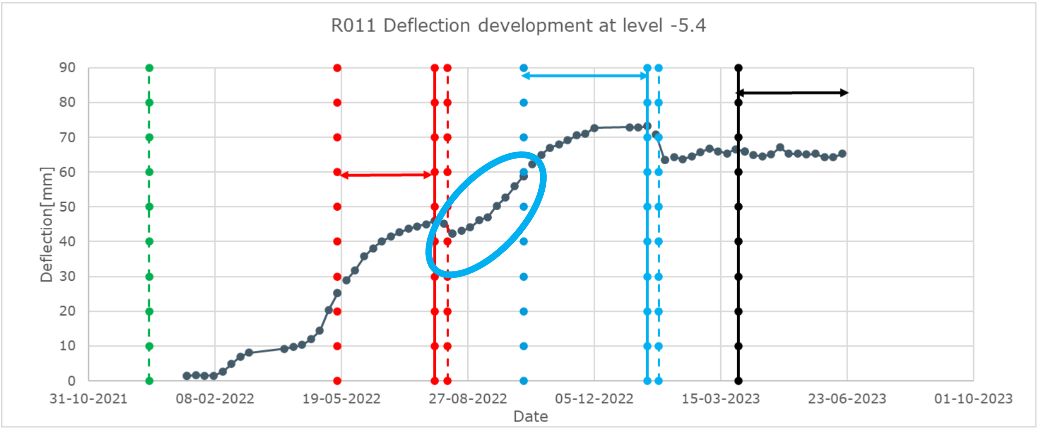
Measured:
With markers • • •





Excavation to third strut level:

- 20 mm additional measured deflection until end of excavation



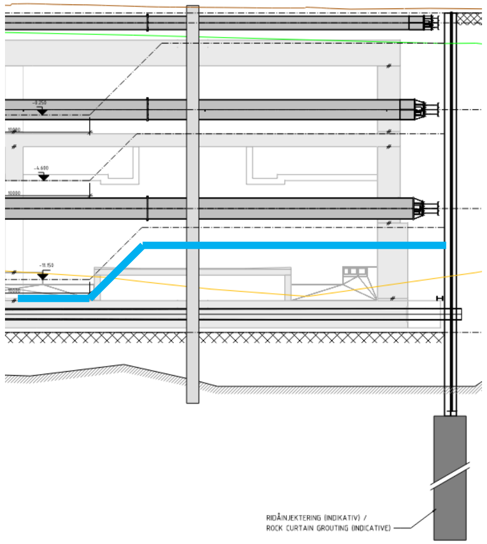
Results

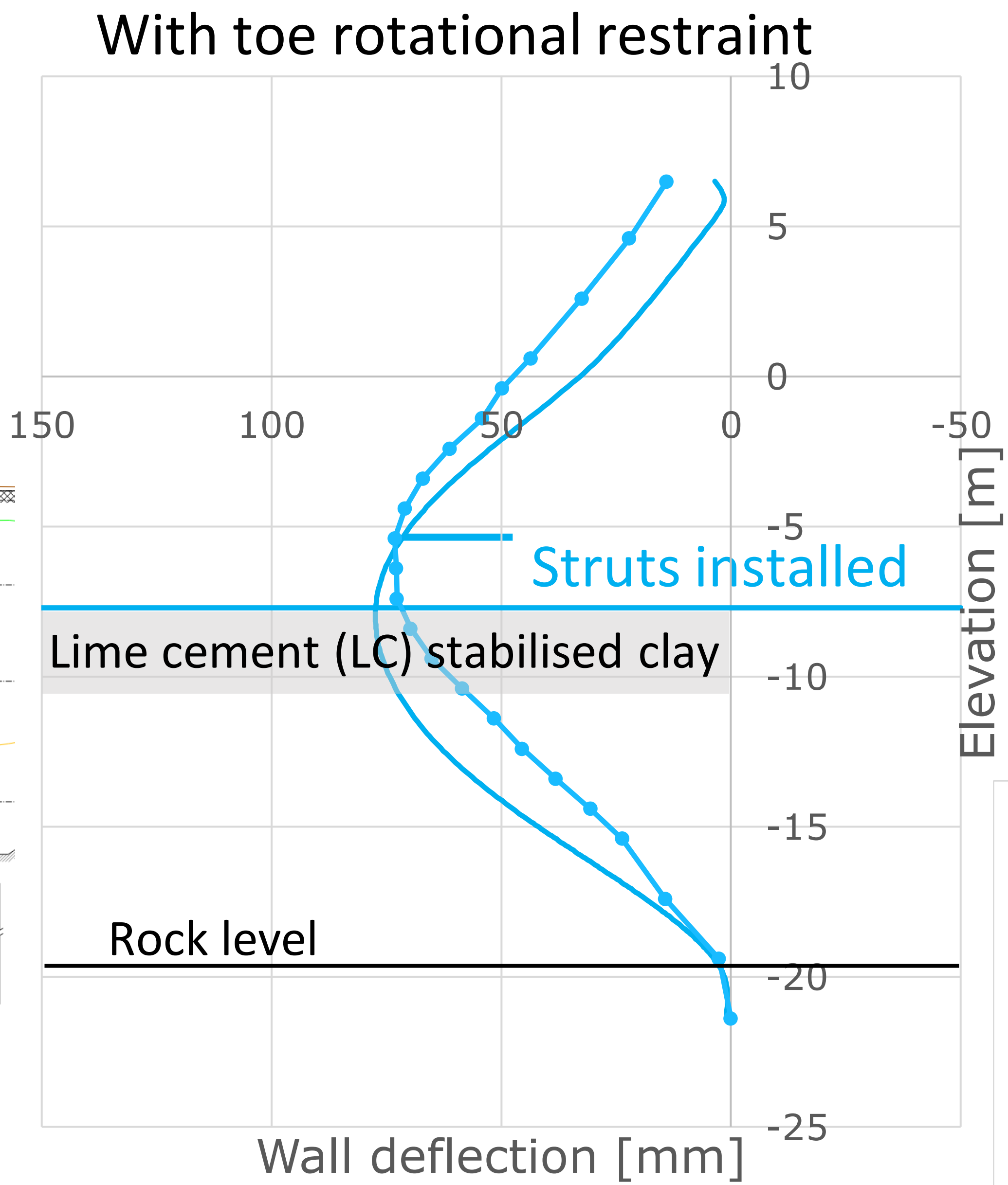
Design calculation:

No markers

Measured:

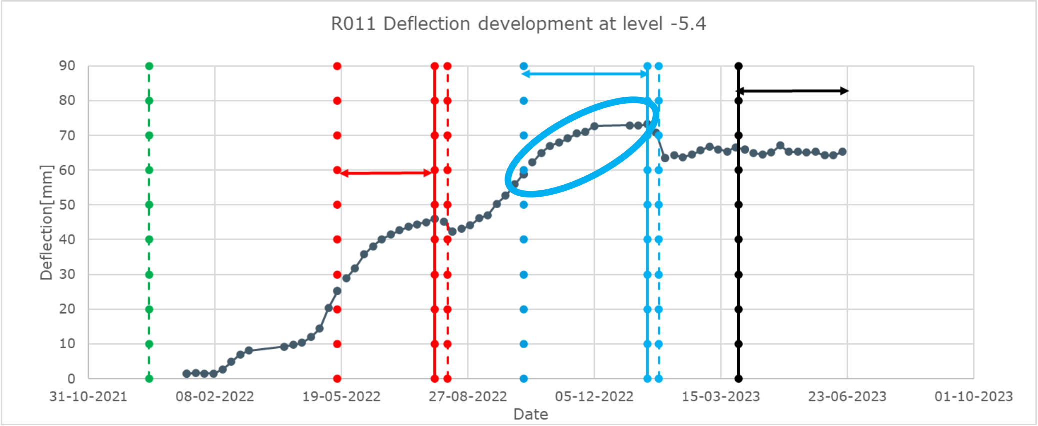
With markers





Third strut level installed over a 3 months period:

- 15 mm additional measured deflection due to LC stabilised clay consolidation
- Additional deflection at strut level 1 & 2 due to temperature effects and northwards deflection of both north and south wall



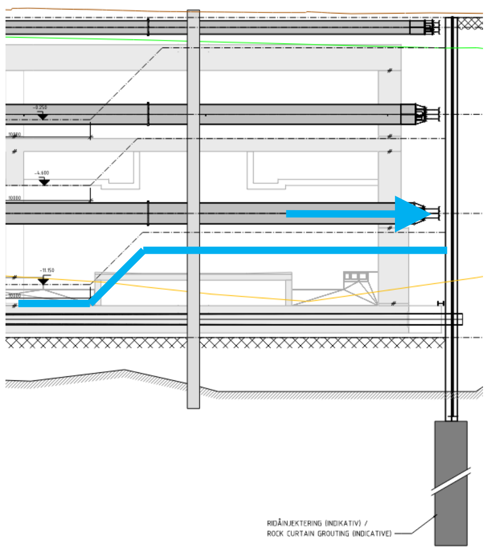
Results

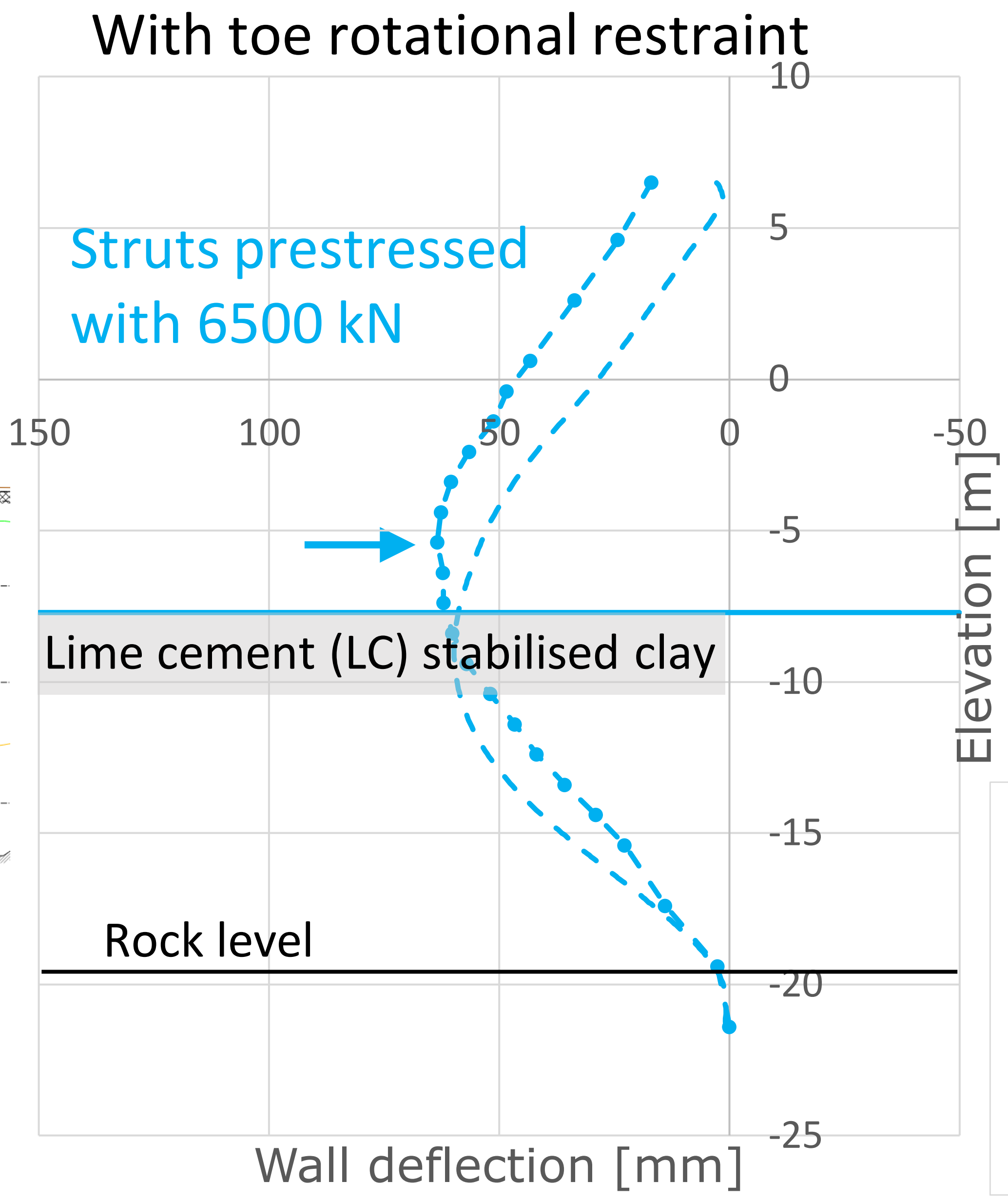
Design calculation:

No markers – –

Measured:

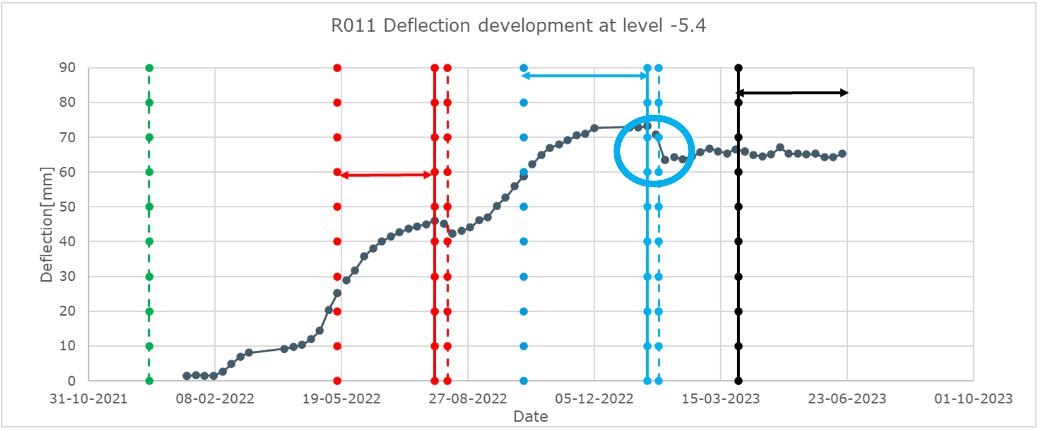
With markers





Third strut level prestressed:

- Measured backwards deflection smaller than calculated -> soil stiffness higher than assumed



Results

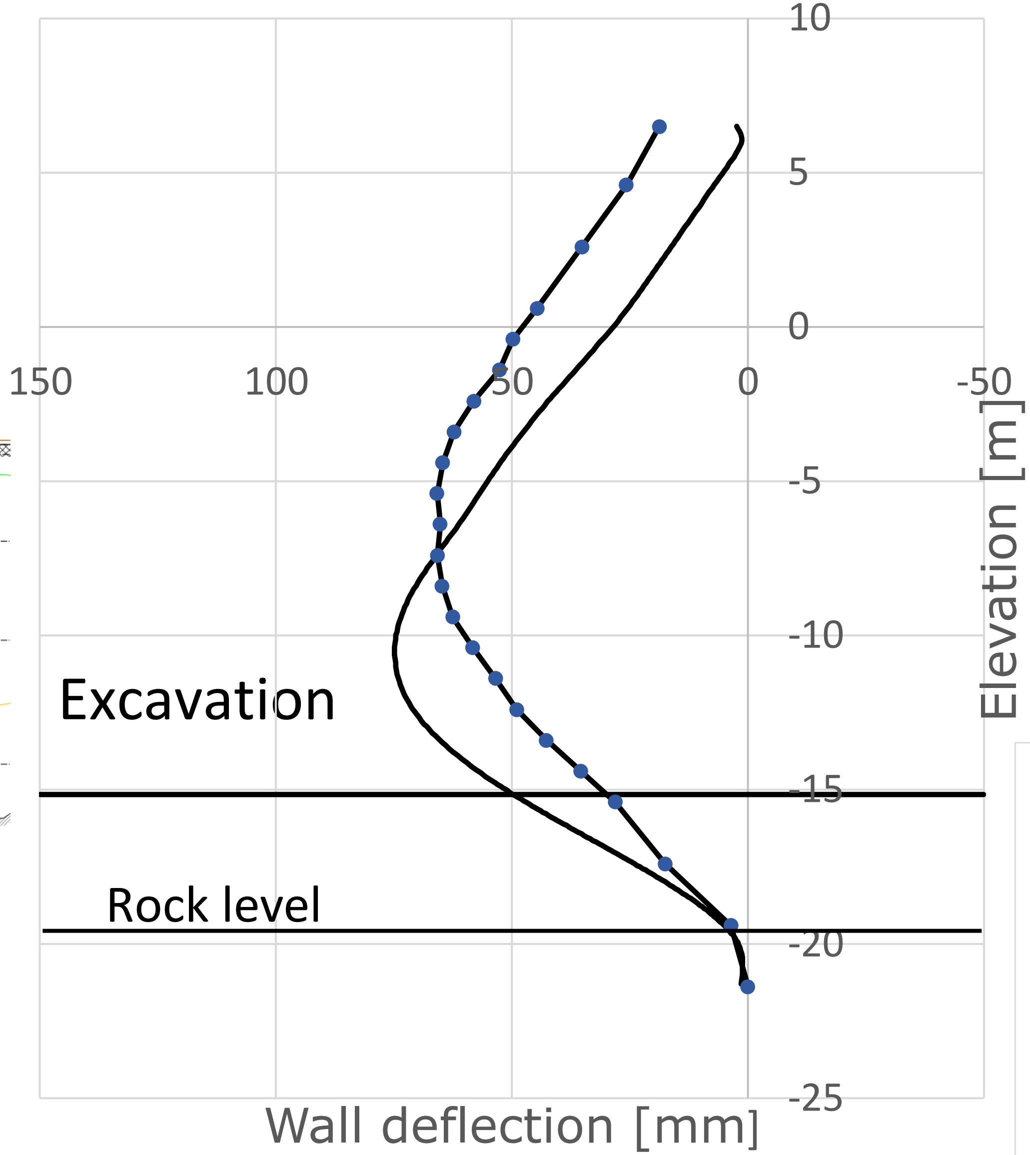
Design calculation:

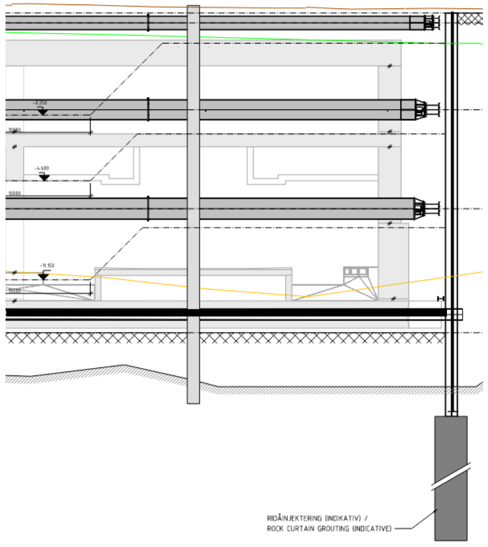
No markers

Measured:

With markers

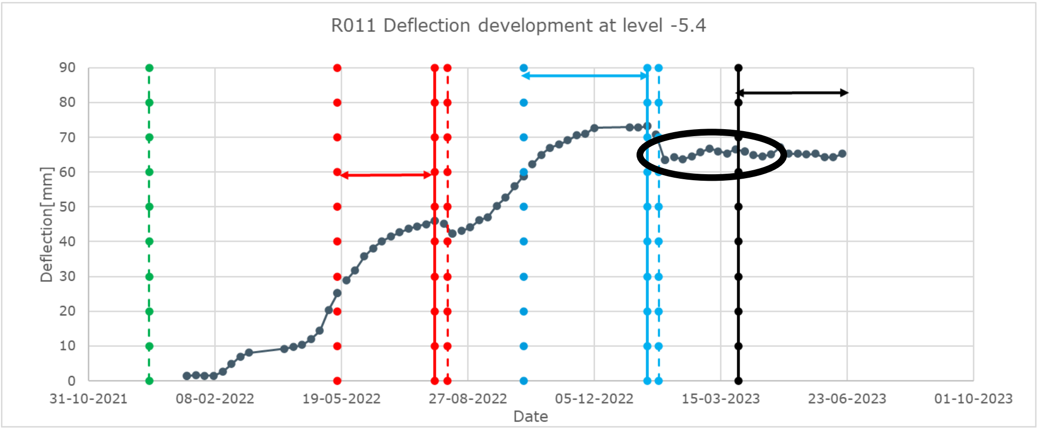
With toe rotational restraint

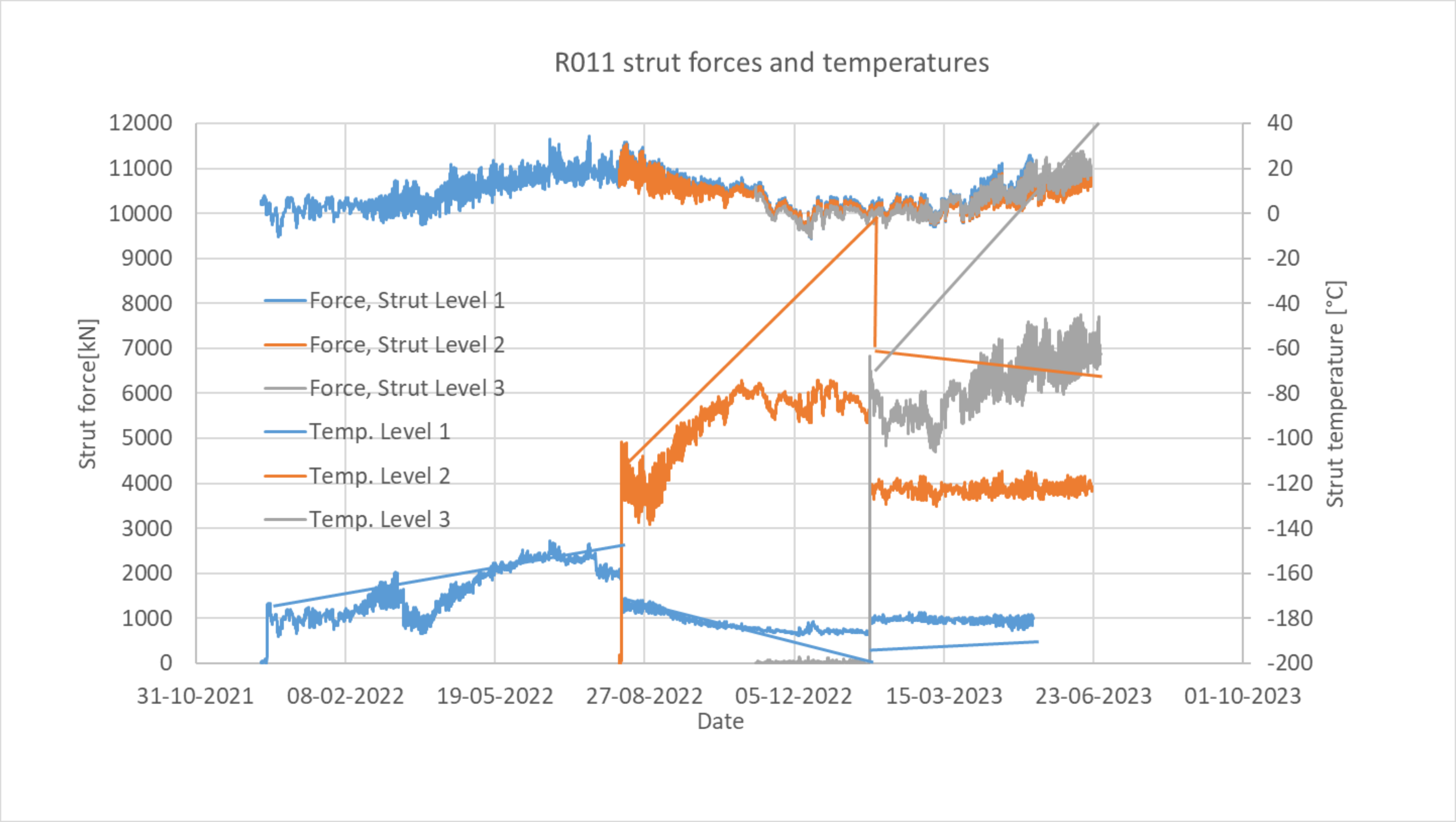




Final excavation:

- Only slight increase in measured wall deflection in lower part of wall.





Measured strut forces notably smaller than calculated (except strut level 1)

Observations:

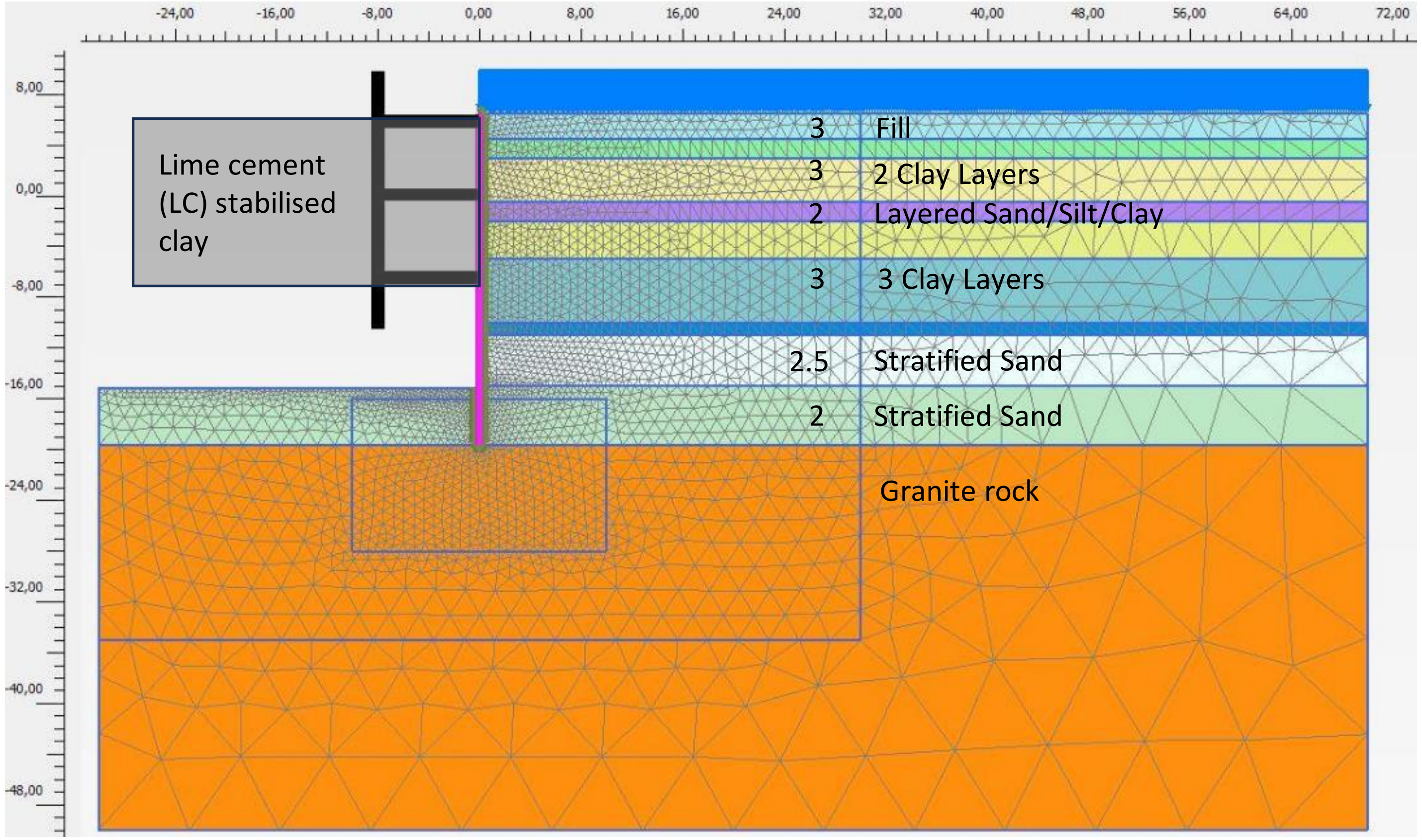
1. Measured backwards deflections due to prestressing of the struts are smaller than predicted, i.e. soil stiffness higher than assumed.
2. Measured deflections in lower part of the wall overestimated in all stages.
3. Significant increase in wall deflections during the strut installation phases of 2 to 3 months due to (full) consolidation of the LC stabilised clay, i.e. transition from initial undrained to (fully) drained behaviour.
4. Second and third strut level: Measured wall deflections after excavation (undrained LC stablised clay) are smaller than predicted. They increase during strut installation (drained LC stabilised clay).
5. Measured strut forces are smaller than predicted.

Back analysis:

A first attempt of a back analysis to better represent the observed behaviour:

1. Soil stiffness calibration to match the backwards deflections due to prestressing of the struts. (Strut prestressing represents a large scale horizontal plate load test on the soil on the active side).
2. Reduce ground water level on active side by 1 m to actual measured level.
3. Lower the rock level by 1 m to actual measured level.
4. Remove the 20 kPa surcharge load.
5. Increase rock support to RMRbas60-80 = average value indicated in MUR Rock instead of RMRbas40-60.
6. Increase of wall stiffness between level -10 and toe of the wall to consider the pile strengthening with welded plates and concrete infill with HE300B.
7. Drained (phi' = 32 deg, c' = 0) LC block modelling to reflect the observed consolidation, and reduce stiffness over depth from constant E = 40 MPa to 40 MPa at the top decreasing linearly to 3 MPa at the bottom since the wall deflections would otherwise be notably underestimated and since missing column overlap with depth is assessed to lead to a notable stiffness reduction (hypothesis). Regarding 3 MPa at the bottom, note M_0 = 9 to 19 MPa and M_L = 0.75 to 1.3 MPa for the untreated clay.
8. Wall deflections for strut level 3 onwards corrected (based on temperature corrected strut forces).

Soil stiffness increase factors (Gur in NGI-ADP model and E in MC model) to match backwards deflections



Spotcheck: Stiffness increase factors for the Sands agree with the ratio between average stiffness data in the MUR Geo and the cautious parameters used in the design

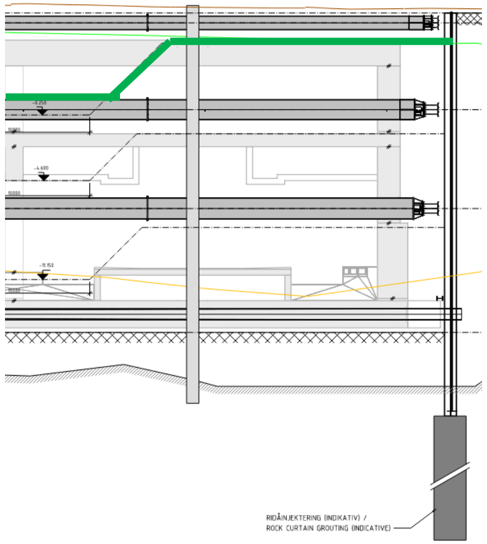
Results

Design calculation:

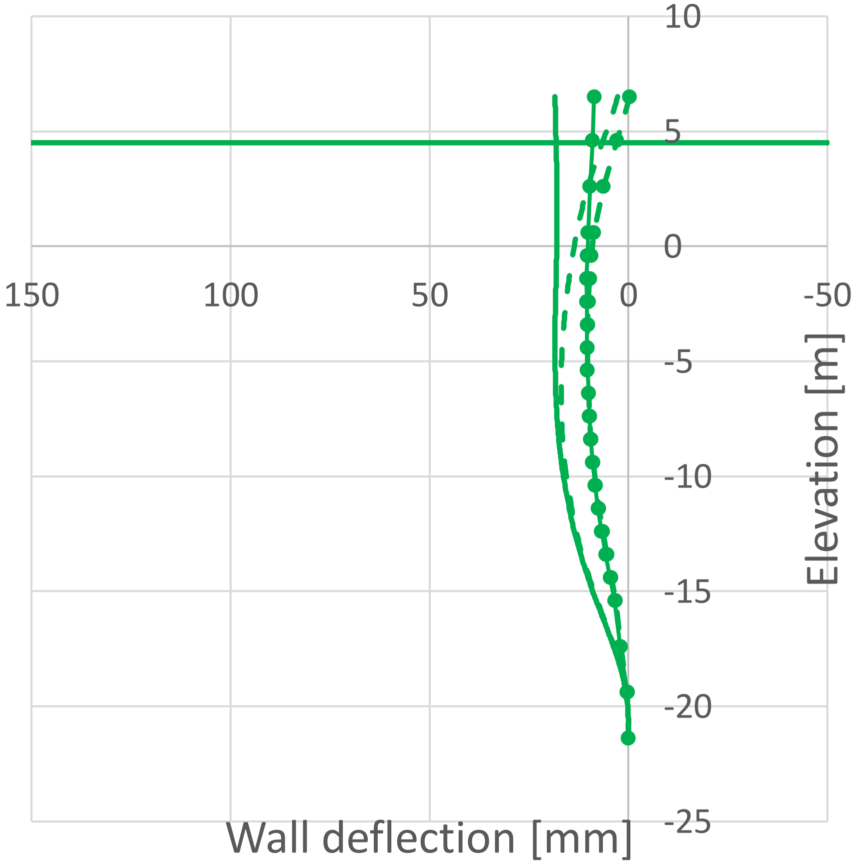
No markers

Measured:

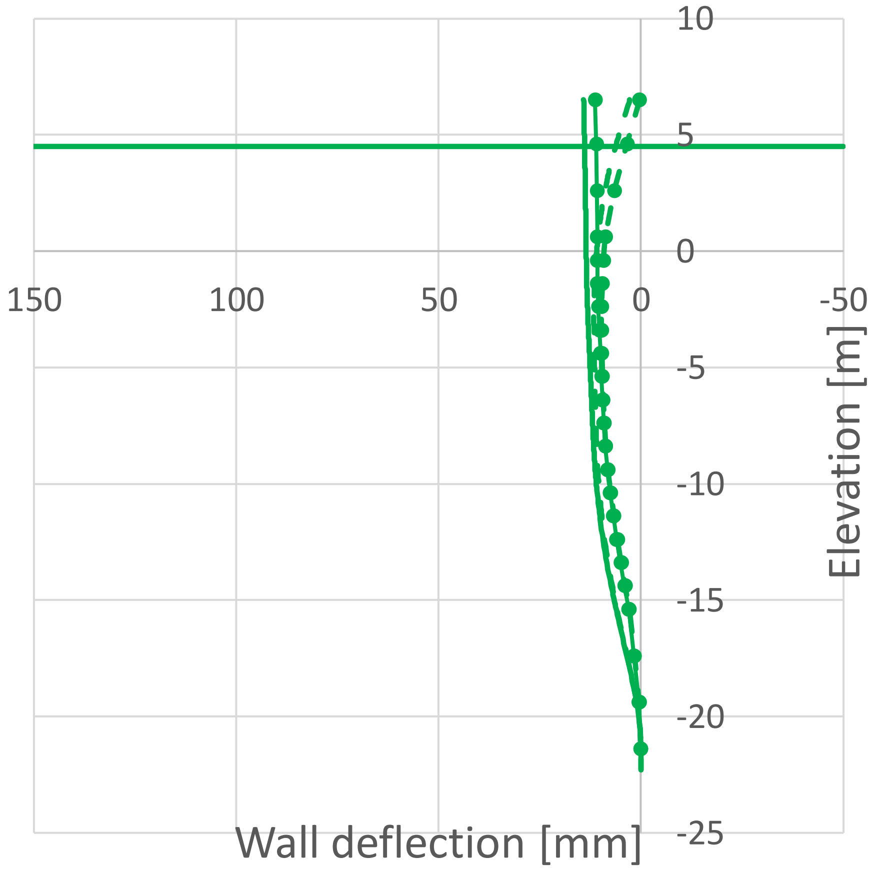
With markers



Original Comparison



Back Analysis



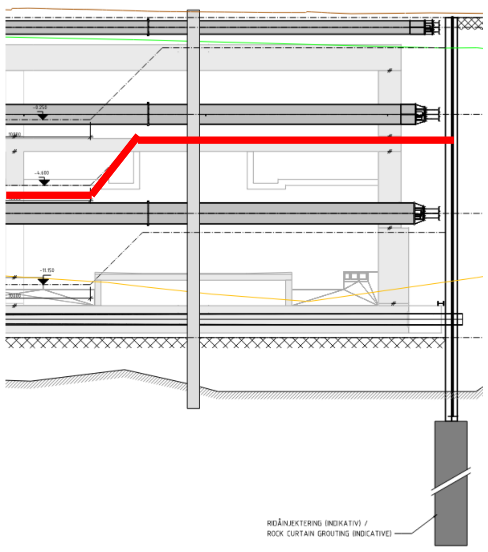
Results

Design calculation:

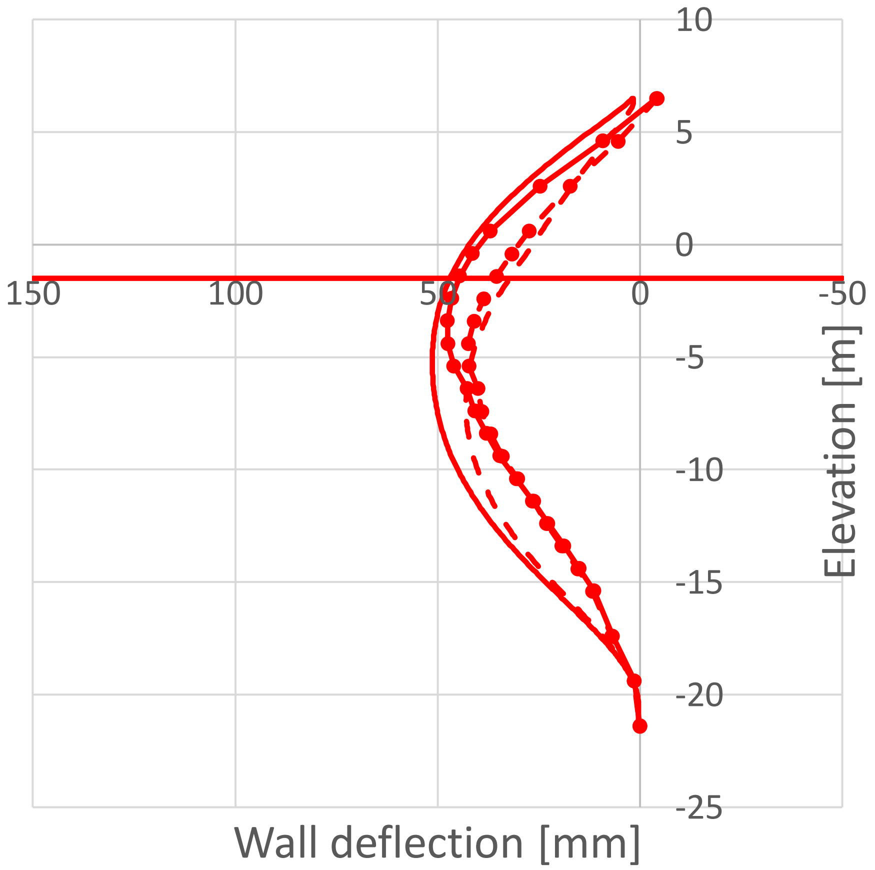
No markers

Measured:

With markers



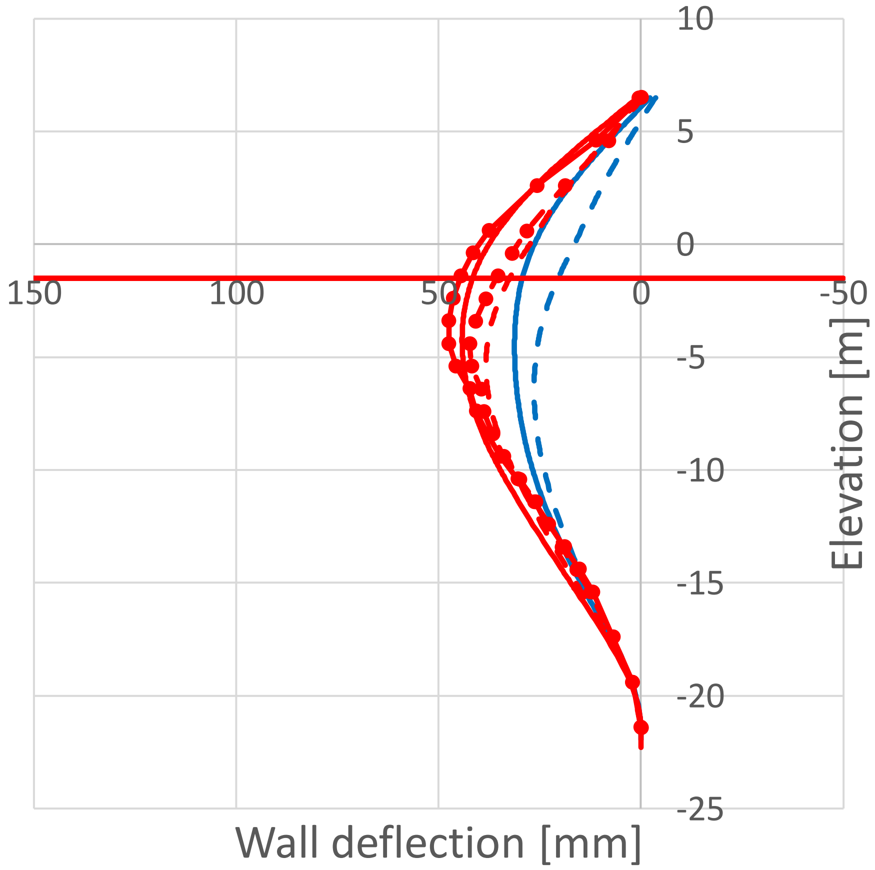
Original Comparison



Back Analysis

E (LC clay) = 40/3MPa

E (LC clay) = constant 40MPa



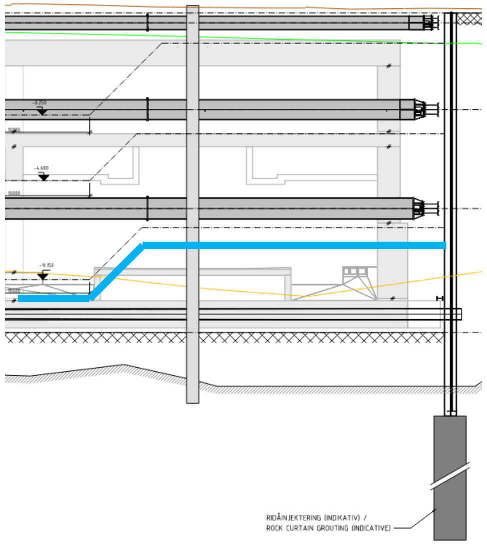
Results

Design calculation:

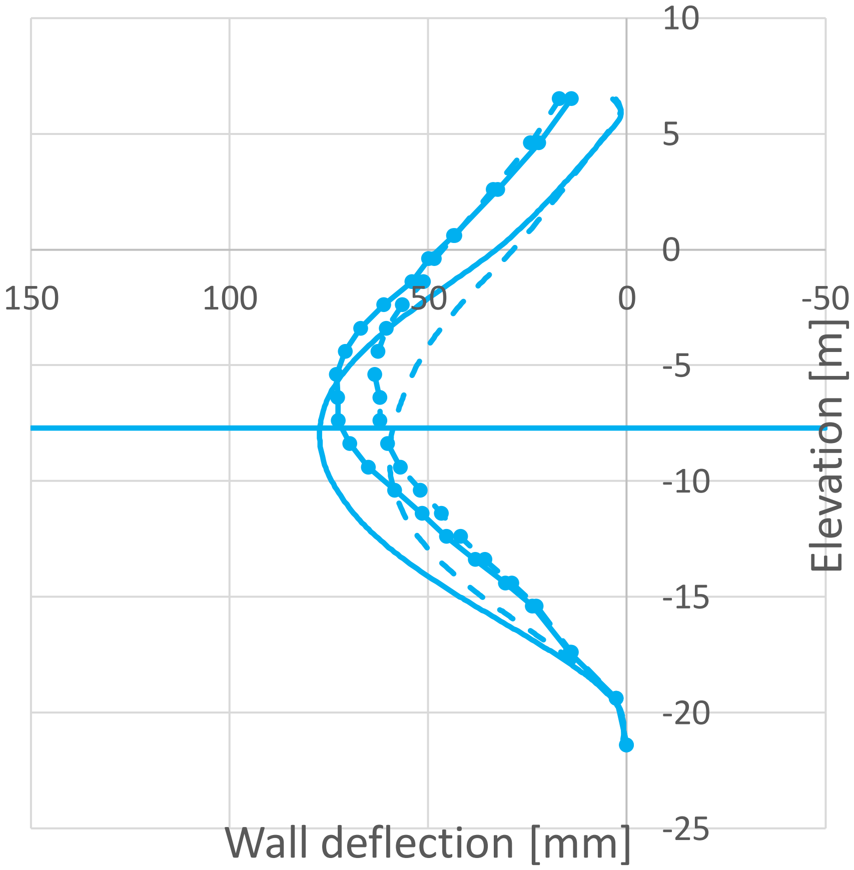
No markers

Measured:

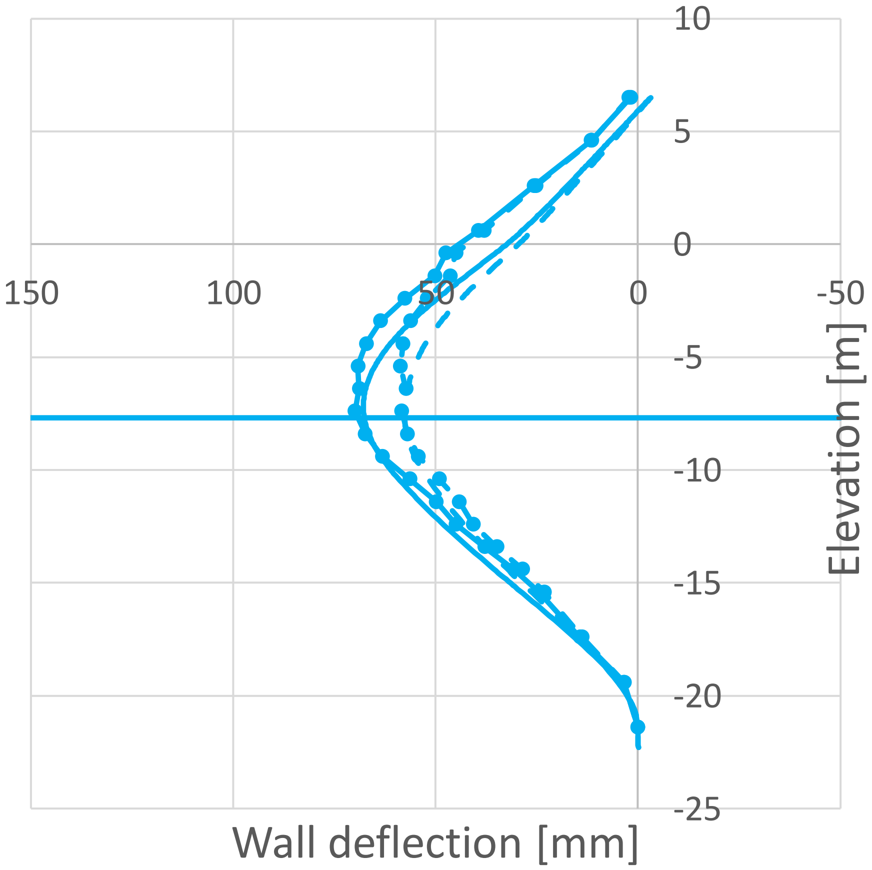
With markers



Original Comparison



Back Analysis



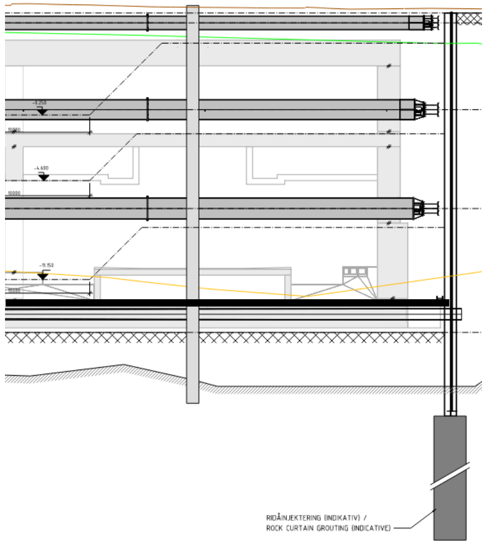
Results

Design calculation:

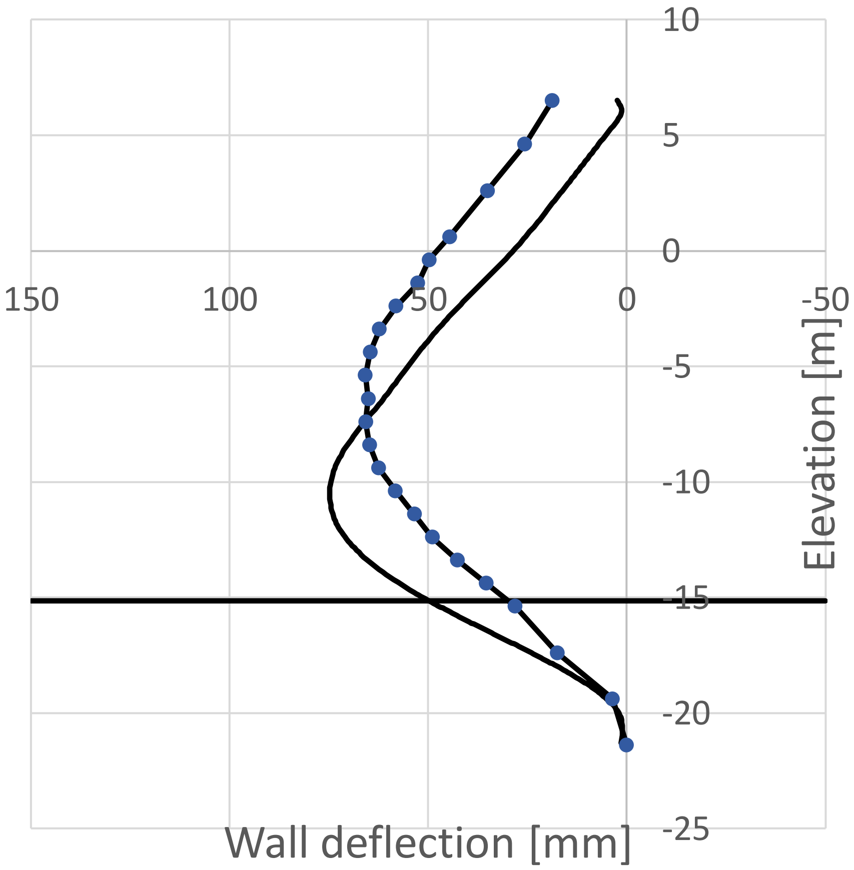
No markers ——

Measured:

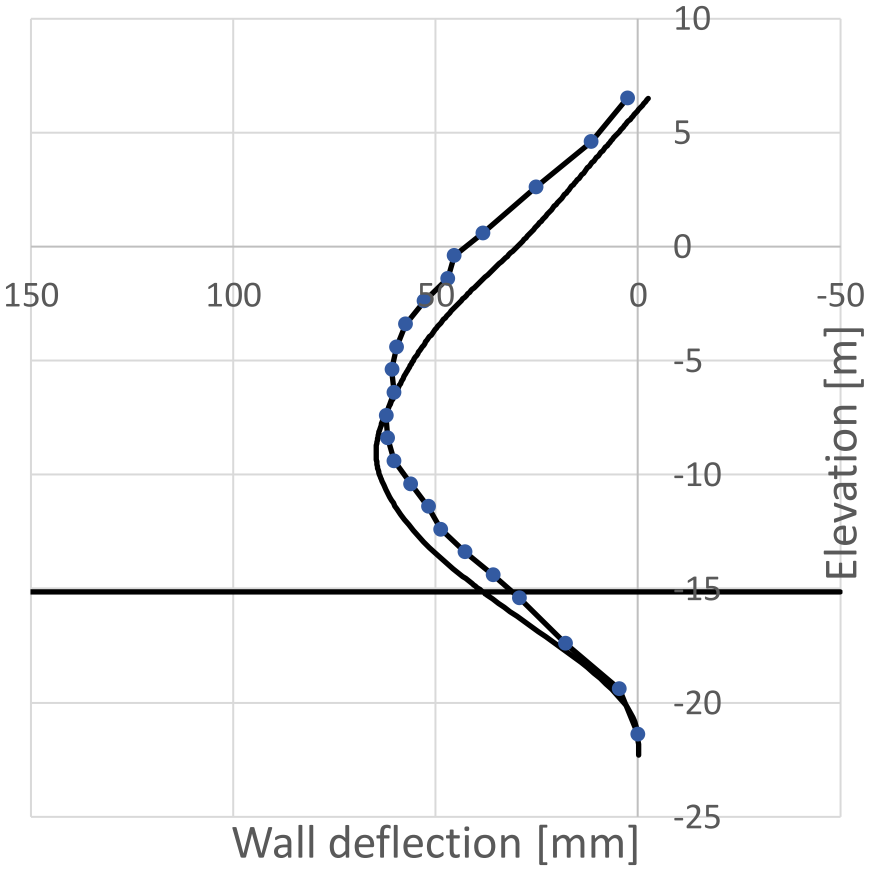
With markers •–•–•



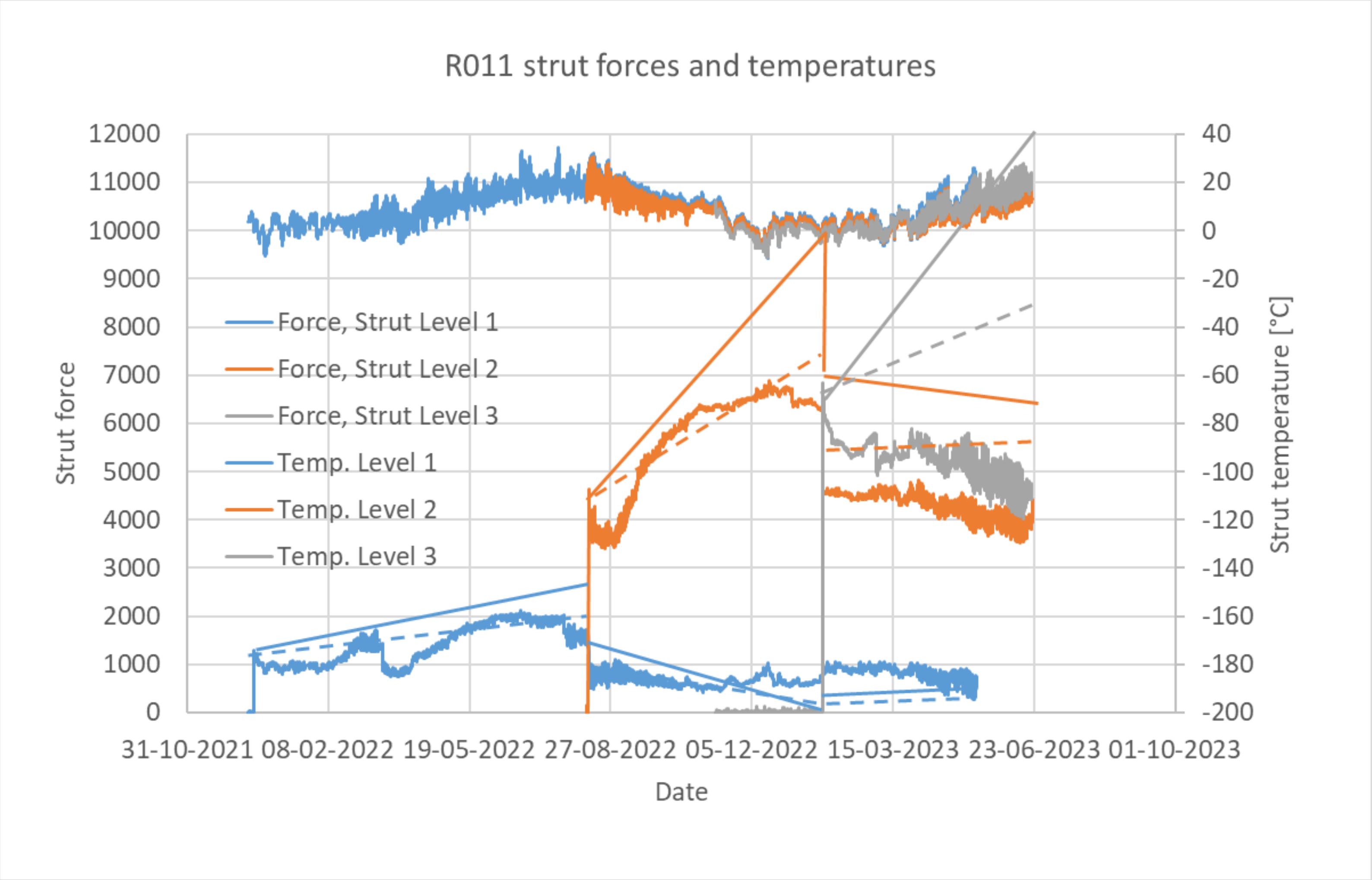
Original Comparison



Back Analysis



Results



Original Comparison:
Solid lines

Back analysis:
Dashed lines

Measured strut forces are now shown as temperature corrected values

Summary and conclusions from back analysis:

1. Good agreement of wall deflections has been achieved.
2. Improved agreement of strut forces has been achieved, but actual strut level 2 & 3 forces are still smaller.
3. A better understanding of the influence of various parameters has been achieved.
4. Further evaluations are ongoing.


Thank you for your attention !
DRILLAB
VOLVO