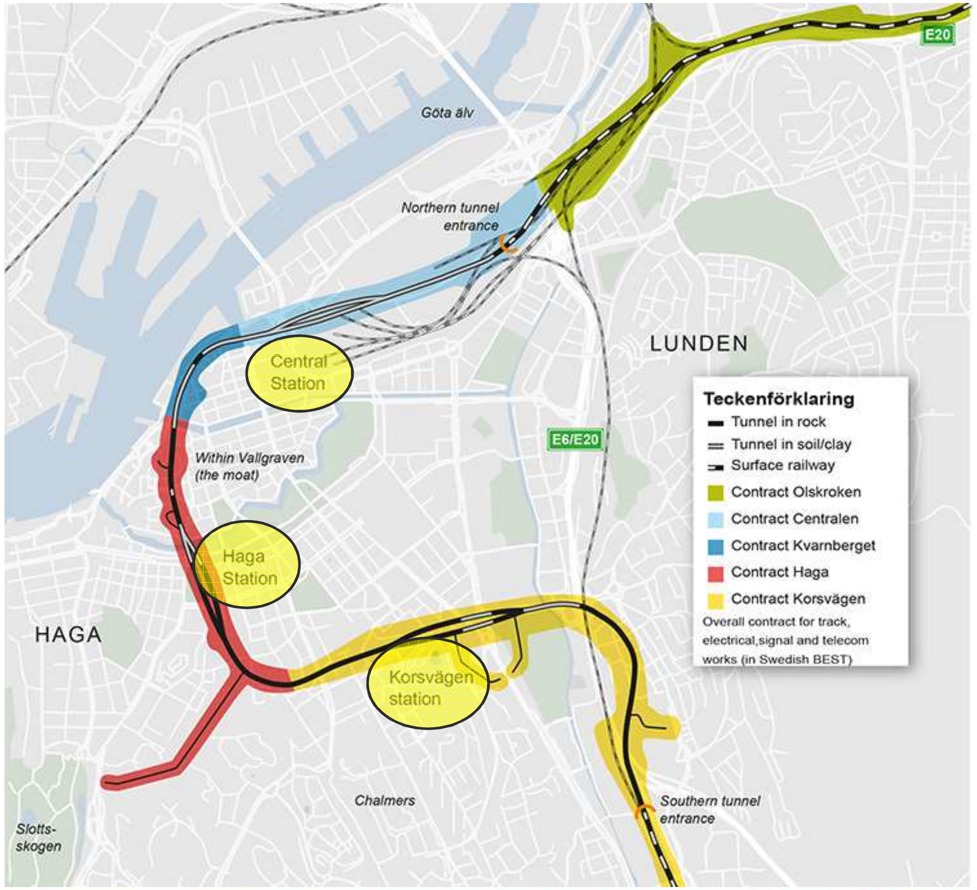
# RETAINING STRUCTURES FOR HAGA STATION

*PÅLDAG 19, Gothenburg 16th May 2019*

***Luca Pirillo***

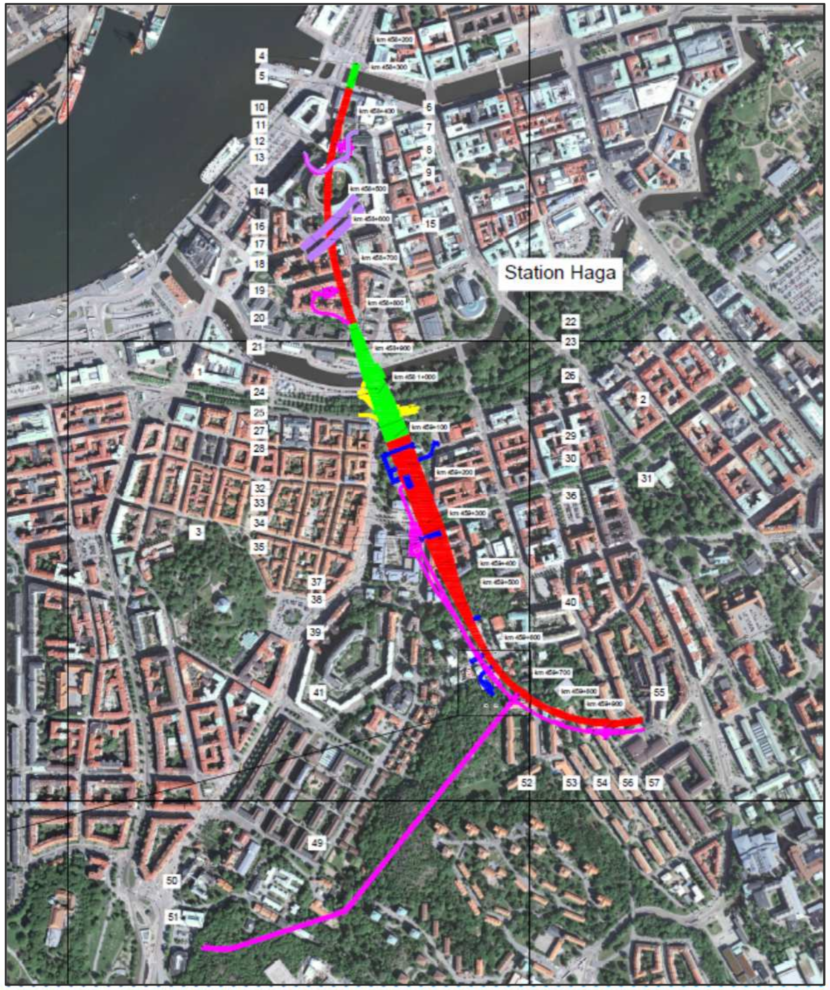



# The West Link Project in Gothenburg

- The West Link is an eight kilometer long double track railway, including a six kilometer railway tunnel, underneath the city of Gothenburg

- Five Contracts:
    - Olskroken
    - Centralen
    - Kvarnberget
    - Haga
    - Korsvägen

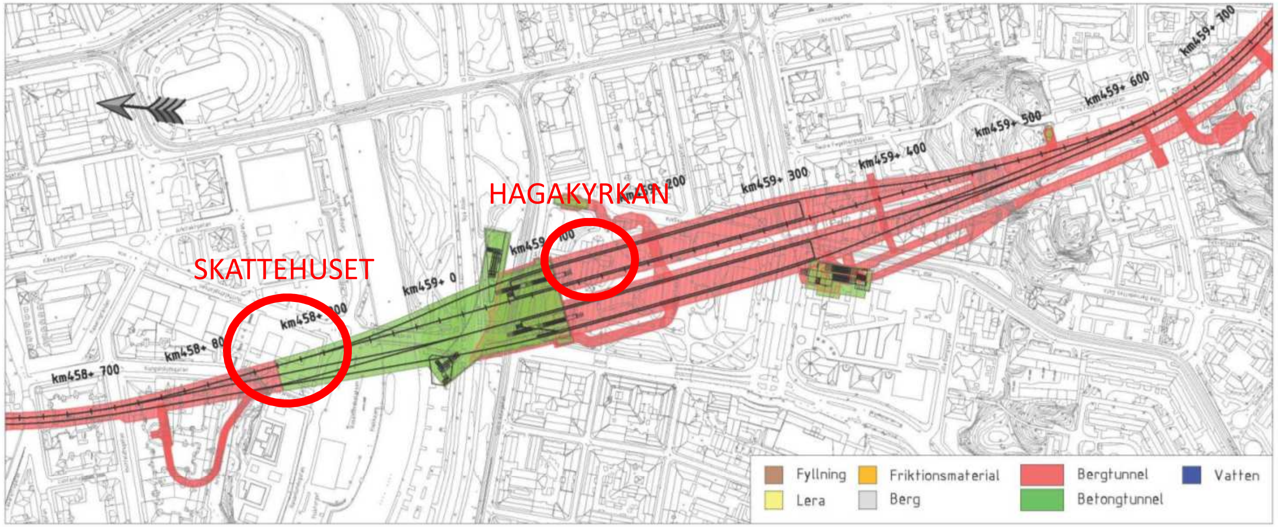
- Three new underground station:
    - Centralen
    - Haga
    - Korsvägen

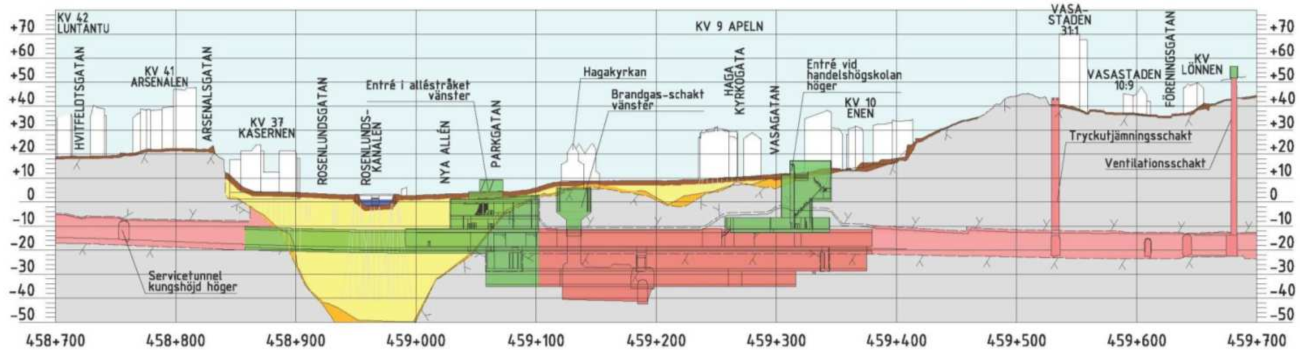



# The Haga Contract

- The Haga construction project is approximately 1,500 metres long, including a station under Haga church, starting north of Norra Hamnkanalen and ending in the south under Annedal.
- To the north, the project connects to the Kvarnberget project and in the south it connected to the Korsvägen project. The contract includes a service and escape tunnel of approximately 900 metres, ending near Linnéplatsen
- The middle part of the project consists of an approximately 240 metre-long soil excavation across Rosenlund, which forms the northern trumpet of Haga station. The excavation is proposed as a cut and cover, divided into various stages
- SOME NUMBERS:
  - Total length, Haga contract: about 1,520 metres
  - Length in rock: about 1,220 metres
  - Length in soil: about 300 metres

  - Volume, rock excavation: about 650,000 m3
  - Volume, soil excavation: about 300,000 m3



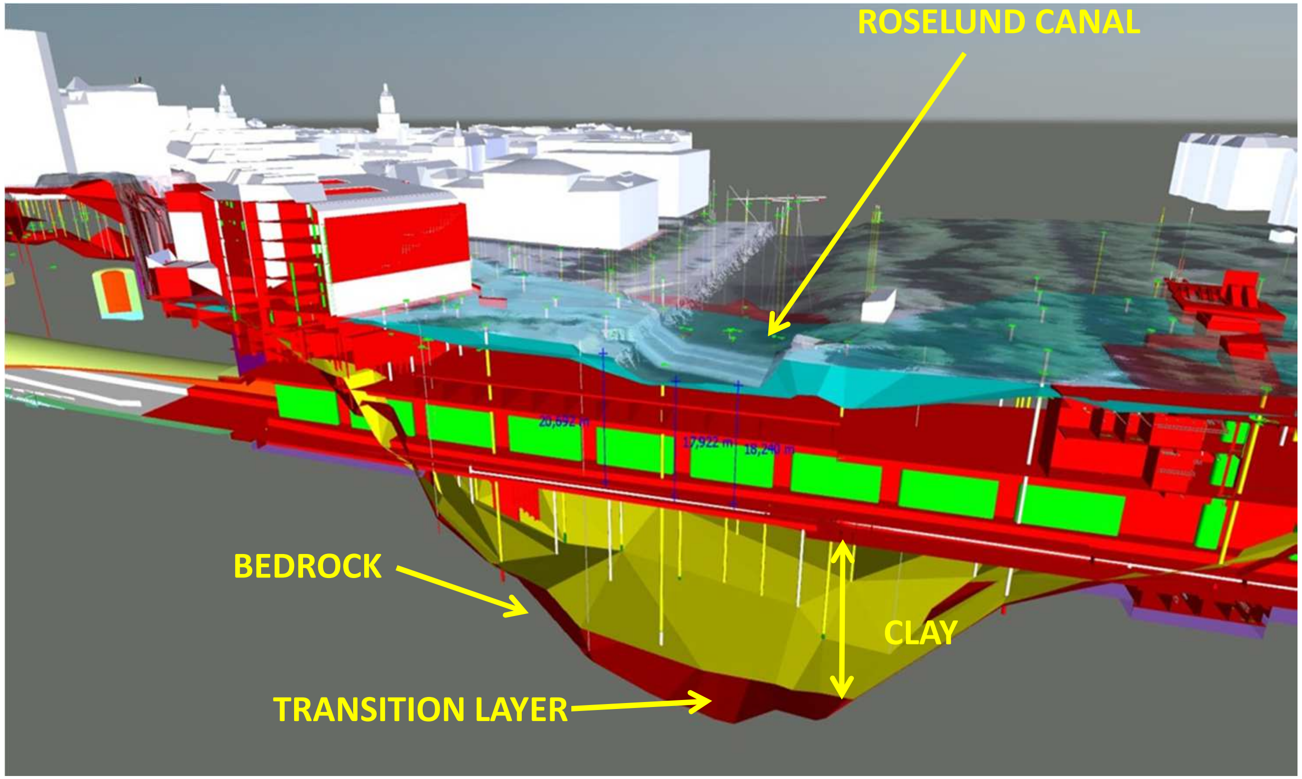




# The Haga Station

- The Haga station is approximately 500 metres length and 50 meters width: 300 m excavated in rock and 200 m in clay.
- The clay part will be excavated in cut & cover in different stages.

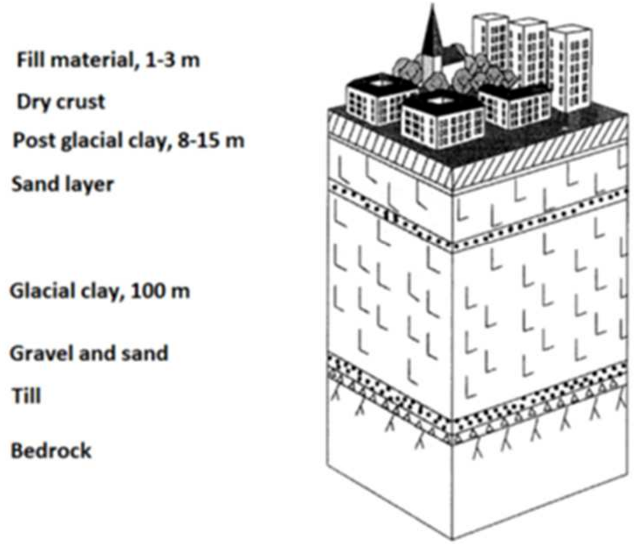
- SOME NUMBERS:
  - Volume, rock excavation: about 350.000 m3
  - Volume, soil excavation: about 160.000 m3

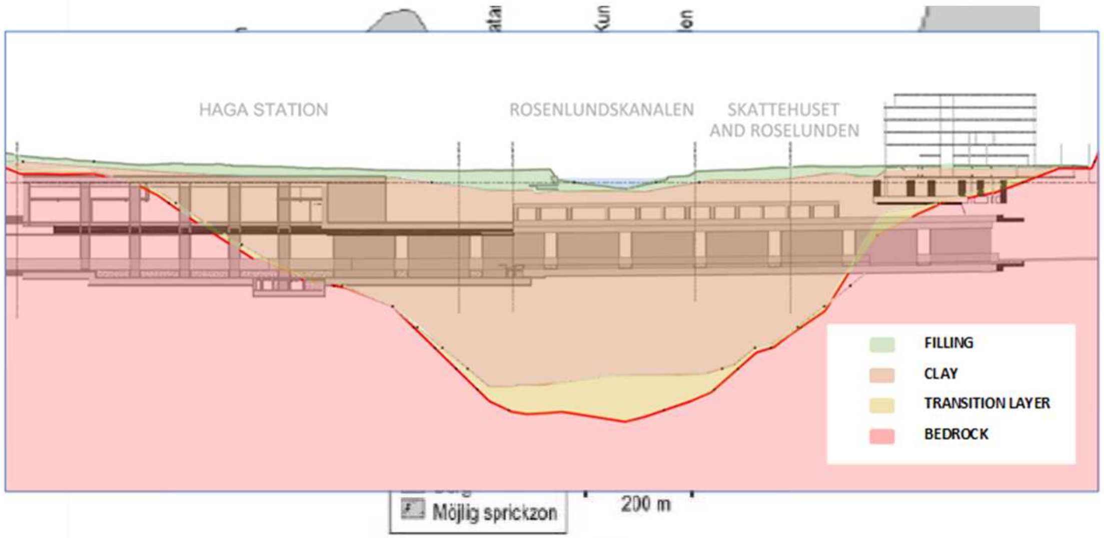
# GEOLOGICAL CONTEST




Gothenburg has very special geological conditions where a "soft" clay lies on top of a "hard" bedrock. These two layers are separated by a variable transition layer of friction soil.

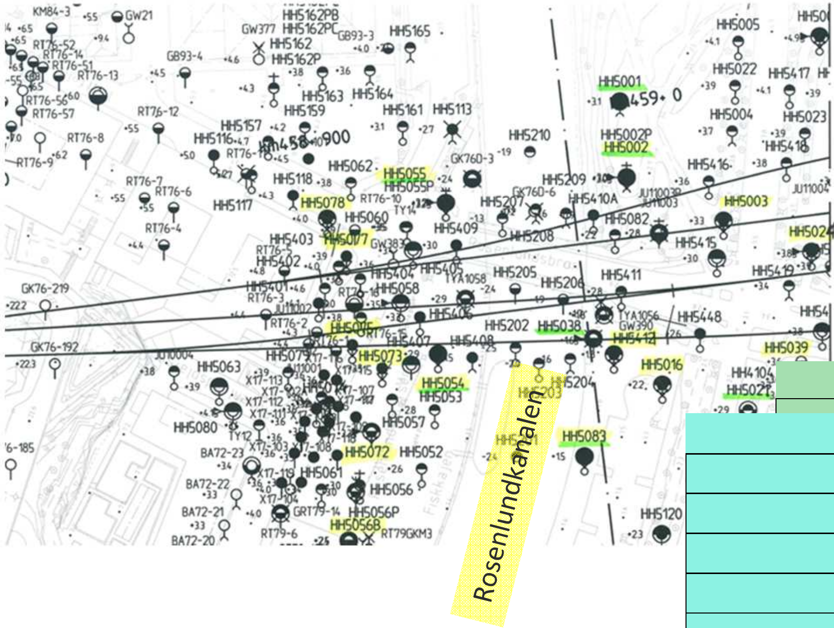
# GEOLOGICAL CONTEST




The geology within the studied area consists of clay-filled valleys and of outcrops of rock.
The thickness of the clay layer varies widely, and quickly, from zero to up to 80 m, or locally even more, but mostly it is less than 30 m.
A layer of frictional soil is generally found between the bedrock and the clay. In the area the layer has a thickness variable from 1 meter to 15 meters.
At the surface a few-meters layer of anthropogenic fill is often found.

# GEOTECHNICAL INVESTIGATIONS



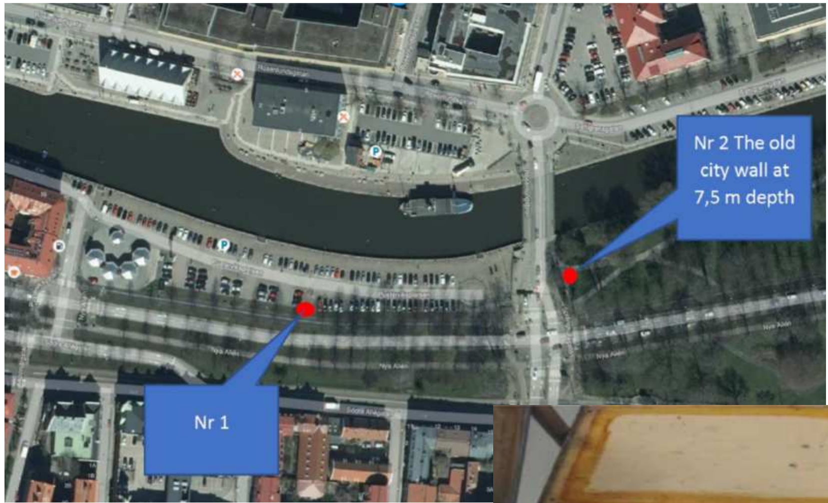

Geotechnical investigations have been carried out within the project West Link, in order to provide a basis for description of the geological and geotechnical condition of the area. The investigations have been conducted during the period 2012 - 2014 by Sweco and later investigations conducted in June-August 2015 by ÅF Infrastructure AB

| | | Sweco _ 2012-2014 | ÅF _ 2015 |
|---|---|---|---|
| Bälgsättningsmätning | - | 3 | |

| | Sweco _ 2012-2014 | ÅF_ 2015 |
|---|---|---|
| LABORATORY TEST | number | number |
| Routine test | 198 | 13 |
| CRS oedometric test | 96 | 1 |
| IL oedometer test | 9 | 4 |
| Direct Shear test | 47 | 11 |
| Triaxial test | 16 | |

Field surveys consist of various sampling, probing and field test such as CPT and Vane test

# ADDITIONAL GEOTECHNICAL INVESTIGATIONS



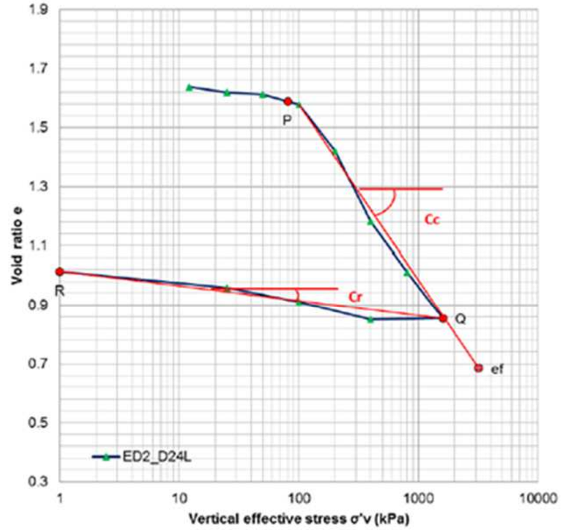

Integrative geotechnical investigations have been performed on 2017 in the area of the planned Haga station.

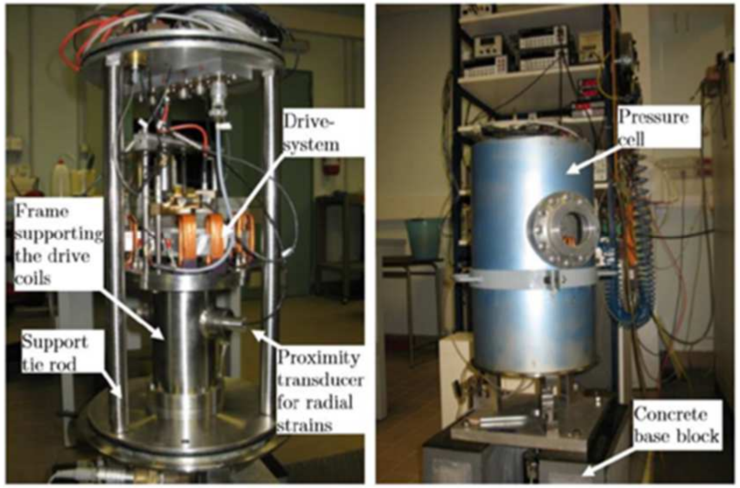

# ADDITIONAL GEOTECHNICAL INVESTIGATIONS

Laboratory test performed:

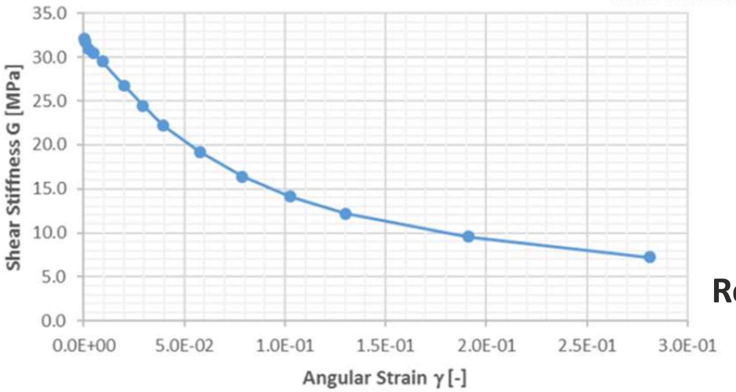
- Grain size test
- Index properties and Atterberg limits
- Soil classification
- Oedometric tests
- Shear tests
- Resonant column tests

**Oedometric Curve**




**Resonant column test apparatus**




**Resonant column test**

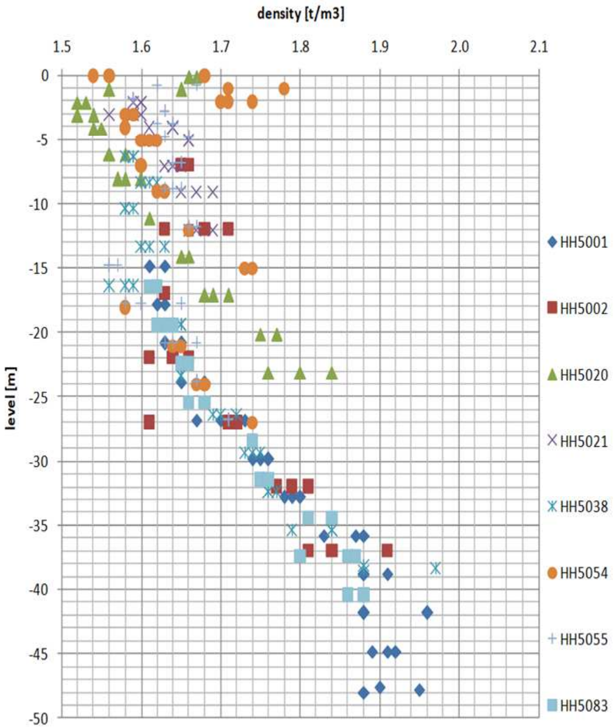
# CLAY GEOTECHNICAL DATA

The elaboration of the laboratory and field test leads to the estimation of the following geotechnical parameters for the clay layer in the Rosenlund area:

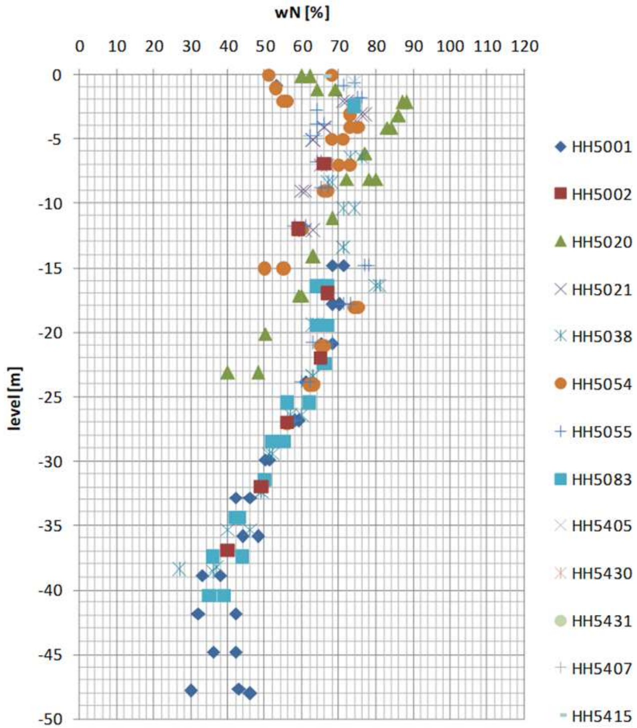
- soil index properties (density, water content, Atterberg limits, sensitivity)
- preconsolidation pressure and overconsolidation ratio
- undrained soil shear strength
- drained soil shear strength
- soil deformability
- creep parameters
- pore pressure values.

# Soil index properties

Density



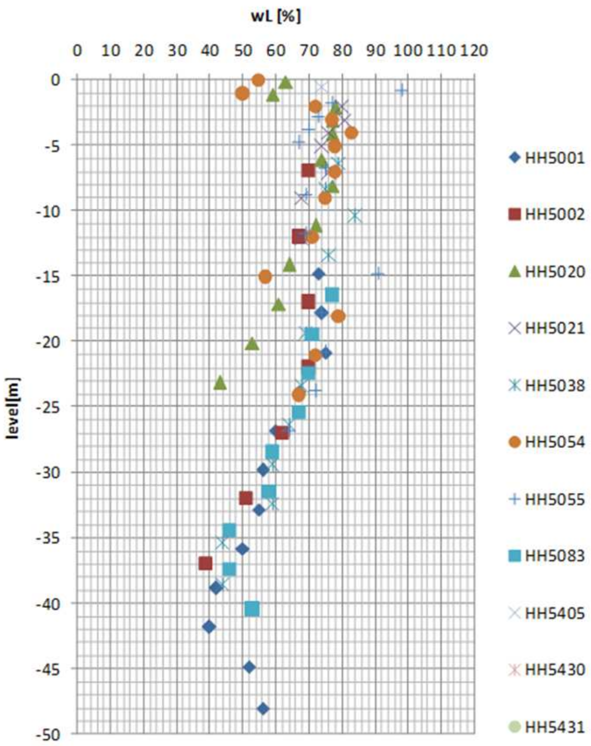

Water content



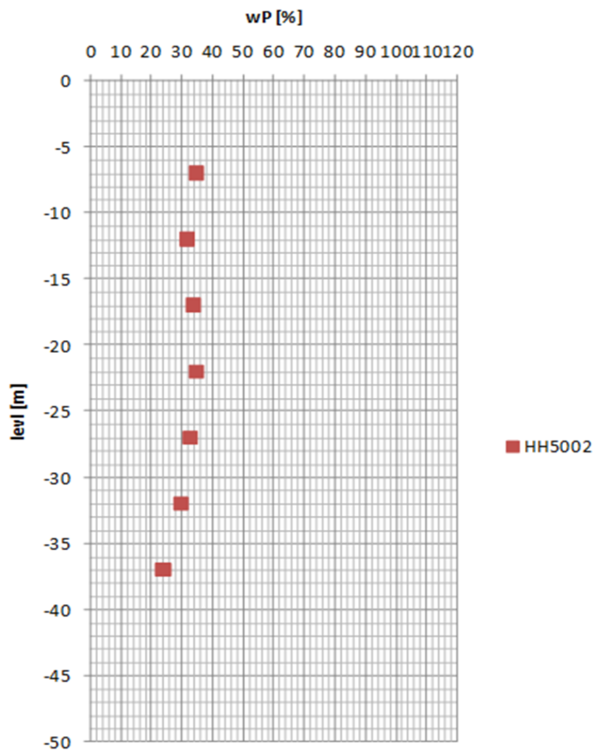

The water content slightly decreases with depth in the first 20 m (60-75%) and then a pronounced decrease from 70% to 40% in between 20-40 m of depth.

# Soil index properties

## Atterberg liquid limit



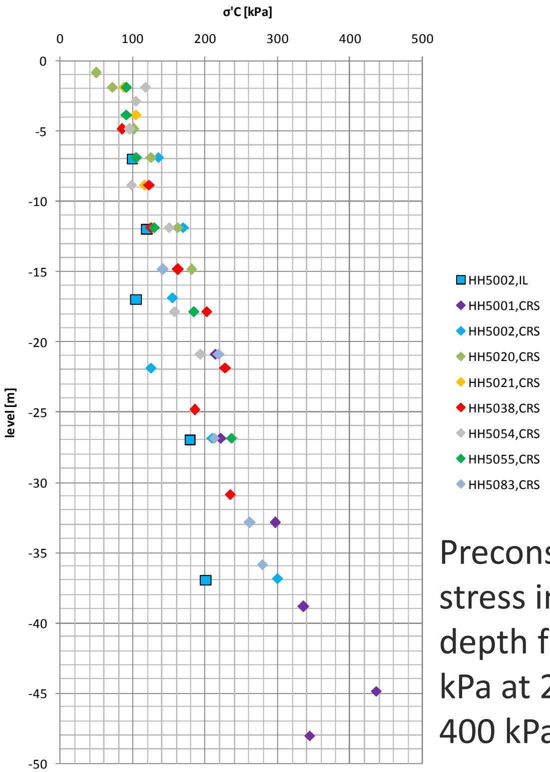

## Atterberg plastic limit




- Atterberg limits have approximately the same trend of the water content.
- Liquid limit values are comprised between 65÷80% in the first 20 m, deeper the values decrease with the depth (wL from 70% to 40%).
- The plastic limit has values around 30÷40% decreasing until 20% from 20m to 40m

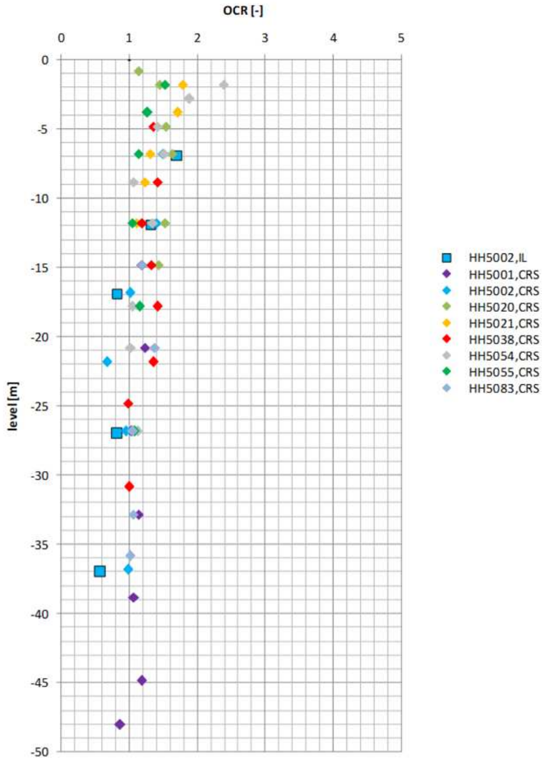
# Soil index properties

## Preconsolidation stress




Preconsolidation stress increasing with depth from about 100 kPa at 2m depth to 400 kPa at 50m

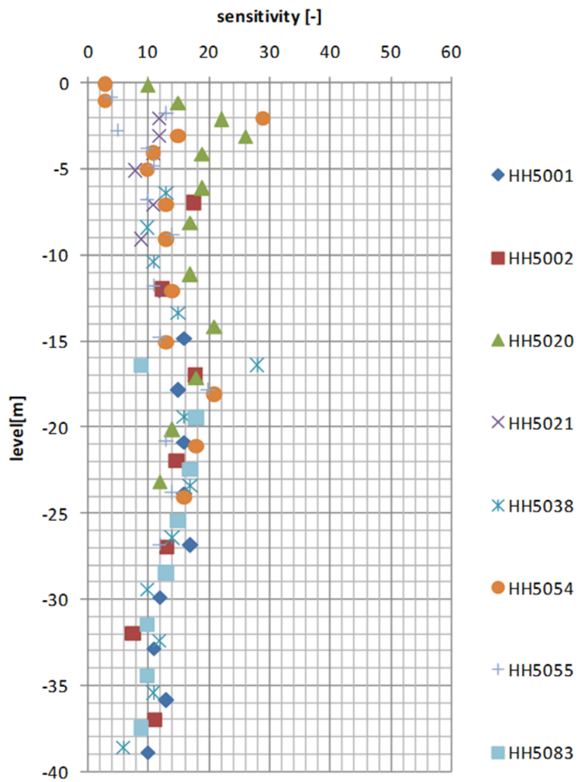
## Overconsolidation ratio




The estimated overconsolidation ratio (OCR) is decreasing with depth, starting from values 1.2-1.8 in the first 10 m to the range of 1.1-1.2 until 20 m depth.

# Soil index properties

Sensitivity




- is defined as the ratio of the undrained shear strength of undisturbed soil to the undrained shear strength of remoulded soil at the same water content
- the clay layer in the studied area is a medium sensitive clay (8 < St ≤ 30) according to Rankka et al. (2004)

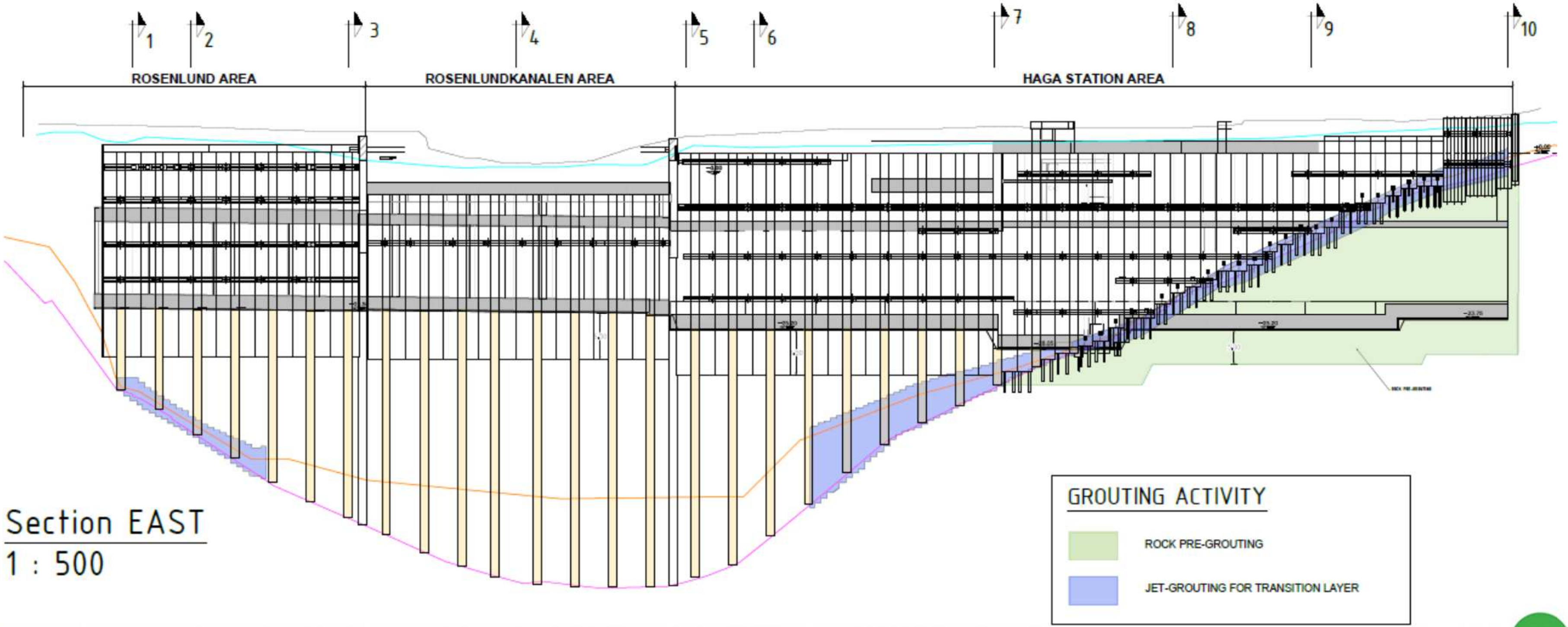
# DESIGN SOLUTION FOR THE RETAINING STRUCTURES

In order to address the different issues related to the geotechnical context and to other aspects related to the design of Haga station, the retaining system has to guarantee the following characteristics:

- Strong static properties, in order to resist the high horizontal thrusts due to the poor mechanical properties of the clay
- High stiffness, in order to limit the deformations due to the low elastic modulus of the clay
- the technological possibility of execution in both soft materials and rock, considering that the final excavation level of the station presents both situations and that embedment in rock has to be guaranteed
- The capacity of supporting a top-down slab, foreseen in order to limit the interferences with the traffic in the area
- Prevention of  settlements, with particular reference to differential ones,  in short and long term
- Waterproofing in short term, during excavations
- Use of a cross-wall system in order to stabilize the base of the retaining walls and limit the deformations

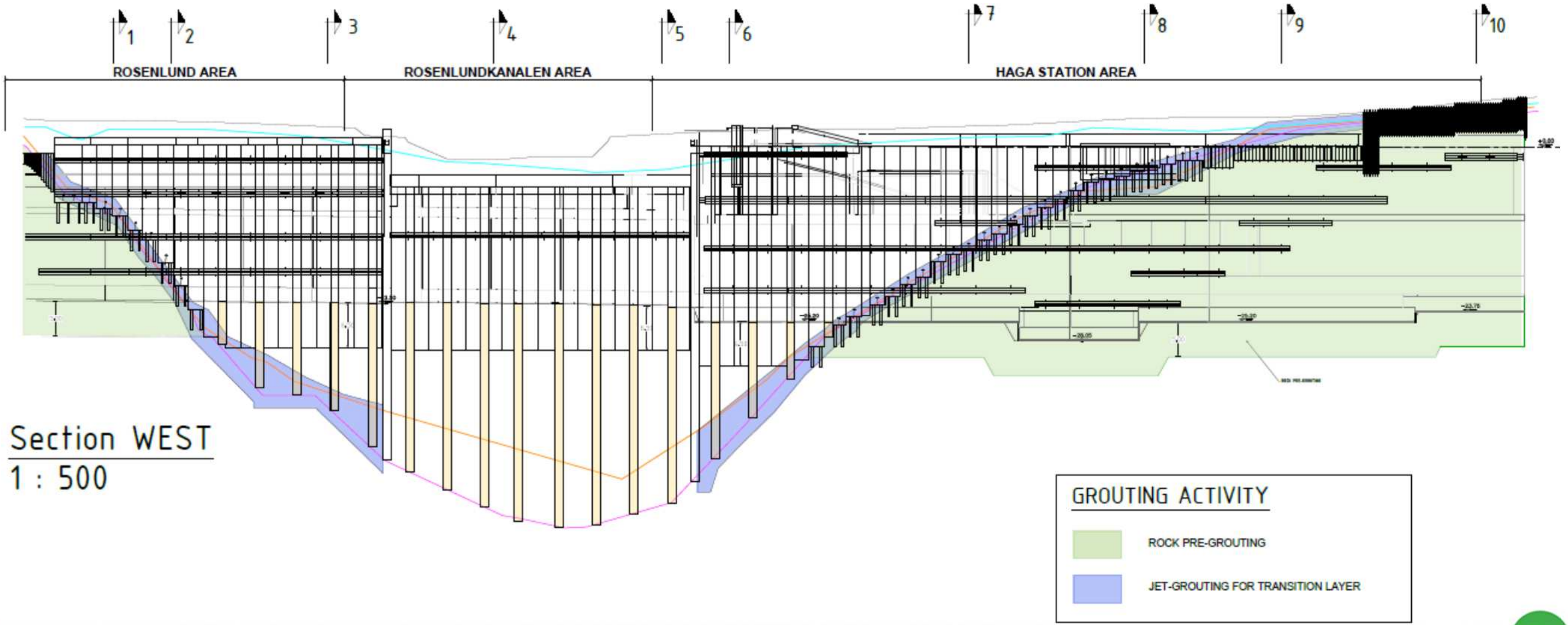
# DESIGN SOLUTION FOR THE RETAINING STRUCTURES

LONGITUDINAL PROFILE - EAST SIDE



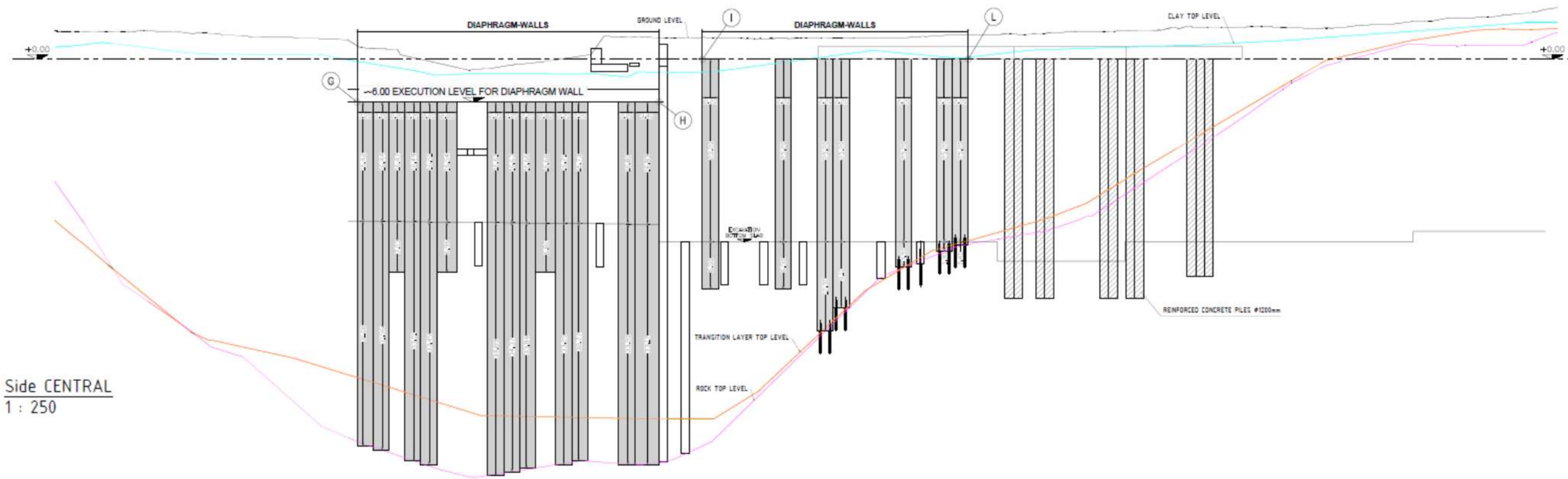
# DESIGN SOLUTION FOR THE RETAINING STRUCTURES

## LONGITUDINAL PROFILE - WEST SIDE



# DESIGN SOLUTION FOR THE RETAINING STRUCTURES

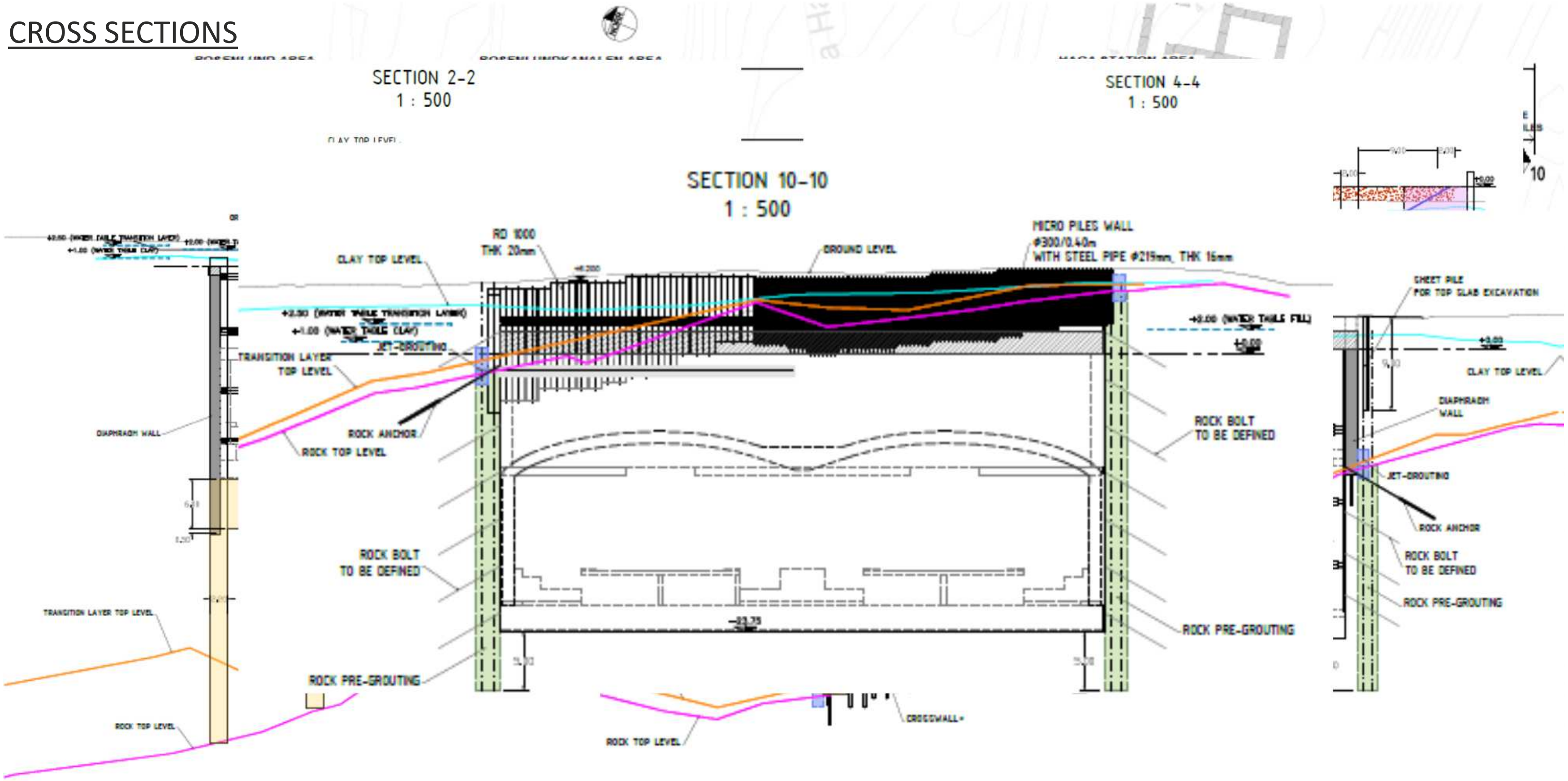
## LONGITUDINAL PROFILE – CENTRAL ALIGNMENT




Side CENTRAL
1 : 250

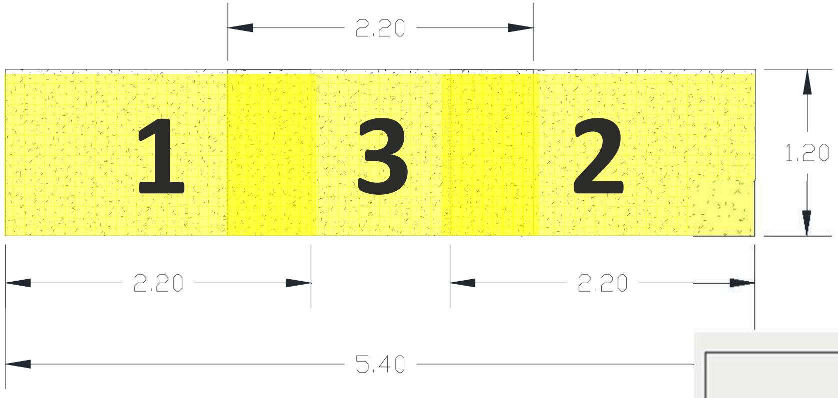
# DESIGN SOLUTION FOR THE RETAINING STRUCTURES

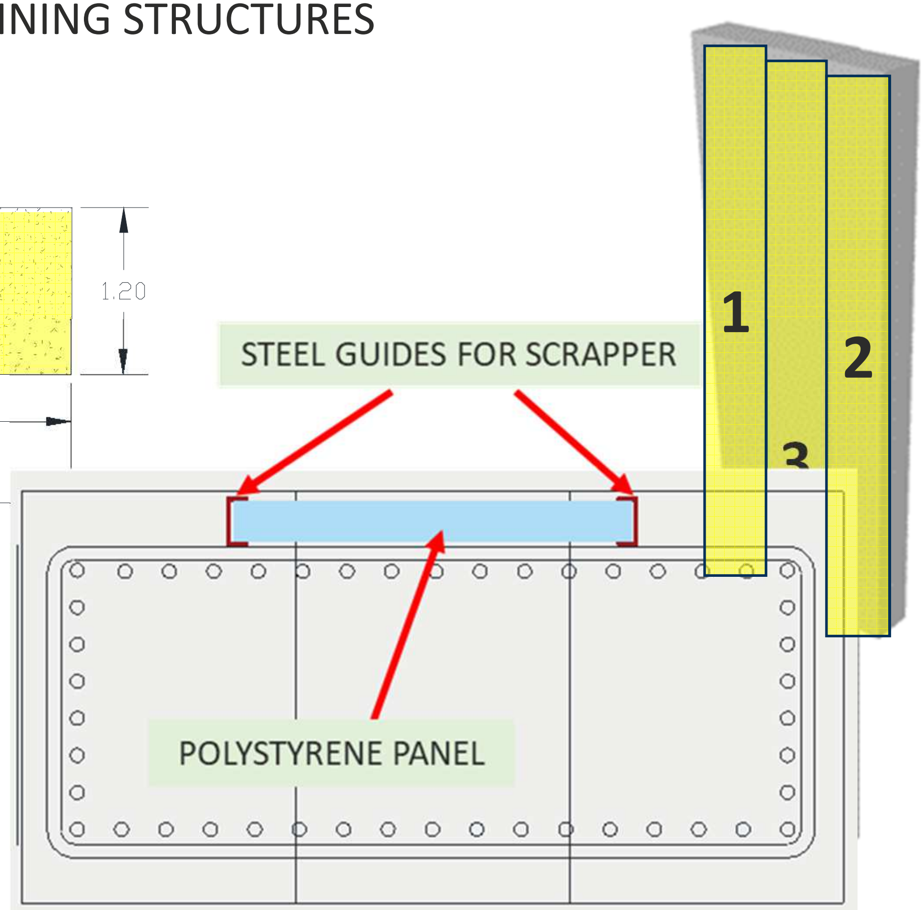
## CROSS SECTIONS

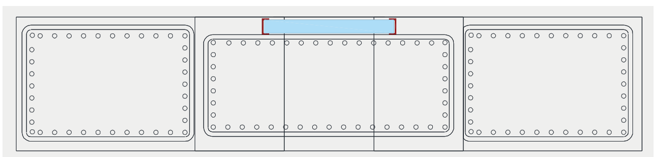


# DESIGN SOLUTION FOR THE RETAINING STRUCTURES

## DETAILS: MULTIPLE PANEL



# DESIGN SOLUTION FOR THE RETAINING STRUCTURES

## EVALUATION OF THE THRENCH STABILITY FOR THE MULTIPLE PANEL

Both numerical and analytical calculations are performed, in order to allow a comparison in the results

**3D numerical simulation (Plaxis)**

**Analytical method**

Elements considered in the analyses:

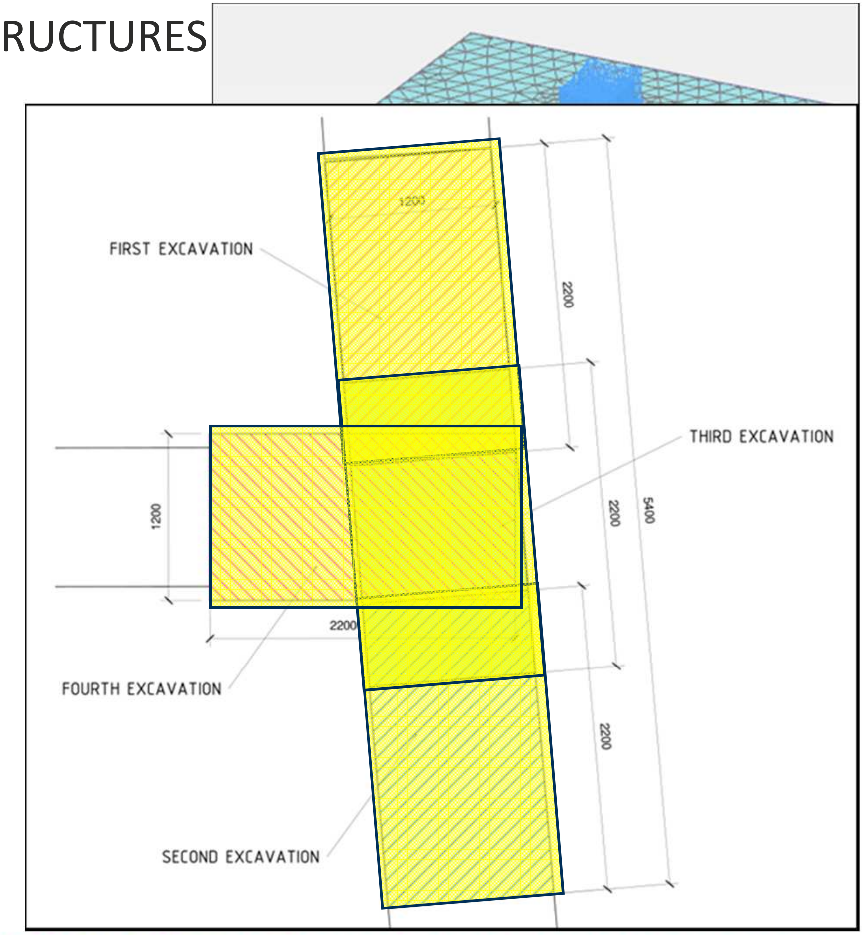
- Geometry of the D-wall (t-shape panel, worst condition)
- Excavation stages
- Geological and Geotechnical context
- Machinery surcharges
- Stabilizing slurry (bentonite)

# DESIGN SOLUTION FOR THE RETAINING STRUCTURES

<u>EVALUATION OF THE THRENCH STABILITY</u>

## Numerical analysis (Plaxis 3D)

Analysis stages:
- GEO: geostatic
- SUR: application of the crane load at ground level
- EXC 1: excavation of the first lateral part of the panel
- EXC 2: excavation of the second lateral part of the panel
- EXC 3: excavation of the central shallow part
- EXC 4: completion of the excavation of the central deeper part
- EXC 5: excavation of the T shape
- DIA: activation of concrete

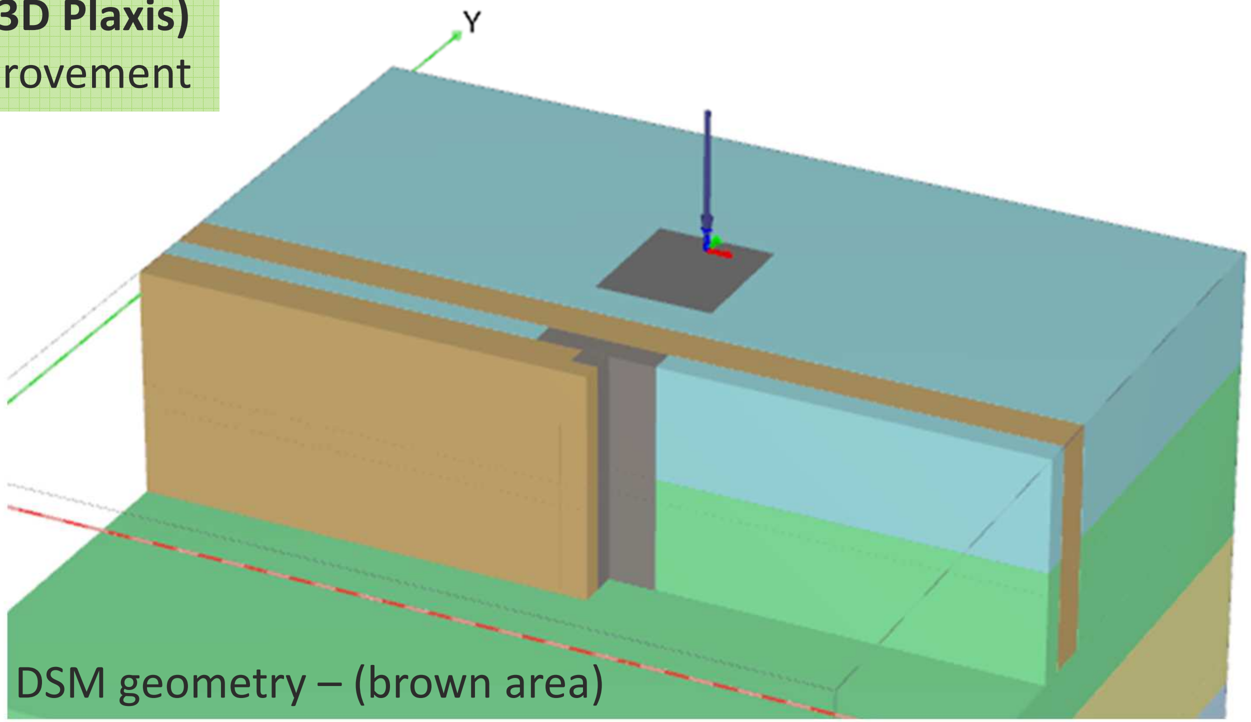


## DESIGN SOLUTION FOR THE RETAINING STRUCTURES

EVALUATION OF THE THRENCH STABILITY

**Numerical analysis (3D Plaxis)**
Deep soil mixing improvement

A second model was studied to evaluate the effect of the ground improvement by Deep Soil Mixing on the stability of the trench



DSM geometry – (brown area)

# DESIGN SOLUTION FOR THE RETAINING STRUCTURES

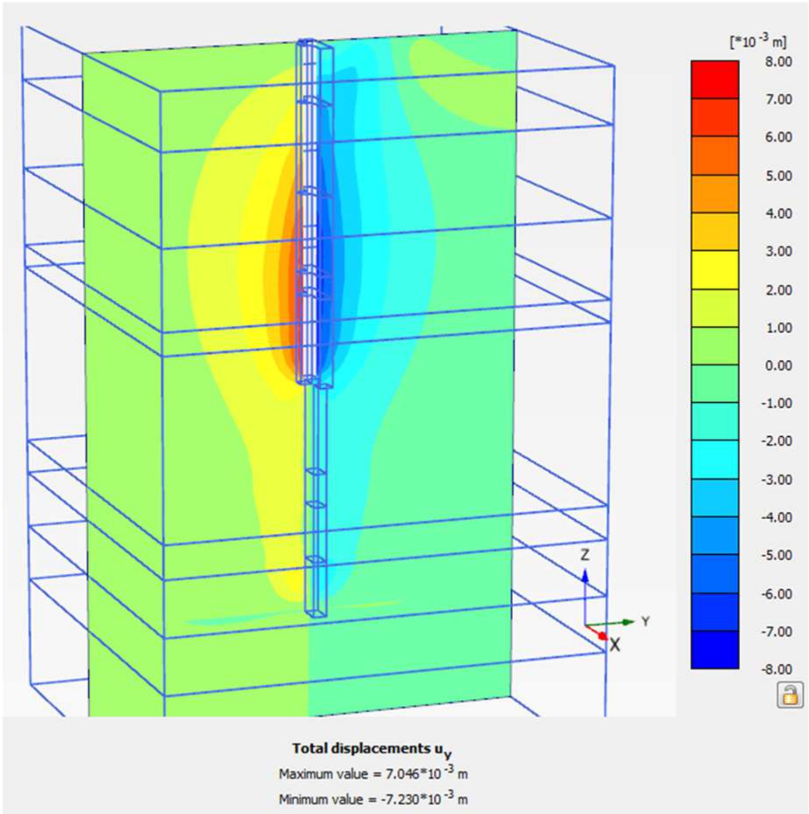
## EVALUATION OF THE THRENCH STABILITY

**Numerical analysis (3D Plaxis) Results**

**Plaxis 3D output – With Deep Soil Mixing**
Maximum horizontal displacement results about 20mm in the transition layer at the bottom of the central part; displacement remains less than 7-8 mm in the clay

**Plaxis 3D output – Without Deep Soil Mixing**
Maximum horizontal displacement results about 20mm in the transition layer at the bottom of the central part; displacement remains less than 8 mm in the clay

A very good improvement with reduced horizontal displacement is visible in the first 10 meters where the DSM has been considered

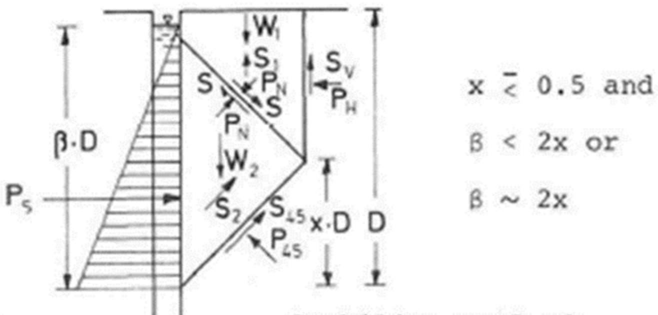


# DESIGN SOLUTION FOR THE RETAINING STRUCTURES

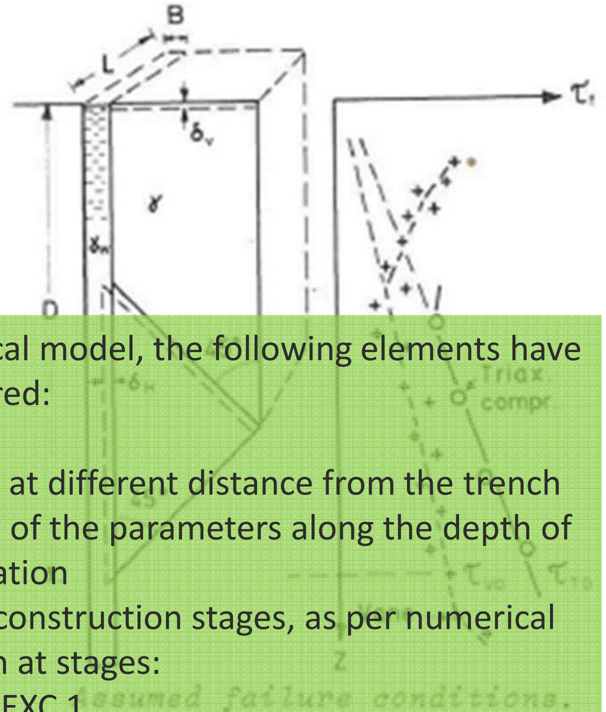
EVALUATION OF THE THRENCH STABILITY

## Analytical method

The evaluation of the stability is carried out also with an **analytical method**, as explained in the report “Stability of slurry trench excavations in soft clay” G. AAS, Head Foundation Section, Norwegian Geotechnical Institute.




Stability analysis.




Assumed failure conditions.

In the analytical model, the following elements have been considered:

- Surcharge at different distance from the trench
- Variability of the parameters along the depth of the excavation
- Different construction stages, as per numerical simulation at stages:
    - EXC 1
    - EXC 3
    - EXC 5

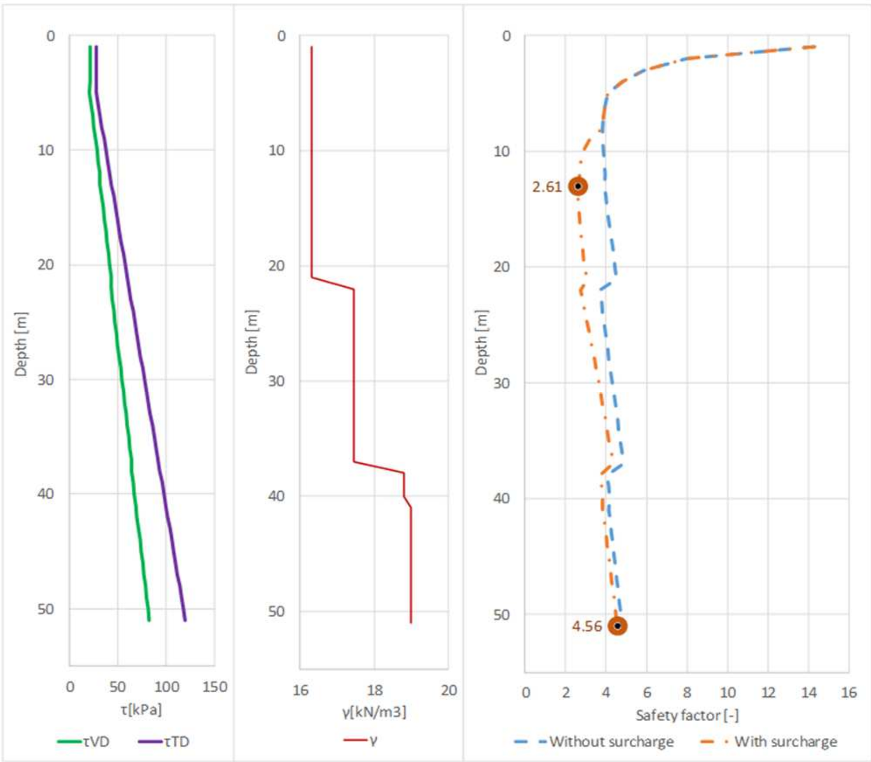
# DESIGN SOLUTION FOR THE RETAINING STRUCTURES

## EVALUATION OF THE THRENCH STABILITY

**Analytical method**
**Results**

The analytical calculation provides the safety factor along the depth of the excavation, considering or not the presence of the surcharge

| | | | |
|---|---|---|---|
| $\gamma$ | [kN/m³] | 19 | |
| $\gamma_F$ | [kN/m³] | 11 | |
| D | [m] | 51 | |
| L | [m] | 2.2 | |
| D/L | [-] | 23.2 | |
| $\tau_{VD}$ | [kPa] | 82.8 | |
| $\tau_{TD}$ | [kPa] | 120.0 | |
| x | | 0.5 | |
| β | | 1 | |
| x*D | [m] | 25.5 | |
| $\beta^2/4*\gamma_F/\gamma$ | | 0.14 | |
| Pressure | [kPa] | 45 | |
| $x_1$ | [m] | 4 | |
| $x_2$ | [m] | 10 | |
| xL | [m] | 5.3 | |
| Surcharge | [kN] | 594 | |
| | | With surcharge | Without surcharge |
| $W_1$ | [kN] | 13590 | 13590 |
| $S_1$ | [kN] | 1966 | 1869 |
| $S_V$ | [kN] | 254 | 242 |
| S | [kN] | 522 | 496 |
| $W_2$ | [kN] | 27180 | 27180 |
| $S_2$ | [kN] | 11798 | 11216 |
| $S_{45}$ | [kN] | 1565 | 1487 |
| $P_S$ | [kN] | 31472 | 31472 |
| $P_N$ | [kN] | 16397 | 15738 |
| eq 1 | | - 0.0 | - 0.0 |
| ***F bottom*** | ***[kN]*** | ***4.56*** | *4.80* |
| | *F (equation 5)* | *D/L<30* | *4.76* |
| | *F (equation 6)* | *D/L<7.5* | *5.01* |
| ***F min*** | ***[kN]*** | ***2.61*** | *3.70* |
| ***@ depth*** | ***[m]*** | ***13.0*** | |



# DESIGN SOLUTION FOR THE RETAINING STRUCTURES

EVALUATION OF THE THRENCH STABILITY

## Safety factor Results

The stability of the excavation is guaranteed by the pressure given by the water plus bentonite; the stability factor is in the range 2.3-2.6 for 3D FEM analyses and in the range 1.60-2.60 for analytical method

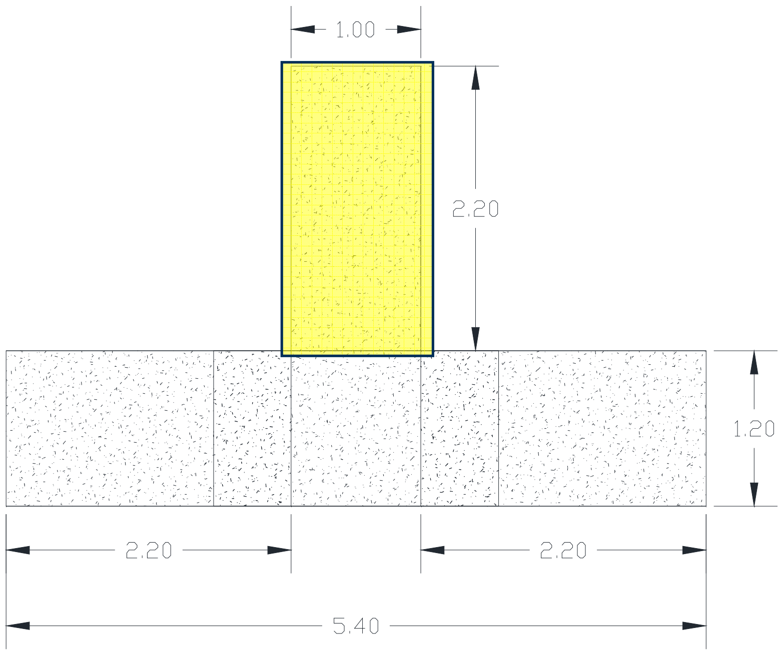
**ANYWAY A TEST PANEL WILL BE PERFORMED TO VALIDATE THE TRENCH STABILITY ANALYSIS**

| Step | 3D numerical simulation | | Analytical method | |
|---|---|---|---|---|
| | With DSM | Without DSM | Surcharge @4m | Surcharge @6m |
| EXC 1 | 2.673 | 2.395 | 2.61 (3.62) | 2.87 (3.62) |
| EXC 3 | 2.606 | 2.242 | 1.58 (1.95) | 1.65 (1.95) |
| EXC 4 | 2.304 | 2.208 | *2.61 (4.65)* | *2.87 (4.65)* |
| EXC 5 | 2.414 | 2.099 | *Not applicable* | |

Safety factor for excavation stability

# DESIGN SOLUTION FOR THE RETAINING STRUCTURES

## DETAILS: CROSS-WALLS

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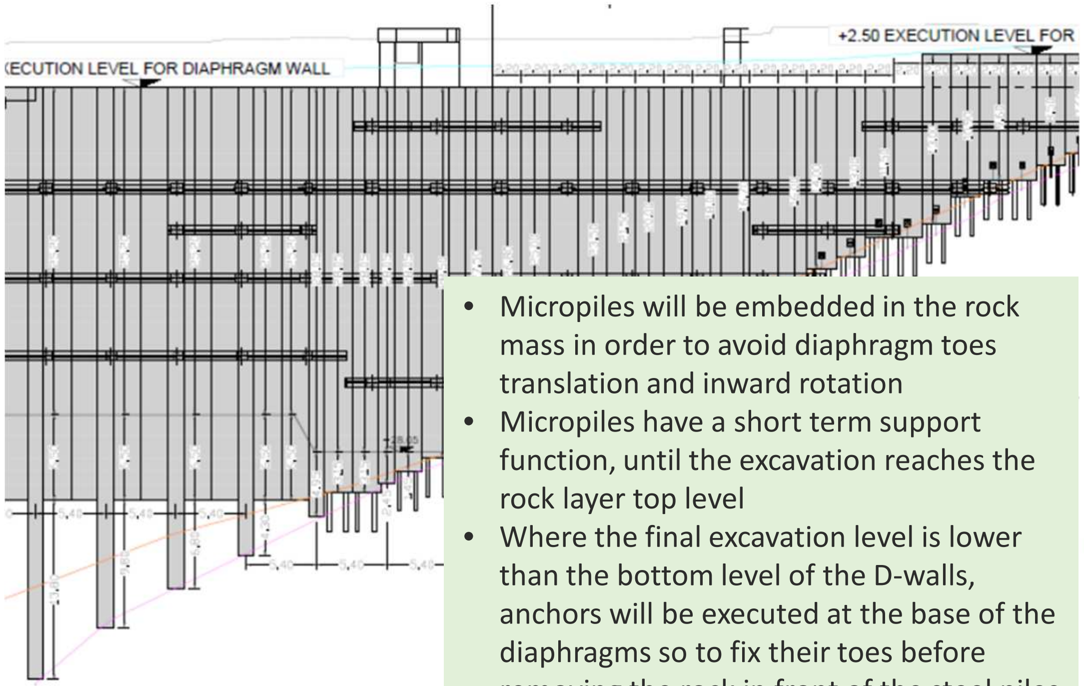
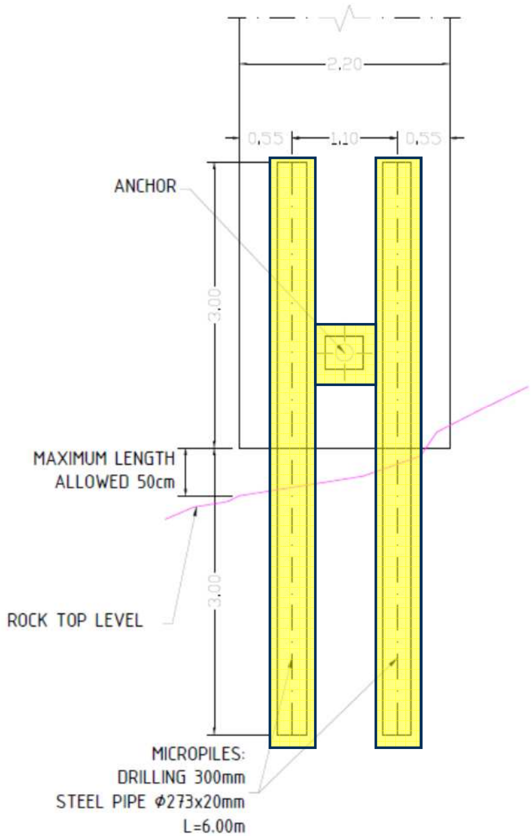
# DESIGN SOLUTION FOR THE RETAINING STRUCTURES

## DETAILS: ROCK ANCHORING

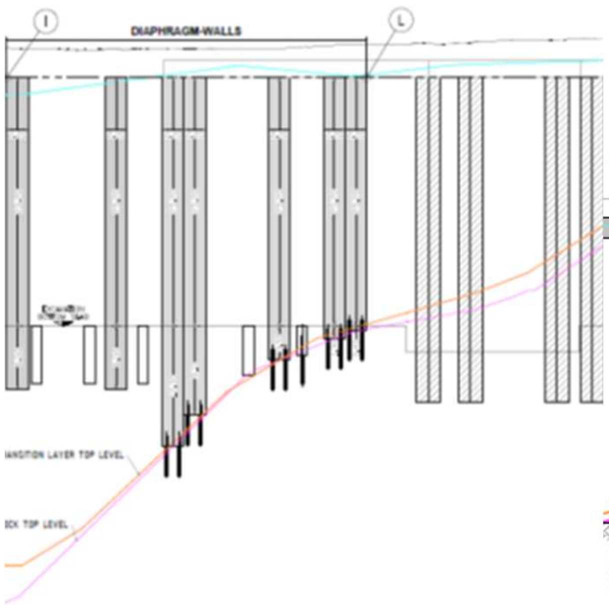



- Micropiles will be embedded in the rock mass in order to avoid diaphragm toes translation and inward rotation
- Micropiles have a short term support function, until the excavation reaches the rock layer top level
- Where the final excavation level is lower than the bottom level of the D-walls, anchors will be executed at the base of the diaphragms so to fix their toes before removing the rock in front of the steel piles

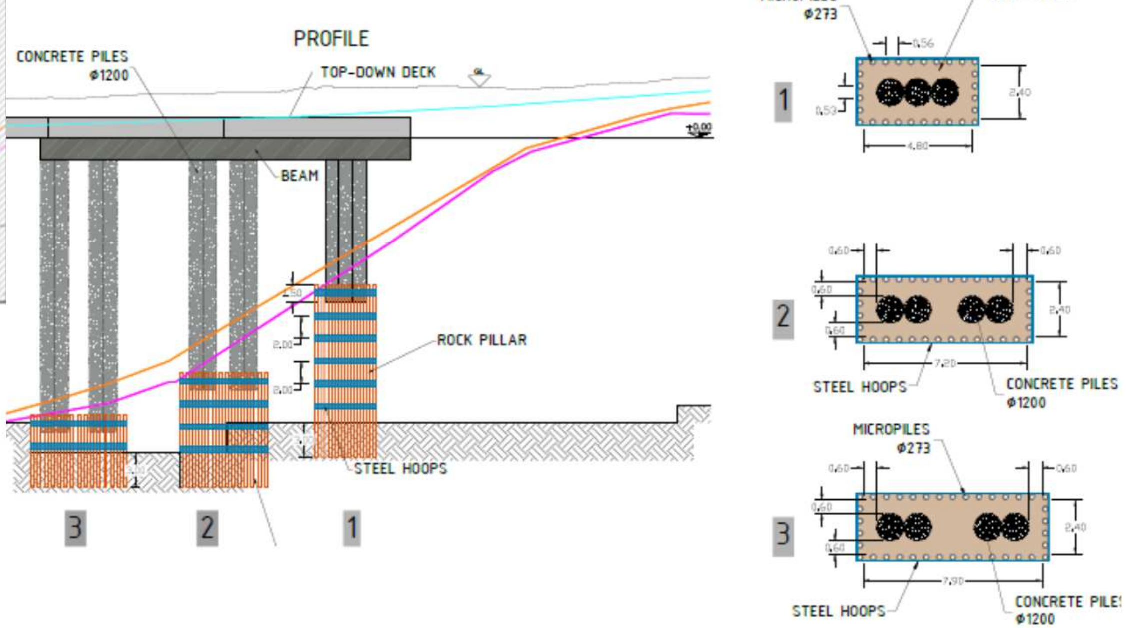


# DESIGN SOLUTION FOR THE RETAINING STRUCTURES

## DETAILS: ROCK PILLARS

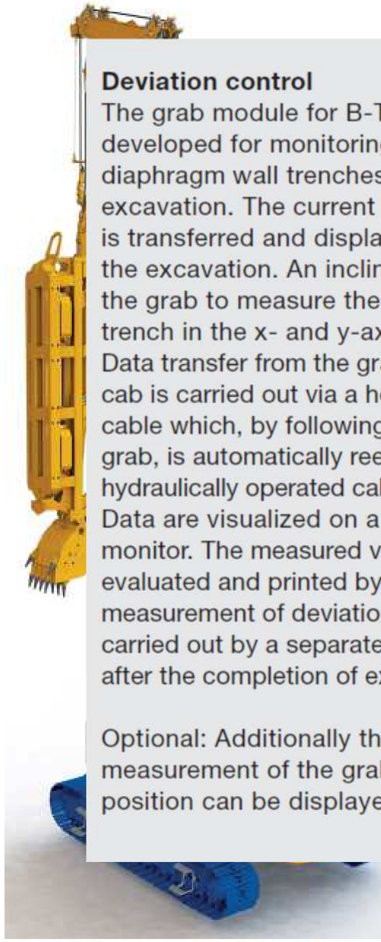



## ROCK PILLAR SKETCH



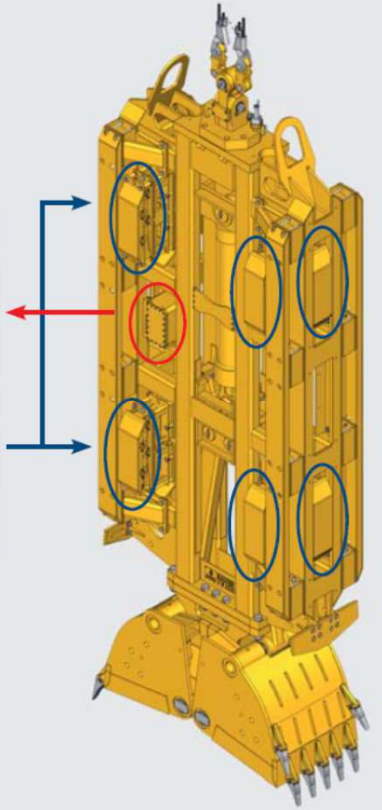
| GB 50 Hydraulic Grab | |
|---|---|
| Max. hook load | 28 t |

Length: 2,400 – 4,200 mm
Width: 600 – 1,500 mm

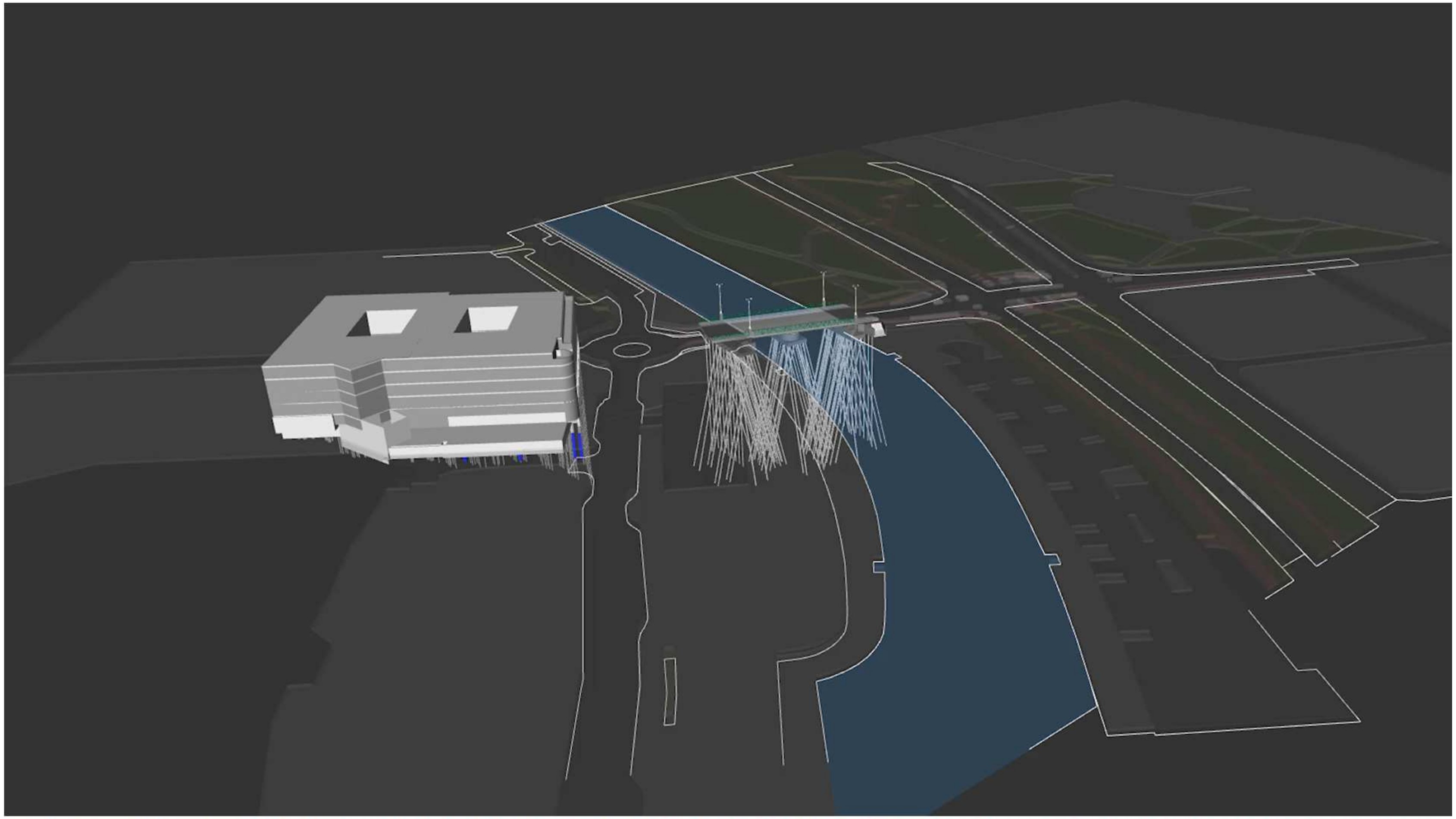


## Deviation control

The grab module for B-Tronic system was developed for monitoring the verticality of diaphragm wall trenches continuously during excavation. The current position of the grab is transferred and displayed online during the excavation. An inclinometer is built into the grab to measure the inclination of the trench in the x- and y-axis.
Data transfer from the grab to the operator's cab is carried out via a heavy-duty electrical cable which, by following every move of the grab, is automatically reeled on and off by a hydraulically operated cable recoil system.
Data are visualized on a touch-screen monitor. The measured values can be stored, evaluated and printed by using a PC. A final measurement of deviation of the trench is carried out by a separate survey of the trench after the completion of excavation.


Optional: Additionally the DHG V can be equipped with a gyroscope and a distance measurement of the grab cylinder. So the deviation on z-axis and the actual shovel position can be displayed on the B-Tronic screen to support of the operator.



# Thank you very much

# Tack så mycket