Sealing the zone between soil and rock to stop water and quick clay

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Abstract: Deep excavations and foundation works performed in soft clay, are known to frequently cause costly damages to neighboring buildings and structures. In 2012, the Norwegian Research Council, NGI, and 22 partners funded a research project called "BegrensSkade". The project aimed to identify possible causes for damages due to building activity, and by increasing the knowledge about these mechanisms also reduce risks for such damages ahead.

In 2016, the research project concluded that the primary factors causing the excessive settlements were 1) the sheet pile walls being supported by drilled tie-back anchors, 2) drilling for piles (*e.g.* casing for steel core piles) being executed from the bottom of the excavation, and 3) all excavations extending to bedrock level have a potential for causing groundwater leakages and pore pressure reduction. The most common causes for pore pressure reduction were listed and cases were studied.

In 2018, "BegrensSkade II" was initiated, to continue the studies on how to execute deep excavations in a safe manner for the surroundings, also covering vibrations, risk assessment etc. The work was supported by 18 partners, including Huth & Wien Engineering AS (HWE). With more than 30 years of experience of grouting in soil and rock, for example to seal leakages below sheet pile footings, HWE could also contribute to the comprehensive guideline "Byggegropveiledningen".

Grouting can be performed with cement, polyurethane, or a combination of the two. At Havnelageret in Bjørvika, Oslo, HWE used one-component polyurethane in combination with cement suspension to seal substantial water leakages below the sheet pile wall. At Fornebubanen in Oslo, polyurethane grout was used to strengthen quick clay in a gap between a sheet pile wall and the bedrock. This paper describes how the sealing capability of polyurethane can be used to stop ingress of water and quick clay.

1. Background

Many small leakages into a building pit can in sum cause substantial pore pressure reduction. If the water leakage is not stopped or decreased enough, erosion in the sediments around the excavation and/or pore pressure reduction may cause settlements in the surroundings. Studies performed in BegrensSkade show that pore pressure reductions were measured around 300-400 m laterally from the excavation [1]. A continuous moraine layer on top of highly fractured bedrock, can result in both large decrease in pore pressure at bedrock level and drawdown at longer distances from the excavation wall.

2. Deep excavations

2.1 Factors affecting risk of settlements

In connection with deep excavations in soft clay, water leakage can sometimes cause large settlements and damage to buildings and other structures in the area around an excavation. In the research project "BegrensSkade", it was concluded that the use of drilled anchors and/or drilled piles increase the risk for both settlements caused by mechanical disturbance and erosion (short term settlements), as well as pore pressure reduction and consolidation settlements (long term settlements). Data on deformation and pore pressure were collected and analysed for a large number of cases, and recommendations regarding drilling procedures were presented [1].

Langford et al. [2] listed the most common causes for pore pressure reduction as:

- Leakage during drilling for tiebacks and/or piles, through the casing or along the drill string
- Leakage through holes taken in the sheet pile wall or the interlocks in the wall
- Leakage through gaps between bedrock and the toe of the wall
- Leakage through joints or fissures in the rock

During "BegrensSkade II" the studies on how to execute deep excavations in a safe manner for the surroundings continued. "Byggegropveiledningen", a guideline on different aspects of excavations and foundation works, with contributions from experts in the Norwegian building industry, was published in 2019. Figure 1 illustrates possible leakage situations for deep excavations in soft clay ground.

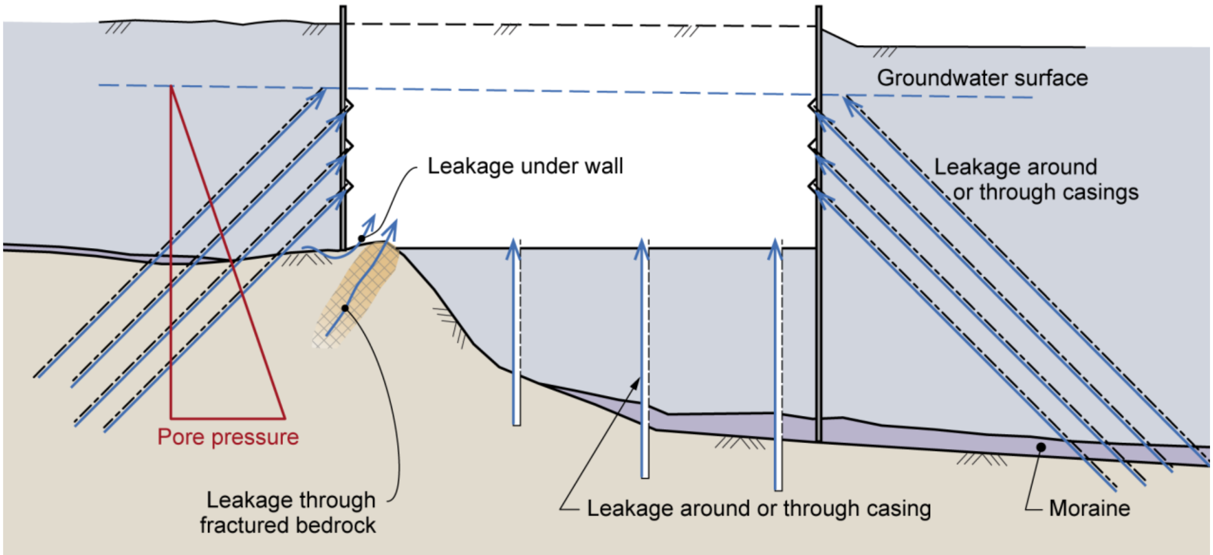

Figure 1 Possible leakage situations for a deep excavation in soft clay [2]

Measures to deal with water leakage through the bedrock, include cement grouted curtains to adequate depths around the pit and/or install infiltration wells before the excavation. Figure 2 shows leakage paths that are typical in a pit; a) water flowing out of the casing for a strand anchor, b) leaks through the holes taken in the sheet pile wall, and c) water causing erosion around the casing for a steel core pile.

Figure 2 Typical leakages in connection with installing tie-back anchors and steel core piles [2]

Figure 3 below illustrates the main causes of settlements for an excavation, and the detail to the right focus on the gap along the casing pipe due to overcoring. The reason for overcoring is discussed in detail in [2] – the erosion of soil can stem from 1) suction around the drill bit (which can lead to removal of excessive amounts of silts and sands), 2) collapse of bore hole (local ground failure), and 3) flushing with air and/or water along the drill string (casing) during drilling (or natural ground water flow).

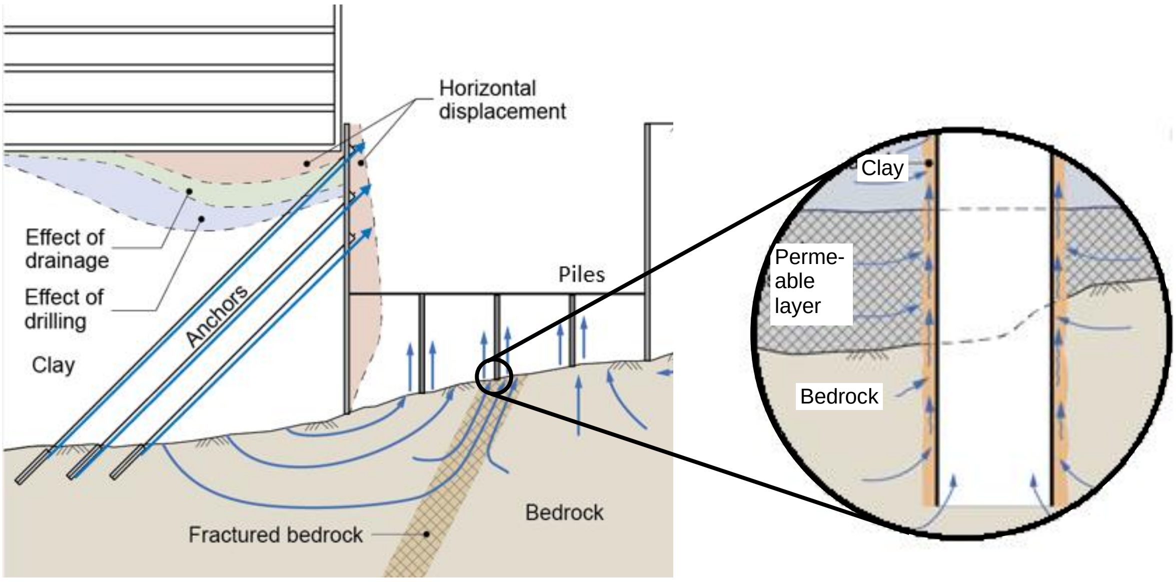

Figure 3 Main causes of settlements connected to deep excavations in soft clay [2]

"BegrensSkade" concluded that the use of air flushing is the main reason for the negative effects from drilling, and that drilling should be carried out using drilling equipment based on flushing with water and/or use of top-hammer [2]. Also, a greater risk of leakage was indicated when drilling casing for piles than for tiebacks. Both because piles are generally drilled from a lower level (*i.e.* higher water pressure), and casings for piles are not systematically tested for leakages and grouted like for anchors.

It is apparent that the drilling of casing pipes is a problematic activity when it comes to deep excavations. Compared with drilling with air flushing, drilling with water flushing causes less erosion, disturbance and drainage. However, the problem with erosion along the drill string, causing collapse and cavities in the ground, can easily be avoided. Anchors and piles that are simultaneously drilled and grouted with cement (*i.e.* Ischebeck TITAN hollow steel bars), do not introduce water nor air in the ground.

These so-called self-drilling bars are installed into the ground with rotary percussive drilling using cement suspension as flushing medium. The drill hole is stabilised by the cement, just like for diaphragm walls. The strong mechanical interlock between the grout body and the soil, enhances the shear bond and prevents erosion.

The cement suspension used for flushing should have a w/c-ratio of ~ 0,7. When reaching the full length, dynamic pressure grouting is performed with a cement suspension with w/c = 0,4–0,5, and the flushing cement is replaced by the stiff mix.

Figure 4 Mechanical interlock grout body/soil

2.2 Grouting to seal a sheet pile wall

Apart from water leakage during drilling for tiebacks and/or piles, a common cause for pore pressure reduction is water leaking through the interlocks in the sheet pile wall or through holes taken in the wall. The sealing capability of polyurethane can be used to stop leakage of water, as well as squeezing in of quick clay, through openings in sheet pile walls or other types of supporting structures. Simple measures to seal such situations will be described in short here.

Leaking sheet pile locks are sealed by grouting water reactive polyurethane into the locks after the sheet piles have been installed. This method is an effective alternative compared with more work- and time-consuming methods, *e.g.* welding.

The procedure is simply to 1) drill a small bore-hole into the sheet pile lock, 2) install a packer in the hole, and 3) grout polyurethane into the locks by use of a small membrane pump. The grout then follows the interlock, reacts with water, expands, and seals it against future water leakage.

This method to seal sheet pile locks requires little resources, since it normally is performed quickly and effectively with light equipment. The sealing work is easily adapted to the extent of the water leakages and the conditions at the site.

Figure 5 Typical water leakage in interlocks

Virtually the same method is used for sealing of holes for anchors in sheet pile walls. To facilitate easier sealing, simple rags and shreds are pushed in place around the anchors. Polyurethane is grouted behind the sheet pile around the anchors, and after contact with water the polyurethane reacts in the gaps around the anchor. The time before the reaction starts after water contact – induction time **-** is set by use of a catalyst. It is chosen based on the magnitude of water flow, and desired grout propagation.

Figure 6 Sealing sheet pile interlocks and openings by grouting water reactive polyurethane HAG

2.3 Grouting to seal gaps between bedrock and sheet pile toe

In connection with deep excavations, gaps between bedrock and the toe of the wall can cause settlements due to pore pressure reduction and/or squeezing in of soft clay. The sealing capability of polyurethane can be used for sealing and strengthening in such situations. A brief introduction of the grouting method is given below, and the next paragraph will describe environmental aspects and the combination grouting in more detail, and finally present examples of such sealing projects.

The method HWE uses to seal the gaps between bedrock and the foot of the supporting wall is to drill TITAN 40/20 hollow bars and grout through these pipes in a downstage grouting process. The grouting can be performed with cement, water reactive polyurethane, or a combination of the two (see fig. 7). We have long experience of this method, which we have used since the beginning of the 90's. This method is also used to seal leakages along casings for piles or geothermal installations.

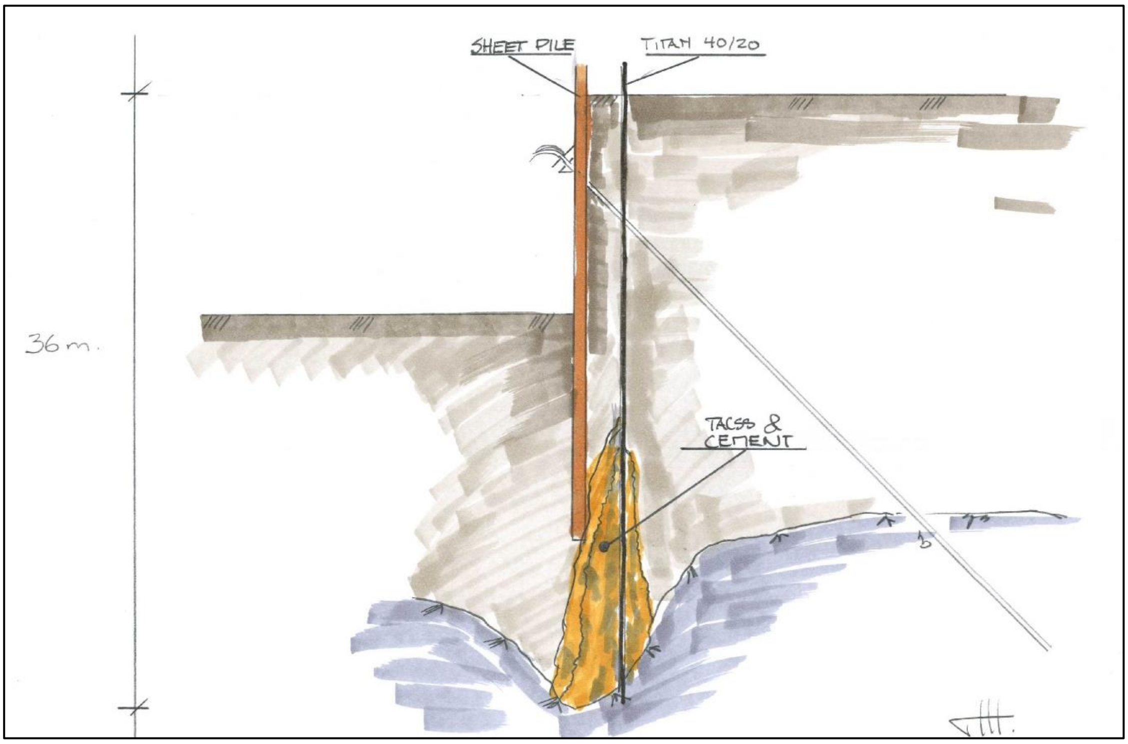

Figure 7 Typical profile of gap between the bedrock and the toe of the sheet pile wall

The water reactive polyurethane grout used is HAG, Hydro Active Grout (previously TACSS), which is a one component polyurethane, developed for grouting rock, soil, and concrete. The polyurethane is non-water-soluble but reacts with water, and during the reaction the material expands and fills channels and voids in the ground. When sealing against ingress of water and/or clay through gaps beneath sheet pile footings, a semiflexible polyurethane grout called HA Cut CFL AF is used.

When HWE is contacted to seal leaks through gaps beneath a wall, we will plan the measure carefully based on information about the ground conditions and the geometry of the supporting structure. The planning includes length of grout pipes, distance between them, type and consumption of grout(s). Then we take steps to hire a drilling contractor, usually with an excavator with an adapted drifter.

HWE would also recommend the project owner to contact the authorities to inform that this measure involves use of chemical grouts. In our experience, the need for an environmental risk assessment is usually not required in connection with deep excavations. For such projects, the water leaking into the pit is collected and treated, which is not the case when sealing for instance artesian leaks.

3. Polyurethane grouting

3.1 Environmental aspects

For almost all types of sealing applications, HWE uses a water-reactive polyurethane grout, either on its own or in combination with cement. This polyurethane grout has been used in several large projects with strict demands to limit contamination. If an environmental risk assessment is required, we would recommend the project to contact a laboratory with long experience of analysing polyurethane grouts.

In connection with a project in the center of Drammen, for sealing around a casing for a geothermal installation to prevent future sink holes, COWI Aquateam performed an environmental risk assessment [3]. The methodology used when performing an environmental risk evaluation is shown in figure 8.

First, easily available information is collected, and an assessment is made about the potential hazards and exposure. The risk is then characterised based on this initial information. If the risk is limited, it is not necessary to gather any more information or decide on measures to handle the risks, and the risk evaluation can be finalised. Such an initial screening of the environmental risk uses conservative values and high safety factors, detailed information is not collected, and the analysis may be rather simple.

If, however, the risk is assessed to be high based on the data collected in the screening phase, the next step is to consider whether additional data is needed.

When a more detailed information has been collected, the risk evaluation is repeated, but this time with a lower safety factor due to the larger information base.

If the risk, after repeated evaluations, still indicate unwanted high risk, a set of measures for handling the risk is decided on and different methods for controlling the pollution are initiated.

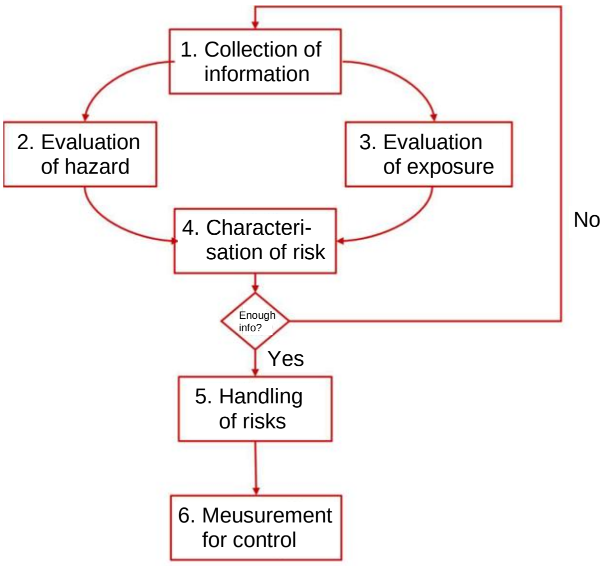

Figure 8 Methodology – environmental risk evaluation [3]

The first example of an ambitious environmental risk evaluation in Norway was performed in 1998, for a major post-grouting operation in the railway tunnel Romeriksporten along Gardermobanen to the new international airport near Oslo. Earlier, around 365 tons of the acrylamide grout Rhocagil had been used for pre-grouting at Romeriksporten. When serious pollution problems occurred due to the same grout at Hallandsås tunnel in 1997, the use of Rhocagil was stopped along with all other chemical grouts.

Thereafter, very high requirements were put on the chemical grouts to be used for the post-grouting at Romeriksporten, and after a thorough investigation of the polyurethane product TACSS with respect to health and environment, two trial grouting rounds were granted in January 1998. The trial grouting work showed that the sealing effects were good, and the pollution from this polyurethane product was well within the set health and environmental limits, so TACSS was allowed for further use [4].

The investigation of the polyurethane product comprised a comprehensive survey of the different chemical substances in the grout. The Aquateam report [4] included both an evaluation of health risks associated with the handling of the product, as well as of possible environmental hazards.

Based on Norwegian standards for contamination in the working environment, the exposure of chemical substances in focus was calculated for different situations; 1) when mixing TACSS with the catalyst, 2) when transporting TACSS, 3) when injecting TACSS, 4) caused by leakage of TACSS components during grouting, and 5) when cleaning the equipment used for mixing and grouting [4].

The analyses did not indicate that the work force involved in the grouting operations with TACSS at Romeriksporten would be subjected to unacceptable health risks. Nevertheless, it was recommended that the exposure be reduced as much as possible and measurements of both air and water be performed regularly. The work force should be educated in the handling of TACSS polyurethane and, of course, relevant protection should be used with regard to skin contact and inhalation.

Finally, it was recommended that a measurement program be set up for supervision of the amount of water leaving the tunnel, as well as the amount of different chemical substances in the water. Based on an assumption of the amount of polyurethane grout that would be used for the sealing works, calculations of the pollution to the recipients were performed. Maximum contaminated discharge water from the tunnel and minimum water flow in the river are important parameters in such calculations.

3.2 Combination grouting

The method of combining cement and polyurethane grout, called Combi Grouting, was established for rock tunnelling. The first time this method was used was in Øvre Otra power station in 1981. Combi grouting makes it possible to adapt the cement grouting to the conditions in the ground. Other times, it is more efficient and/or practical to grout with water reactive polyurethane only.

- In soil grouting, combination grouting can be used to create a watertight barrier of polyurethane and cement in the ground. Systematic grouting through hollow bars establishes a sealing in the leaking area, and water ingress into the excavation is prevented.

- In rock grouting, where polyurethane is added to the cement grouting, combination grouting can reduce the cement take in difficult zones substantially. Decreased grout take saves grouting time as well, so this method can be economically advantageous.

In our experience, polyurethane grout is suitable to use for sealing in many situations, both on its own and together with cement. For sealing of large water-bearing structures, in which cement grout is both diluted and transported away or back into the tunnel by flowing water, no counter pressure is obtained, or simply when the grout take is too large; the take of cement can be controlled with polyurethane.

The polyurethane grout is transported with the cement grout to the most permeable area in the ground, where the polyurethane reaction starts after a certain, set time. Reacting polyurethane should mix well with the cement suspension, but the polyurethane does not interfere with the hardening of the cement or block the grout hole, so the cement grout can continue to fill the remaining fractures in the ground.

When only cement grouts are used for the post-grouting in rock, there are always situations when the suspension in fractures and faults is flushed away by the streaming water or flows out of the fractures before it has cured. In Romeriksporten, post-grouting with cement and polyurethane in combination was performed between March and June 1998, reducing leakages to around 80% of the set target [5].

The remaining leakage was more difficult to come to terms with – small leakages are more difficult to locate and, as the tunnel is getting tighter, the groundwater gradient to the tunnel increases. It is a known fact that a rapid strength development for the cement suspension is of vital importance for a successful grouting result, especially at high groundwater pressure. Not only to speed up the excavation of the tunnel, but also because a cement suspension with a too low strength can be flushed out of the fractures. In Romeriksporten, flushing out of cement grout proved to be a central problem [5].

3.3 Examples of sealing work

The methodology for sealing water leakages (downstage grouting) has been used by HWE in connection with supporting structures for deep excavations in a number of projects. Table 1 lists a compilation of 16 projects with problems with leaking water and/or soil, through or beneath the supporting wall.

Table 1 Projects where downstage grouting has been performed to prevent water and/or soil ingress

Year	Project location	Assigning parties	Project description, extent, and details
2006	Havnelageret, Oslo	NCC/ NSP/ NPRA	Excavation for tunnel access. Leakage at gaps at sheet pile foot, through interlocks and anchors openings. For example, combination grouting (polyurethane and cement) in hollow bars, to a depth of 34 m.
2007	Sørenga, Oslo	AF/ NPRA	Excavation for tunnel access. Leakage in interlocks and openings for anchors in the sheet pile wall. Polyurethane packer sealing and grouting around anchors from the building pit.
2008	Bjørvika plug, Oslo	NCC/ NSP/ NPRA	Interface at tunnel access. Water ingress between sheet pile wall and concrete tunnel. Polyurethane grouting in hollow bars to prevent water ingress into the building pit.
2010	Midgards-ormen, Oslo	Olimb/ Oslo kommune	Excavations for sewage tunnel. Sealing around holes in the sheet pile for no-dig tunnel. Polyurethane packer sealing around pipes and horizontally through hollow bars.
2012	Cultural Centre, Bodø	FAS/ Bodø kommune	Excavation for development of cultural centre. Sealing of large water leakages with polyurethane through hollow bars from the terrain and from the pit, at the sheet pile footing.
2013	Gardermoen Airport, Oslo	NCC/ OSL	Excavation for infrastructure for new extension at the airport. Sealing of soil around the entry of concrete culvert. Sealing with polyurethane through hollow bars.
2013	Sørenga, Oslo	Implenia	Excavation for infrastructure to building developments. Sealing of soil around the entry of pipe culvert. Polyurethane sealing with packer in a concrete wall.
2013	Hogga dam, Telemark	NCC/ Statkraft/ Slusebolaget	Old historical lock system at Telemark canal with stone block walls. Sealing of large water leakages through the walls with polyurethane through hollow bars from the terrain.
2014	Deichmanske A8, Oslo	ÅF Advansia/ Oslo kommune	Excavation under sea level for new national library. Large leakages in the interlocks of the sheet pile wall. Polyurethane grouting through hollow bars and packers to prevent water ingress into the pit.
2014	Diagonale A9, Oslo	Insenti/ A9 Palékaia	Excavation under sea level for building development. Large leakages in the interlocks of the sheet pile wall. Polyurethane grouting through hollow bars and packers to prevent water ingress into the pit.
2015	Nye Nasjonal-museum, Oslo	HAB/ Statsbygg	Excavation under sea level for new art museum. Leakage at gaps at sheet pile foot, in interlocks and openings for anchors in the sheet pile wall. Polyurethane grouting through hollow bars and packers.
2018	Brenna, Mortensrud	NGI/ Implenia	Excavations for water and wastewater facilities. Gaps between rock and sheet pile wall, stabilisation of quick clay needed around the wall. Polyurethane grouting through hollow bars beneath/beside the wall.
2019	Munkhaug, Mjøndalen	NEK/ Kjeldaas	Excavations for water and wastewater facilities. Stabilisation of silt behind sheet pile wall before opening for pipe pressing. Polyurethane grouting through hollow bars beside the wall.
2021	UDK02, Drammen	Veidekke/ Banenor	Excavation for cut and cover tunnel. Water leakage from damaged interlocks in the sheet pile wall. Grouting with polyurethane through packers and hollow bars from the terrain and from the pit.
2021	UDK03, Drammen	NCC/ Banenor	Excavation for water culvert. Leakage of water and silt in damaged interlocks, sheet pile overlaps, and open corners in the sheet pile wall. Polyurethane grouting through hollow bars from the terrain.
2022	K4 Fornebu-banen, Oslo	Skanska/ Fornebubanen	Excavation under sea level for train station. Large gap between rock and sheet pile wall. Strengthening the quick clay around the wall by polyurethane grouting through hollow bars behind the sheet pile wall.

Usually, the major water leakage is located beneath the wall, in gaps between the foot of the wall and the bedrock, but in the A8/A9 projects the leakages were in fact through the interlocks. There, the interlocks were very open and the water flow into the pit was very large. It was even too large to empty the pit from water by pumping. So, the simple method described in section 2.2 could not be used.

The sealing results for the projects in table 1 were successful, except for the two projects Munkhaug and UDK03. The causes for an unsatisfactory sealing result are always complex and will often be debated, but a common denominator for these two projects was the presence of silt. The fine soil fraction is known to be devious (hard when dry and flows like water when saturated) and difficult to grout.

In the following, short descriptions give more detailed information about the polyurethane grouting to stop ingress of water at Havnelageret and quick clay at Fornebubanen.

4. Case histories HWE

4.1 Sealing against water ingress

The Bjørvika tunnel in the center of Oslo, links the Festning tunnel in the west with Ekeberg tunnel in the east. Complex work from the quay side and into existing tunnels was required at both ends. The first contract was signed in May 2005 with AF Spesialprosjekt for the Sørenga contract (west). The contract for the sea section with the immersed tunnel was signed with Skanska with partners Bam Civiel and Volker Stevin in August 2005. The last main contract was signed with NCC in September 2005 for the Havnelager contract (east). An overview of the Havnelager excavation is shown in Figure 9 below.

One of several challenges for the contractor was to establish a watertight foot for the sheet pile wall in the permeable ground of hard moraine with blocks.

At the Havnelageret project, HWE co-operated with NPRA, NCC and NSP from 2006 to 2008, to perform sealing of the building pit and adjoining concrete structures [6].

The water leakages into the excavation were prevented by grouting of the ground, both by Combi Grouting (a combination of cement and polyurethane), and with polyurethane alone.

Polyurethane grouting only requires small equipment and no water supply, so it can often be easier to perform.

In some areas, jet grouting had been performed to seal the leakages, but in this area supplementary sealing was also performed by downstage grouting.

Figure 10 illustrates gaps where the sheet piles had been driven to false stops before reaching bedrock.

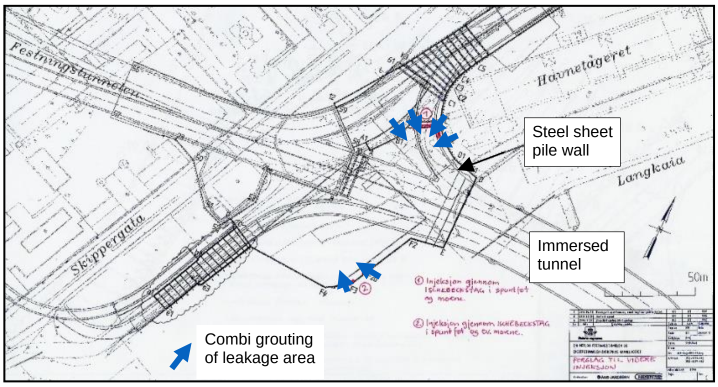

Figure 9 Overview of the Havnelager excavation [6]

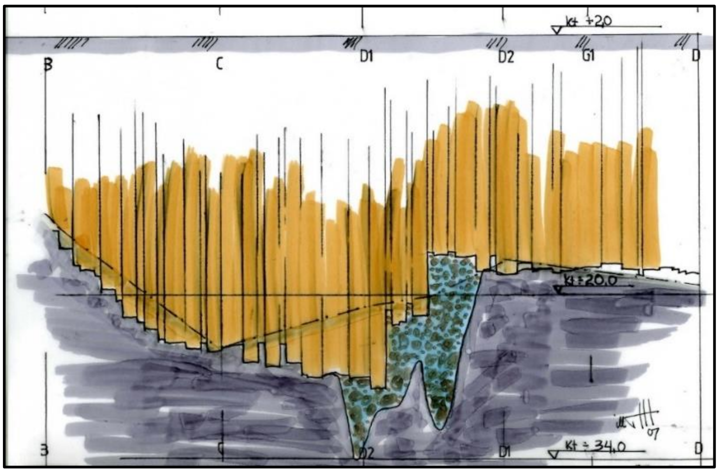

Figure 10 Illustration of false stops in the moraine [6]

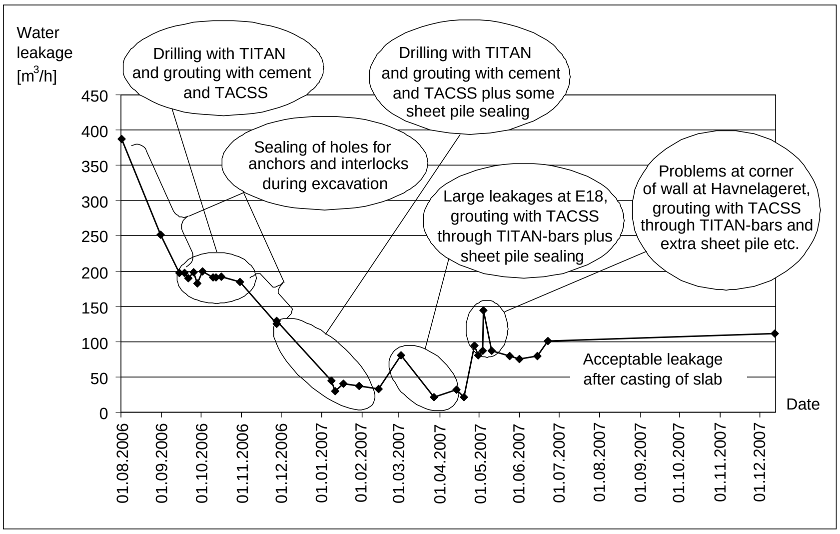

Figure 11 Water leakages to the building pit at Havnelageret [6]

At Havnelageret, the polyurethane TACSS 020 NF(i) was combined with cement suspension in order to seal major leakages below the sheet pile wall. TACSS polyurethane was also used for sealing holes for anchorages in the sheet pile wall, as well as of leaking interlocks.

The response on the water flowing into the excavation, after the grouting performed on many different leakages, between August 2006 and December 2007, is shown in figure 11.

Simultaneously drilling of hollow bars and grouting with cement suspension and water reactive polyurethane is a demanding and complex sealing operation. It should be performed by a workforce with previous experience of this type of work. At Havnelageret, the hollow bars were drilled to varying depths, to a maximum depth of 34 m. The drilling was performed with a carbide button drill bit for rock, and the grouting was performed during the drilling in a downstage process, alternatively with cement suspension and water reactive polyurethane. Careful planning is essential for combi grouting.

4.2 Sealing to prevent quick clay

The method of drilling hollow bars and performing downstage grouting, has been used by HWE to stop quick clay from being squeezed in through gaps beneath a sheet pile wall. Sealing against water ingress has been performed in a long row of projects but sealing to prevent quick clay from flowing into the building pit is not as common. The Brenna project in 2018 may be mentioned, where this application was utilized on a larger scale, and in 2022 we took on an interesting challenge at Fornebubanen.

Fornebubanen is a rail line under construction, which will serve the peninsula of Fornebu – a newly developed area near Oslo, in need of a transit system to handle many commuters during rush hour. After a long planning process, it was decided to add a metro line to the Oslo Metro. The commuter line will start at Majorstuen Station in Oslo and end at Fornebu Senter, and it will run in an appr. 8 km rock long tunnel. Skanska had the contract for a large excavation for the depot located at Fornebu.

Drilling of sounding holes to establish the bedrock surface, revealed a deviation. The drilling met rock after appr. 7 m, drilled 2-3 m in rock, and exited it again.

After driving the sheet pile wall, the situation had been preliminary drawn up with depths. The planning of the grouting, for placement of grout holes etc., was based on this information.

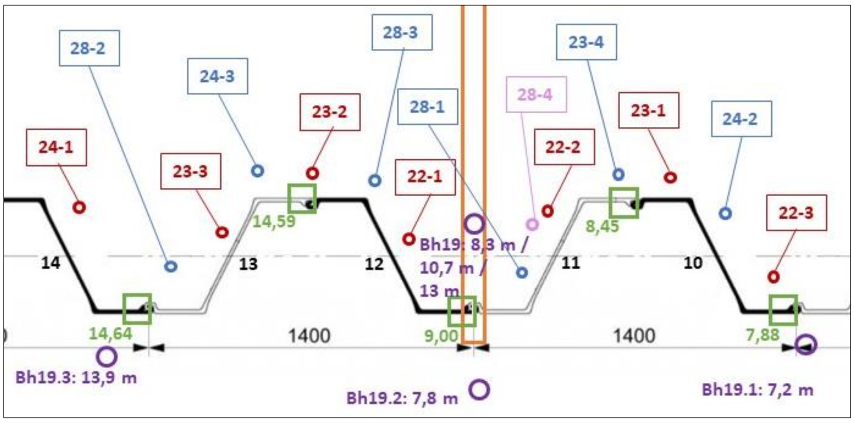

Figure 12 Placement of grout holes in two rounds, *i.e.* split spacing

The planning of the grouting was made unnecessarily difficult since the 3D-model of the sheet pile wall was not in agreement with the installed sheet pile wall. Also, the hollow bars had to be placed in a secure distance from the strand anchors.

The drilling of the hollow bars had to be performed by use of water through the fill in the upper 5,5 m (see fig. 13). Both, the drilling through the fill of large stones was easier to perform with water flushing, and also the consumption of polyurethane was dedicated for strengthening of the clay.

The effect of the grouting was observed during the excavation to full depth. HWE was present during the excavation to the two lower anchor levels, prepared to perform supplementary grouting if pockets of untreated quick clay would require it.

In figure 14 below, the polyurethane can be seen in the clay below the protruding rock. The grouted quick clay was stable and steel plates could be welded on from the back of the sheet pile to the bedrock.

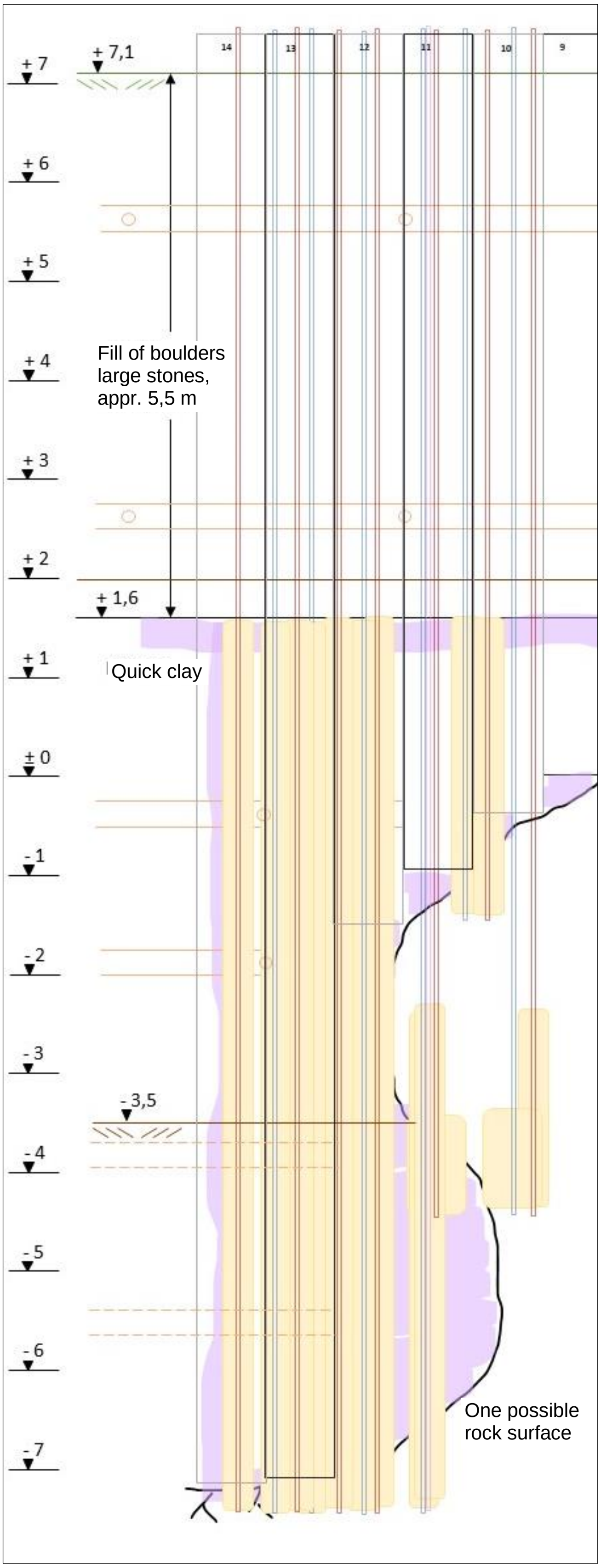

Figure 13 Theoretical placement of polyurethane grout

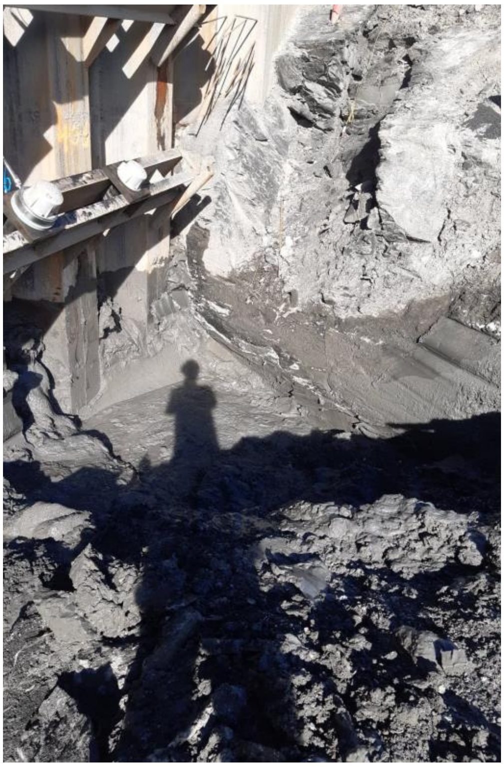

Figure 14 Polyurethane mixed with clay

5. Summary

BegrensSkade listed typical leakages in connection with installing tie-back anchors and steel core piles, and showed how groundwater a) flows out of the casing for a strand anchor, b) leaks through the holes taken in the sheet pile wall, and c) causes erosion around the casing for a steel core pile. Another cause for pore pressure reduction is water leaking through the interlocks in the sheet pile. All of these small leakages into a building pit can in sum cause substantial pore pressure reduction.

The sealing of all these leakage problems can be solved by grouting with water reactive polyurethane. The work is performed by few workers without the use of heavy machinery. In fact, the method can be regarded as simple and on the verge of primitive, but can be more effective than other alternatives. The sealing is easily adapted to the magnitude of the leakages and the prevailing conditions at the site.

Gaps between bedrock and the toe of a supporting structure can cause settlements due to pore pressure reduction and/or squeezing in of soft or quick clay for example. Downstage grouting can be used to seal or strengthen the ground, either with polyurethane alone or in combination with cement. In short, the philosophy of combination grouting is to create a grouted barrier by help of the polyurethane, within which the cement suspension can be used without risk of being flushed away.

Simultaneously drilling of hollow bars and grouting with cement suspension and water reactive polyurethane is a demanding and complex sealing operation. It should be performed by a workforce with previous experience of this type of work. A downstage process is used, where grouting is performed alternatively with cement suspension and water reactive polyurethane. Careful planning is essential for grouting with these grouts in combination, for example to avoid plugging of the drill string.

Different methods can be used for placing polyurethane grout, where its outstanding sealing capability can come into good use. In some cases, the use of this rather pricy grout can be more economical than grouting with cement only. When polyurethane and cement is used in combination, the cement take in difficult zones can be substantially reduced. Decreased grout take saves grouting time as well, so this may well be economically advantageous.

Finally, it is important to remember the environmental aspects – these are addressed when it is necessary, where strict demands to limit contamination are called for due to the background values in the recipient. Then, a risk assessment should be performed by an experienced laboratory with a clear methodology. This involves an initial screening, repeated risk evaluations with increased levels of information, and handling of identified risks by measurement for control.

6. References

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