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Frozen retaining structure (Berlin shoring with ice-infill) for inner city construction pit, Sturegalleria/Stockholm

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ABSTRACT: The exclusive and historic Sturegallerian in the inner city of Stockholm is currently being renovated. Before the renovation work could begin, the Sture Quarter was extensively underpinned with jet grouting columns to stabilize the old buildings and to transfer future building loads. In connection with the renovation work, five large construction pits were built using artificial ground freezing technology. The project involved complex geotechnical and hydrogeological challenges, particularly due to the proximity to existing buildings with sensitive foundation conditions, including wooden piles. The temporary construction phase required minimizing groundwater lowering, while there are also water-bearing fractures and drainage plans in the rock that need to be sealed. It was important to prevent damming during the permanent phase. Within the construction area, which is over 130 years old, there is a mix of different foundation techniques and remnants, making the installation of traditional tight sheet piling or drilled steel pipe walls problematic. To meet the stringent requirements of the environmental permit regarding groundwater impact, a Berlin shoring was built with steel pipes embedded in rock, into which 19-meter-long freezing pipes were installed into the ground. Instead of the traditional sheet metal or wooden shoring, the 1.2-meter gap between the steel pipes was bridged with an ice shoring to create a watertight retaining wall. A brine freezing method was chosen for freezing the ground to minus 33 degrees Celsius. The construction pits were up to 12 meters deep and back anchored with two levels of bracing. The pits were dug in both soil and rock.

KEYWORDS: ground freezing, frozen retaining structure, berlin ice-shoring, frost wall, historic buildings.

1 INTRODUCTION

The Sperlingens Backe quarter, also known as Sturekvarteret, is undergoing extensive renovation to modernise the old premises, which were built in the 20th century. The renovation includes creating clearer communication routes within the neighbourhood and improved connections and accessibility to the underground. The extensive work has been carried out in several stages called Preworks and Mainworks. The developer Sturegallerian AB, in collaboration with TAM Group AB, reinforced the foundations of several buildings in the neighbourhood in Pre Works using jet grouting. The work was designed by Sweco Sverige AB and carried out by Züblin Scandinavia AB in 2021 and 2022. As part of this phase, a couple of retaining walls were also constructed for use in Main Works.

The major new construction and renovation project, called Mainworks, began with the southern stage, which started in 2023 and is scheduled for completion in 2026. The project was awarded to Peab Sverige AB and is being designed by Sweco Sverige AB with Züblin Scandinavia AB as a subcontractor for all ground and foundation work, see Figure 1 for location.

Figure 1. Overview of the renovation area marked in red (buildings 51a and b, 52, 31a and b, 41, 42).

Mainworks involved complex foundation work with deep soil and rock excavation below the groundwater level (max. approx. 9 metres below the existing basement floor) right next to existing buildings, as well as the construction of new buildings. Logistics and careful planning are crucial to the success of the project, and nothing can be left to chance.

2 PROJECT DESCRIPTION

To carry out the work in a time-efficient manner in production, Mainworks needed to be divided into five stages, see Figure 2. In areas 1, 2, 3B and 4, existing buildings were completely demolished. Heavy demolition began in area 1 and, as it progressed towards area 2, shoring installation began in area 1.

Once excavation and foundation work had been completed in one area, in-situ casting and frame erection began. Once excavation and foundation work had been completed in one area, on-site casting and frame erection began.

Within the area, most of the adjacent buildings, except for two, are owned by the developer. The foundations for the buildings around the excavation vary and consist of, among other things, dry stone walls on friction soil/rock, steel core piles and wooden piles. The buildings not owned by the developer are founded on wooden piles. To enable excavation in Mainworks and taking into account new load plans, three buildings founded on wooden piles, By 31, By 32 and By 41 in Preworks, were therefore reinforced by jet grouting underpinning, see Figure 2.

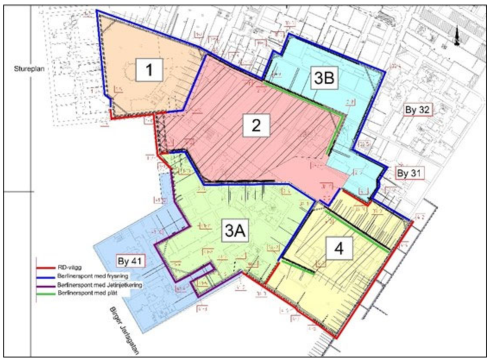

Figure 2. Division of work stages 1 to 4 and location of the reinforced buildings 31, 32 and 41 in the Sperlingens Backe quarter. The hatched areas in Areas 2 and 4 show completed rock excavations.verview of the renovation area marked in red (buildings 51a and b, 52, 31a and b, 41, 42).

3 GEOTECHNICAL CONDITIONS

The area is characterized by varied geology. The soil layers in the eastern part of the area mainly consist of fill, loose clay and friction soil above rock. To the west and Stureplan, the area connects to the edge of Brunkebergsåsen, a boulder ridge. The soil depth, from the existing basement floor, varies between approximately 2 and 10 meters within most of the area and increases significantly towards Brunkebergsåsen, with soil depths of up to 30 meters.

The fill consists mainly of sand, gravel and residues from older foundations, as well as blocks of varying thickness. The loose clay varies in thickness from approximately 1 to 8 meters and is in places sulfide-stained and sandy. The characteristic shear strength of the clay varies between approximately 17 and 22 kPa. The friction soil consists of sand and silt and contains a lot of stones and blocks. The layer also varies greatly in thickness, from approximately 0.2 to 5 meters, with the storage density varying with depth from low to medium closest to the rock.

Core sampling carried out in the area shows that the fracture frequency is higher in the upper meters of the rock profile. Water loss measurements indicate that the fractures in the upper part of the rock are open and probably in contact with the overlying soil layers.

4 ARTIFICIAL GROUND FREEZING

Inner-city projects such as Kv. Sperlingens Backe, where excavation is carried out near existing buildings and with complex geotechnical and hydrogeological conditions, present many challenges. So, what was the reason for choosing a Berlin shoring with ice-infill?

The main reasons were the strict requirements in the environmental permit regarding the impact on groundwater in the surrounding area. Both lowering during the temporary construction phase due to the sensitive foundations with wooden piles in nearby buildings, and permanent groundwater damming.

There are also several large, water-bearing cracks and fault planes in the rock, which are partly filled with fine sand and silt, which were important to seal. This is particularly important given the nearby Brunkebergsåsen ridge. This can be a challenge with traditional curtain/bottom grouting using cement-based grouting agents. Here, freezing replaced traditional curtain grouting and was carried out to a depth of 10 m below the bottom of the excavation.

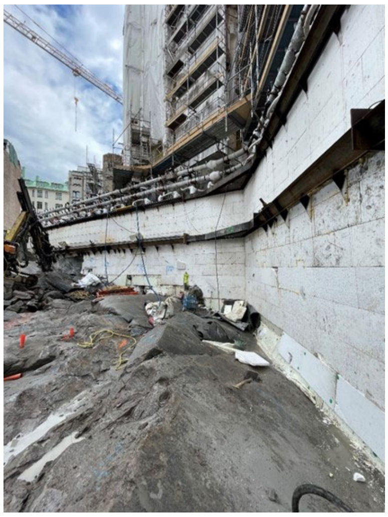

Figure 3. Image of insulated frost barrier in Area 2, excavation depth approx. 8 m to bedrock.

Within the neighborhood, which is more than 130 years old, buildings have been rebuilt, renovated, reinforced and demolished over the years. This means that there is everything from dry stone walls, wooden, concrete and steel-plastic piles, remaining sheet piling and reinforced and unreinforced foundations within the area. Obstacles in the ground make it difficult to install traditional sheet piling or drill continuous steel pipe walls without encountering problems.
In addition to reducing the risk of collisions and gaps in the sheet piling during production, the freezing solution also significantly reduces the amount of steel required. This is partly because the use of Berlin sheet piling is made possible and partly because the uniaxial compressive strength of the soil increases significantly when it freezes.

4.1 *Underlying freezing concept*

Artificial freezing of soil is carried out in this project using a cooling system with circulating fluid, which is cooled in a conventional mechanical cooling plant. The cooling system consists of a ‘two-stage’ plant with a primary cooling loop in the cooling unit itself. This loop also contains a condenser that uses water or air to remove heat.

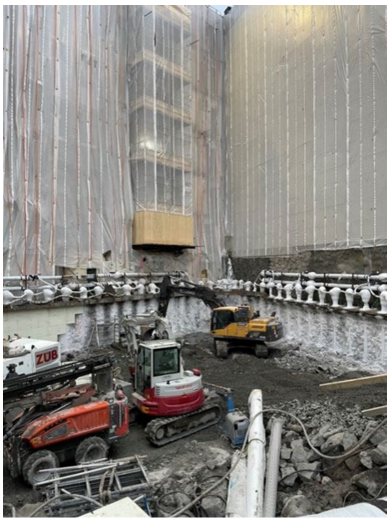

Figure 4. The image shows excavation work in progress, milling of frozen soil inside sheet piling and insulation in Area 1. Above the Berlin shoring, the feed lines and connection to the freezing pipes are visible.

In addition, there is also a secondary loop, which contains the coolant that circulates in the freeze pipes. These pipes absorb heat from the ground, after which the liquid is cooled in the heat exchanger. This loop uses a solution of NaCl, known as brine. Temperatures as low as -35°C can be achieved (varies slightly between systems). The freezing time for this method is weeks or months, depending on the diameter of the freezing pipes and the distance between them. The main advantages of this method are that the freezing process is easy to control and the equipment is inexpensive to operate over long periods of time.

When dimensioning a frost barrier, the following factors must be considered:

- The thermal properties of the soil (water content and porosity are important factors).
- The time available for freezing (determines the diameter of the cooling pipes and the distance between them).
- Groundwater flow velocity and salinity.
- Assessment of ground movement and pressure increase as a result of the freezing and thawing process.
- Space for cooling equipment, water and electricity supply.

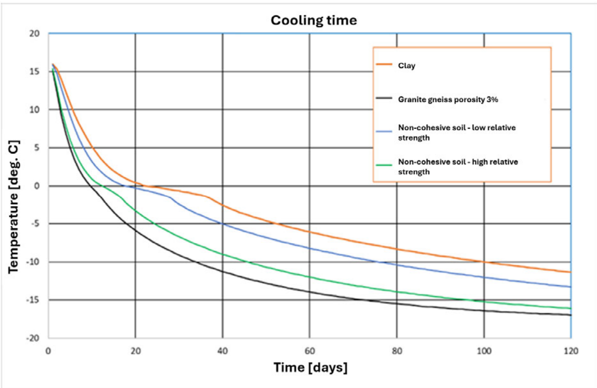

Figure 5. Cooling time in different soil and rock types in the Kv. Sperlingens Backe project.

When installing cooling pipes in the ground, a casing pipe, Φ 139.7 mm, is first drilled 1 m into the rock. After installation, underdrilling is performed in the rock and a closed steel pipe is installed inside the hole down to the required depth, see Figure 7. Plastic hoses Φ 40 mm are then installed in the steel pipe through which a cooling medium is circulated, see Figure 11. Throttle and shut-off valves are installed on groups of supply and return hoses so that a cooling pipe can be closed and disconnected in the event of leakage or damage. The flow through each cooling group must be able to be regulated by the throttle valve. The feed and return lines to the cooling plant are laid along the sheet pile.

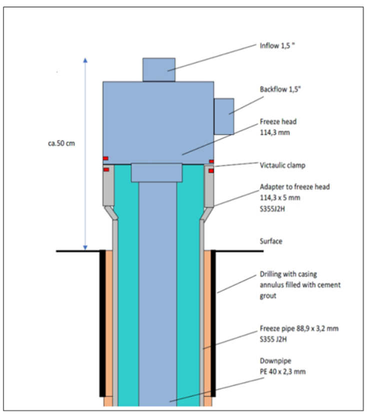

Figure 6. Cross-section of the freezing head.

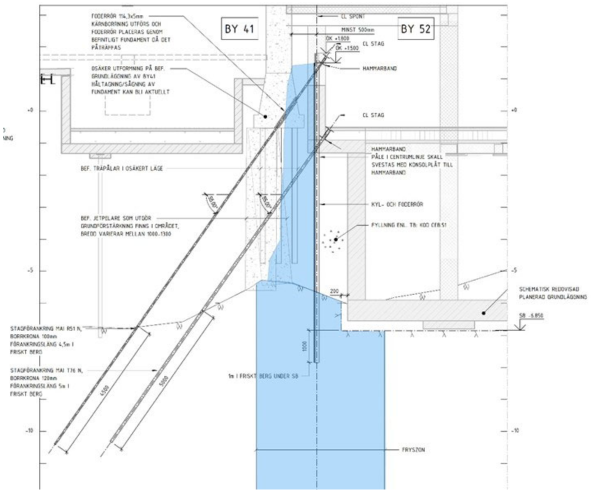

Figure 7. Typical section for freezing. Note that the figure shows buildings in their finished state.

4.2 *Monitoring in production*

During the project, it has been important to ensure that the calculation models work as intended. Therefore, movements in pile walls and buildings have been monitored using prisms, the temperature in the freezing body using temperature sensors, the outlet and return temperatures of brine and shear forces using strut force sensors.

4.2.1 *Temperature control*

In order to monitor temperature developments during cooling and continuously track the temperature throughout the excavation work, a number of temperature measurements have been installed. Due to lack of space, the sensors were placed 250 mm behind the sheet pile line between two cooling pipes approximately 10 m apart around the entire excavation. The distance was chosen with consideration given to sealing and the creation of arching between the casing pipes. Sensors have also been placed at other distances at strategic points, e.g. 1, 4 and 8 m from the piling line.

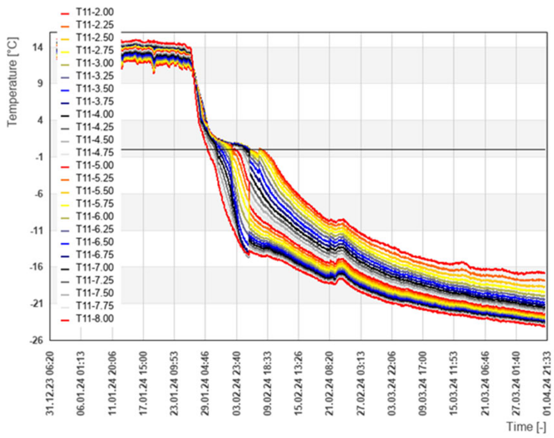

Figure 8. Temperature development during cooling recorded in one of the installed temperature pipes. All data is managed via an online project portal.

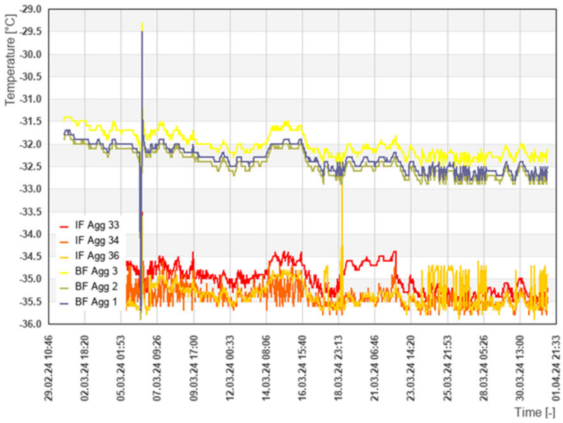

Figure 9. Brine temperature. 'IF' inflow brine from cooling unit. 'BF' backflow brine to cooling unit after a complete cycle in the pipe system.

4.3 *Movements*

Figure 10 presents measurement data for horizontal movements at the ridge beam level around the excavation. The data is taken from the automatic measurement system and, as it can be seen, the movements are generally small and correspond well with the forecasts. However, there are a few points, SP25-28, where the deformations are greater than expected. These points are all located in an area where existing wooden piles were pulled up before the pile wall was installed. This impaired the lateral resistance of the soil, thereby increasing the deformations in this area.

The accuracy of the automatic measurements is sometimes lower than expected, partly because it is a tight worksite where the prisms are sometimes obscured. However, this has been manually checked in cases of doubt.

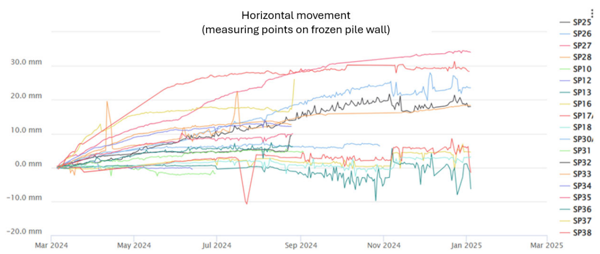

Figure 10. Horizontal movements (perpendicular to the center line) around the quarter. It should be noted that the measurement accuracy is slightly greater than desirable due to the confined workspace, where points are sometimes hidden from the automatic measuring station. The points where measurement data ends during September have been terminated at the same time.

4.4 *Tension force sensor*

The project considered that frozen ground, the risk of frost heaving and an expanded freeze body could lead to increased anchor stresses, and several anchor tension sensors were installed. The results show that all anchor tension sensors, regardless of whether they were installed at anchor level 1 or 2 and regardless of the preload used, have shown constant values over time.

5 CONCLUSIONS

This special project in central Stockholm has provided a number of findings, both expected and unexpected. Below are some of them:

- Measurements of temperature development and the size of the frozen body correspond well with forecasts and calculations. The exception was a part of the area that was affected by external factors, where it took longer to freeze.
- Test pumping carried out within the project showed that the construction is essentially as tight as it can be, with virtually no environmental impact in terms of groundwater lowering. This was also true during excavation, where only a few liters per day were pumped at most. In areas with other types of sheet pile construction than freezing, the environmental impact has been greater.
- Several layers of rock and crushing zones in the rock meant that it took time to install the cooling pipes inside the casing pipes as the holes collapsed again. And some grouting was required. In similar conditions, it would have been advantageous to install the casing pipes to full depth in order to save production time.
- It is possible to install anchors through the frost body below the groundwater level without a preventor systems without major problems with leakage causing the freezing body to thaw. In the project, this was done up to about 3 m below the groundwater level.
- Unsurprisingly, the time aspect of freezing is crucial both for the start of excavation and for how large the frozen body grows during that time. This means that an extended production schedule may require the frozen body to be monitored to a greater extent.
- Removing the frozen soil from the inside of the excavation pit was sometimes very time-consuming as the soil was very hard. This was especially true if it took longer than planned from the start of freezing.

Kv. Sperlingens Backe is a complex project with many challenges, both in terms of design and production. Despite a number of challenges, the work has progressed very well. To succeed, close cooperation between the client, contractor, and designer was required.
The freezing concept "Berlin shoring with ice-infill" has been a successful solution for such a deep retaining structure in the inner city, especially considering the environmental impact on groundwater in the surrounding area, which has been essentially zero.

6 REFERENCES

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