

When theory meets interactive practice – Jet-grouting takes the complex stage at Liseberg West

Robert Thurner, Ronald Veider
 Keller Grundläggning AB

Jan Derksen, Ralf Krutwig
 Wayss & Freytag Ingenieurbau AG

ABSTRACT: As part of the West Link project in Gothenburg, the joint venture Special Foundations Liseberg West, comprising Keller Grundläggning AB and Wayss & Freytag Ingenieurbau AG, carried out comprehensive jet and rock grouting works at the Liseberg West construction site. This involved underpinning and sealing of a top-down excavation pit, built with diaphragm walls, in geo-hydraulically challenging conditions. The complexity resulted from the partly hydraulically pressured conditions in combination with a large variation in the prevailing ground conditions ranging from cement-stabilised clay, densely bedded sand, a moraine layer with boulders to fractured and competent rock. The bedrock level varied approximately between 25 m and 42 m depth. The execution of the works comprised the following steps: First, sacrificial casings were installed, and the boreholes were measured using an inclinometer. Then, these measurements were analysed to forecast the jet-grouting columns in the context with the existing diaphragm walls, adjacent jet-grouting columns and casings. Hereby, it was decided whether and how to execute specific columns, re-drill a casing or reject the point. Finally, the jet-grouting drilling was also measured, enabling the JV to continuously update an as-built 3D-model in Revit, which was regularly exchanged for further assessments. Therefore, this project involved a highly interactive production engineering and planning process that needed to be established in terms of quality, time and costs. In conclusion, this article provides an overview of the opportunities and challenges of the interactive approach and concludes with some lessons learned from the project.

KEYWORDS: underpinning, sealing, complexity, interactive approach, 3D-model.

1. INTRODUCTION OF CONSTRUCTION SITE

1.1. West Link Project

Currently, comprehensive constructions works are ongoing within the West Link Project in Gothenburg, as shown in Figure 1. An 8 km double railway track tunnel is being constructed for commuter trains in order to facilitate travelling by increasing train frequency and reducing commuting times. This infrastructure measure involves in total about 6 km of railway tunnel and three underground stations, overall divided into five constructions lots (see Figure 1).



Figure 1. Overview Korsvågen Project.

As part of the West Link project, the joint venture Special Foundations Liseberg West, comprising Keller Grundläggning AB and Wayss & Freytag Ingenieurbau AG, carried out comprehensive jet and rock grouting works as a subcontractor at the Liseberg West construction site within the section Korsvågen (see Figure 2).

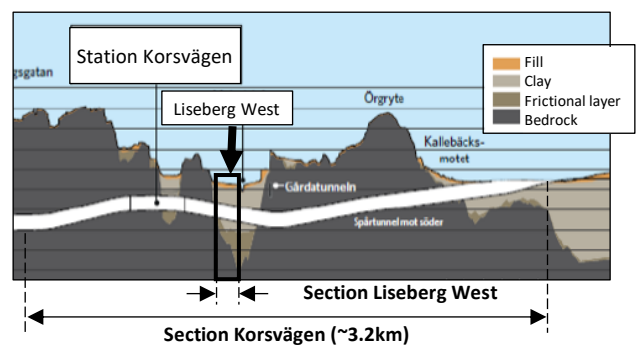


Figure 2. Subsection Liseberg within the Korsvågen Project.

1.2. Subsection Liseberg West

The subsection Liseberg West is located within the area of the Liseberg amusement park, as shown in Figure 3. The construction site is limited in space by Liseberg's buildings Rondo in the north and a restaurant in the south. The intended tunnel line enters the site from the west close to the main entrance of Liseberg and is directed east towards the river Mölndalsån.

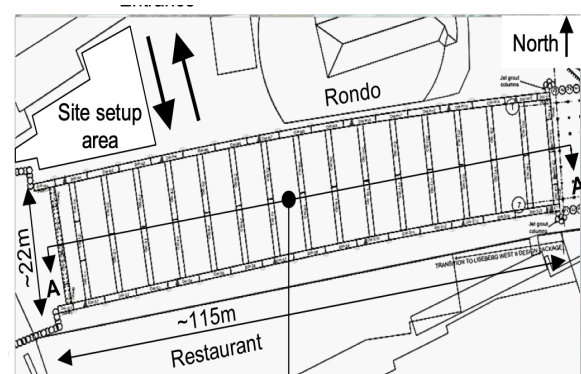


Figure 3. Top view.

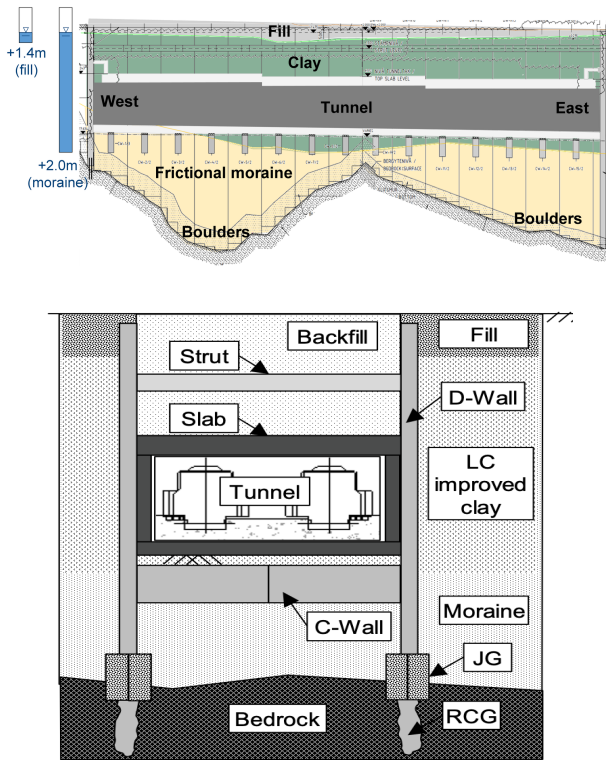


Figure 4. Geological longitudinal and cross section.

In the Liseberg West subsection, the main part of the tunnel was constructed within a top-down excavation pit with dimensions of approximately 115 m in length and 22 m in width, as visualised in Figure 3 and 4. For this purpose, diaphragm walls (D-wall) had previously been installed from ground level down to the bedrock by *Wayss & Freytag Ingenieurbau AG* as part of another contract. However, jet-grouting and rock curtain grouting required underpinning and sealing of the D-wall down to the bedrock. Then, the top slab of the tunnel was casted and the topsoil was back filled. The area could then be used again for its actual purpose and the tunnel was excavated and built underneath the cover.

1.2.1. Geological, hydraulic and other boundary conditions

Figure 3 (b) shows a geological section along the tunnel line from west to east. The naturally present clay layer with a thickness of up to 25 m was replaced in the upper 2-3 metres by a gravel layer as a working platform. Underneath the gravel layer, the clay was stabilised with lime-cement columns (LC) using the deep soil mixing technique (DSM). The clay is underlain by a frictional moraine, consisting of densely compacted sand and silt. The moraine varies in thickness and follows the bedrock level, which drops from the western end to approximately 42 m and then rises again in the middle of the excavation pit before dropping again towards the eastern end to a maximum depth of about 40 m. During the D-wall excavation and test field drillings for previous grouting works, several zones with stone, blocks and boulders were encountered within the frictional moraine forming an inhomogeneous soil layer. The relatively non-permeable clay layer hydraulically separates the top filling and the underlying moraine. The ground water level of the fill is given at about +1.4 m, which is about one meter below the ground surface. Within the moraine, the confined groundwater has a level of around +2.0 m, which underlines the requirement for a sealed connection between the D-walls and the bedrock during excavation of the pit. Overall, the geo-hydraulic complexity resulted from the partly hydraulically pressurised conditions in combination with a

large variation of the ground, ranging from cement-stabilised clay, densely compacted moraine with boulders up to fractured and competent bedrock.

The limited space for the working and site setup areas further added to the complexity of the site. For instance, the construction site could only be accessed via one entrance, which was also used as an exit, leading to detailed coordination of transports. Moreover, the adjacent buildings are sensitive towards settlements and heave, wherefore continuous monitoring was conducted.

1.2.2. Main works

The design had foreseen several jet-grouting and rock grouting activities in different sections over the Liseberg West construction site, which was subdivided into the areas West I and II, as indicated in Figure 5. The execution contract comprised in total approximately 656 jet-grouting points with a total length of about 4526 m and 141 points for rock curtain grouting.

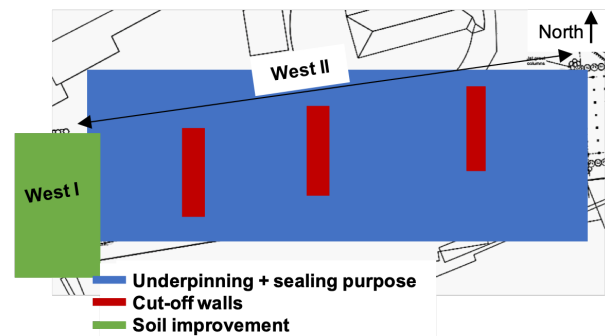


Figure 5. Illustration of main works: top view on site.

The main part of this job consisted of the underpinning and sealing of the excavation pit in subsection West II by connecting the existing D-walls to the bedrock. For this purpose, jet-grouting columns were jetted from the bedrock to approximately 1 m above the toe of the D-walls alongside the D-Wall panels of the north, south, east end wall; as indicated in blue in Figure 5. It should be noted that the west end wall had been part of previous works. Moreover, long columns were installed at the stop-ends of two neighboring D-wall panels for sealing the joints (see Figure 6). Additionally, a rock curtain was established along the D-wall by grouting within the bedrock for additional sealing.

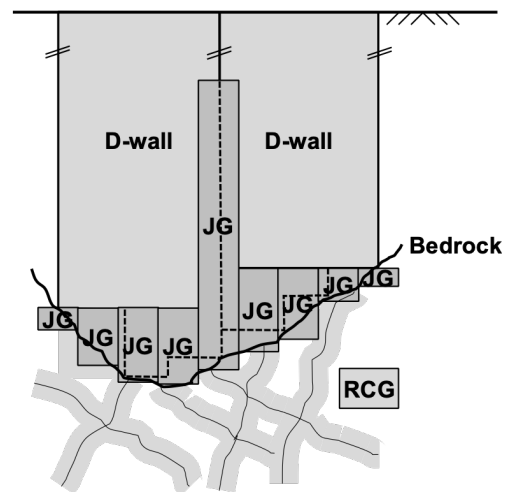


Figure 6. Side view of jet-grouting (JG) works for underpinning and sealing purpose plus rock curtain grouting (RCG) works.

As indicated in red in Figure 5, three cut-off walls made from jet-grouting columns were intended to divide the excavation pit into four compartments, enabling the possibility of pump testing in each section. Moreover, jet-grouting was required in the subsection West I as soil improvement measure behind the west end wall of the excavation pit, as marked green in Figure 5 in order to stabilise the area for the drill and blast tunnel entering the top-down-excavation pit from the western end by the New Austrian Tunnelling Method (NATM).

2. PRODUCTION PROCEDURE AND SEQUENCE

2.1. Jet-grouting (JG)

Figure 7 illustrates the production procedure for the jet-grouting works in the subsection West II including the underpinning and sealing columns plus the cut-off walls.

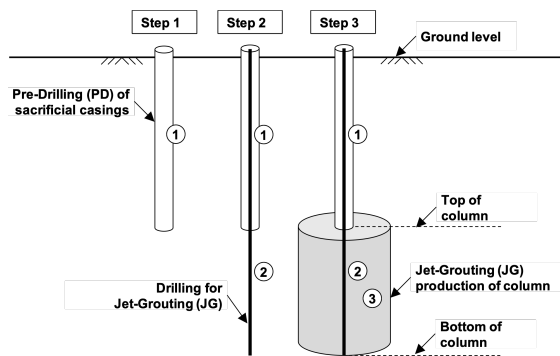


Figure 7. Illustration of the production procedure of the jet-grouting (JG) works.

The sequence comprises the following steps that are described in detail in the following subsections:

- Step 1: Installation of sacrificial casings at jet-grouting positions and 1st borehole measurement
- Step 2: Jet-grouting drilling, 2nd borehole measurement
- Step 3: Jetting of column

2.1.1. Installation of sacrificial casings

As a first step, sacrificial casings were installed at the positions of corresponding jet-grouting points, as represented in step 1 in Figure 7. The findings from a previously executed test field showed that casings were required to properly convey the backflow to the surface. Sacrificial casings were drilled down to the designed top of column using an inner diameter of 219 mm. The boreholes were drilled by using a water driven down-to-hole (DTH) hammer. The bottom of the sacrificial casings was drilled to the foreseen top of the column.

The installation of the sacrificial casings comprised the following steps:

- Setup of the drilling rig at the drilling point.
- Preparation of the starter casing by welding the ring set at the bottom.
- Preparation of the drill string and locking the pilot in the ring set within the casing.
- Water driven DTH drilling of the starter casing and extension of casing by welding until final design depth is reached.
- Flushing of borehole with water.
- Deviation measurement (1st) of the borehole by using an inclinometer.

The production process followed the principle of a double pilgrim procedure for the pre-drilling and jet-grouting works. In a primary round, every third sacrificial casing was installed

and then jetted. Afterwards, the closing sacrificial casings were drilled and jetted in the secondary and tertiary rounds.

2.1.2. Jet-grouting production

Once the sacrificial casing were installed, the jet-grouting column of the specific point could be executed, following the steps below as shown in Figure 7:

- Setup of the jet-grouting rig.
- The drill string was lowered to the bottom of the sacrificial casing drilling (see previous subsection).
- Jet-grouting drilling with water driven DTH hammer to the defined depth into the bedrock (see step 2 in Figure 7).
- Flushing of borehole with water.
- Deviation measurement (2nd) of the borehole by using an inclinometer.
- Exchange of the DTH hammer with the jet-grouting monitor.
- Pre-cutting of the column.
- Jetting of the column (see step 3 in Figure 7).

After pre-cutting was finished, the jetting of the column was executed. Cementous grout was pumped through nozzle with small diameter under high pressure while the rotating rod was withdrawn. As a result, the eroded soil was mixed and displaced with the grout forming a jet-grout column. The backflow was pre-treated on site using a filter press to reduce the liquid content. Additionally, pools were installed to buffer the backflow.

Similar to the casing drilling, two independent units were operating for installation of the jet-grouting columns, each consisting of the standard key machinery and equipment for jet-grouting.

Besides a previously executed test field, additional test columns were executed during regular production to confirm the required quality, whereby the feasibility of production of larger diameters was proven by using the acoustic column inspector (ACI). This evaluated the column diameter by piezo-sensors in feeler drillings.

2.2. Rock-Curtain-Grouting (RCG)

After the previously described jet-grouting activities, a rock curtain was installed by grouting to reduce the permeability of the bedrock. For this purpose, the pre-installed sacrificial casings were reused as illustrated in Figure 8 in continuation of Figure 7.

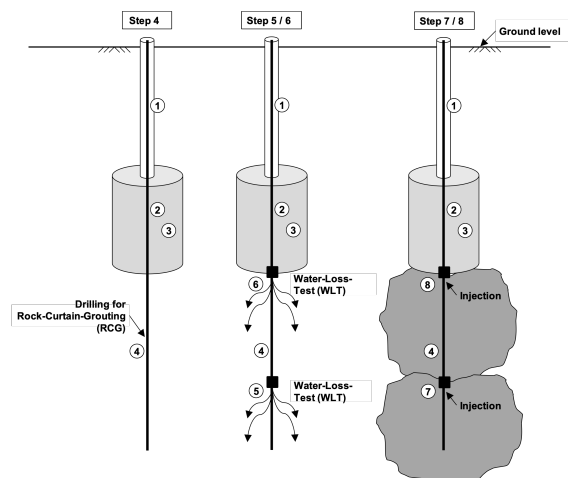


Figure 8. Illustration of the production procedure of the rock curtain grouting (RCG) works.

The detailed steps for rock grouting are listed below:

- Setup of the drilling rig at the preinstalled sacrificial casings from the former executed jet-grouting measures.
- Drilling with air driven DTH hammer to the defined depth into the bedrock (see step 4 in Figure 8)
- Flushing of boreholes with air.
- Removal of drilling string.
- Execution of water loss tests (WLT) at defined depth within the borehole following the designer's method statement (see step 5 in Figure 8)
- Evaluation of WLT test results (Lugeon value) to define the grouting parameters depending on rock permeability following the designer's method statement.
- Injection of grout at pre-defined pressure at defined depth until stop criteria is met (e.g. flow, volume, time) following the designer's method statement (see step 6 in Figure 8)

As an initial measure before the grouting activities started, pilot holes were tested within regular production points to provide an evaluation basis to the designer for determining the depth of the grouting curtain. Then, the general production sequence followed the principle of primaries and secondaries. Further decisions on additional tertiaries were taken by the designer depending on the evaluation of the grouting success of the executed works.

3. THE AS-BUILT – A RESULT OF INTERACTIVE PRACTICE

The key for fulfilling the underpinning and sealing purpose of the excavation pit through the executed works was an interactive practice between the involved parties. This approach involved a continuous exchange of design and as-built information. As a result, the as built was the outcome of an interactive working procedure as described in the subsections below.

3.1. Interactive working procedure

First, the deviation measurement of the boreholes from the sacrificial casings (see section 2.1.1) were provided to the geotechnical grouting experts. Then, this information was used to forecast the potential as-built jet-grouting column position in the context with the existing diaphragm wall and adjacent jet-grouting columns.

Second, the experts decided to either execute specific columns or whether the point needed to be rejected and re-drilled instead. In case the column was decided to be executed, the jet-grouting drilling was also measured before jetting (see section 2.1.2).

Third, the actual jet-grouting measurement was shared with the experts to determine the actual as-built position of the installed column.

3.2. 3D-visualisation of as-built

The previously mentioned as-built information of the executed jet-grouting columns was used as a database for a 3D-visualisation in Revit by Autodesk. The model was continuously updated by the site management in coordination with the back office according to the production. Then, the 3D-visualisation was regularly exchanged for further assessments and documentation purposes. Figure 9 shows a typical status of the production as 3D-visualisation.

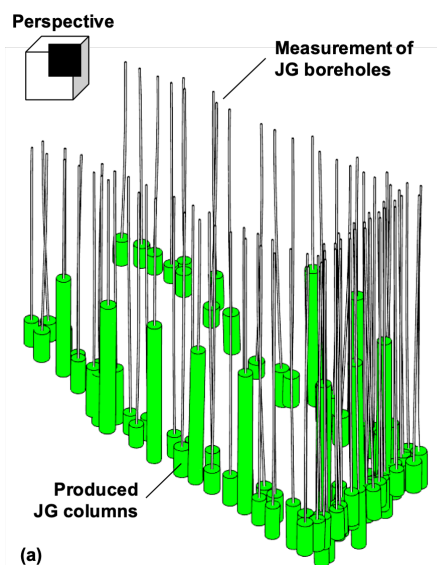


Figure 9. 3D-Visualisation of as-built status in Revit: executed jet-grouting columns.

4. CONCLUSIONS AND LESSONS LEARNED

The joint venture *Special Foundations Liseberg West* carried out comprehensive jet and rock grouting works at the Liseberg West construction site within the section Korsvägen as part of the West Link Project in Gothenburg. This involved underpinning and sealing of a top-down excavation pit, built with diaphragm walls, in geo-hydraulically challenging conditions. The paper presents the technical solution including sacrificial casing drillings and subsequent execution of jet-grouting columns. The project required interactive practice between all involved parties, continuously adjusted design and as-built information. The following lessons learned shall be taken for the reader:

- Technical success only with flexibility and a common goal.
- Qualified personnel with specialized knowledge and equipment required.
- Successful realization of complex construction projects requires interactive practice between all parties involved.
- Complex solution finding requires open, intensive and clear communication between all parties involved.

5. ACKNOWLEDGEMENTS

We would like to extend our gratitude to all project participants (Trafikverket, West Link Contractors, JV Special Foundations Liseberg West) involved in the Liseberg West section of the West Link project in Gothenburg. The successful execution of the comprehensive jet and rock grouting works was made possible through the dedication, expertise, and collaboration of the entire team at Liseberg West. Your commitment to safety, quality, and innovation has been instrumental in achieving project milestones and advancing the overall goals of the West Link development.

6. REFERENCES

- COWI A/S 20231009_Draft-Method-Statement-rock-grouting-LV2_COWI
 WLC West II, JG sealing and underpinning column layout
 Trafikverket / COWI
 E05-16-015-5310-0_0-1236 Arbets och metodbeskrivning för installation av slitsmurar, Bygghandling, Gokänd 2021-07-09