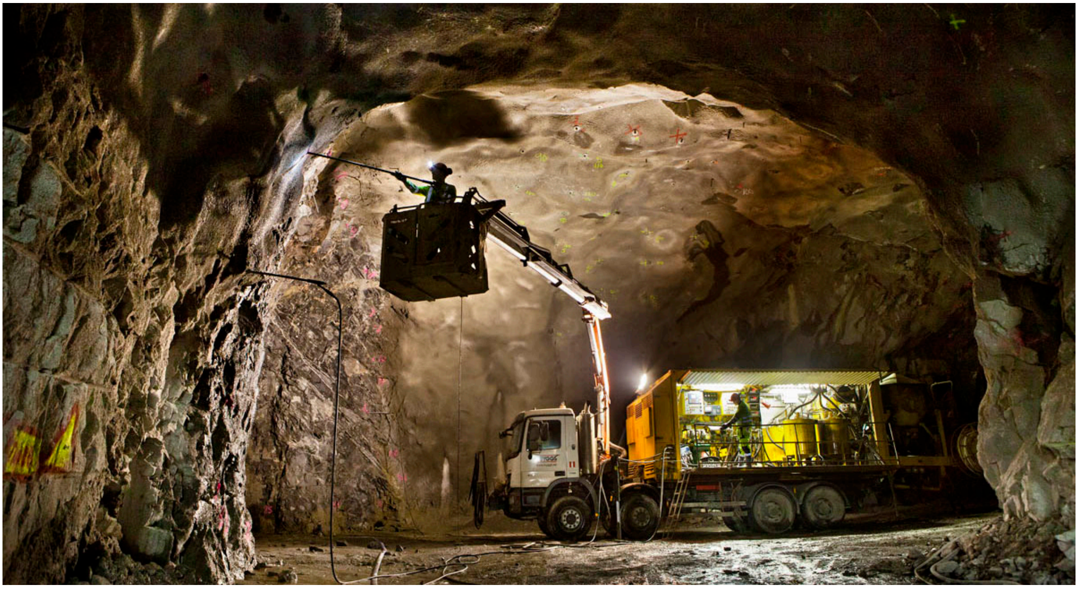
SVENSKA BERGTEKNIKFÖRENINGEN
Swedish Rock Engineering Association

10th Nordic Grouting Symposium 12-13 september

PROGRAM



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12 september 2023

08.30 - 09.00 Registration: Hilton Stockholm Slussen, The Gallery

09.00 Opening ceremony

09.15 Keynote: Transformation of grouting from black magic to art of engineering

Håkan Stille , Geokonsult Stille AB

09.50 - 10.20 Coffee and exhibition

10.20 Presentation from prime sponsor: Epiroc Rock Drills AB

Tomas Otterberg, Epiroc Rock Drills AB

Session 1: Requirements and verifications

Session chaired by Thomas Dalmalm, Trafikverket

On the use of pressure relief holes in remedial grouting of rock foundations under existing dams

Suihan Zhang, KTH Royal Institute of Technology, Sweden

Data-driven control of compensation grouting measures

Florian Özkoral, Züblin Spezialtiefbau Ges.m.b.H, Austria

Digital and mechanical development in grouting

Tomas Otterberg, Epiroc Rock Drills AB, Sweden

11.15 - 12.30 Lunch

12.30 Session 2: Concepts and design for grouting

Session chaired by Ulf Håkansson, Skanska

Pre-investigation data in grouting design: recommendations regarding fracture transmissivity distributions

Sara Kvartsberg, SGI, Sweden

Technological insights into Hybrid Grouting

Sewerin Sabew Häny AG, Switzerland

Theoretical analysis of rock grouting with varying injection pressure

Liangchao Zou, KTH Royal Institute of Technology, Sweden

Optimizing the fan layout with respect to the grouting boreholes and identified geological structures

Johan Funehag, Tyréns Sverige, Sweden

Shear modulus as a new parameter to characterise grout

Wilhelm Åberg, Luleå University of Technology, Sweden

Classification of rock masses for adjustments of the grouting procedure

Björn Stille, Trieng AB, Sweden

12 september 2023

14.00 - 14.30 Coffee and exhibition

14.30 Keynote: Challenges of Grouting for groundwater control in Hard Rock Tunneling
Knut Garshol, K.Garshol Rock Engineering Ltd.

15.00 Professional Discussion
How do we improve the grouting results?
Session chaired by Lisa Hernqvist, Trafikverket
Introduction and division of participants into groups

16.55 - 17.00 Closure of Day 1

19.00 Welcome mingle at the Gallery, Hilton

20.00 Dinner, Panorama restaurant, Hilton
Hand over ceremony to the next NGS host

Epiroc

13 september 2023

08.00 - 08.30 Registration: Hilton Stockholm Slussen, Gallerian

08.30 Welcome to Day 2

Presentations from the Professional Discussion

Session chaired by Lisa Hernqvist, Trafikverket

Presentation from general sponsor: Heidelberg Materials Cement Sverige
Stefan Sandelin, Heidelberg Materials, Lars-Olof Larsson, Besab

09.30 Session 3 - Grouting of soil-rock-concrete interfaces

Session chaired by Mikael Creütz,WSP

Sealing under artesian circumstances to stop water causing collapse
Helen Andersson, Huth & Wien Engineering AS, Norway

Pre-grouting from a TBM. The follo Line EPC TBM project (Oslo, Norway)
Fernando Vara Ortiz De La Torre, ACCIONA, Spain

Sealing the zone between soil and rock to stop water and quick clay
Helen Andersson, Huth & Wien Engineering AS, Norway

Presentation from general sponsor: GMA Ground Machinery Applications AB
Niklas Olsson

10.30 - 11.00 Coffee and exhibition

11.00 Session 4 - Case Studies

Session chaired by Sindre Log, SINTEF

The Anneberg-Skanstull high voltage cable tunnel, Stockholm, Sweden
Mikael Creütz,Golder/WSP, Sweden

Adjustment of a grouting design during the production phase. Examples from the West Link-project
Magnus Zetterlund, Norconsult AB, Sweden

Evaluation of grouting design considering favourable and unfavourable geological conditions
Mashuqur Rahman, Typsa AB, Sweden

Real-time analysis during pre-excavation rock mass grouting - methods and benefits
Helene Strømsvik, SINTEF AS, Norway

Potentials and limitations of using artifical intelligence to predict grouting parameters - Results of a case study in a tunnel project in Scandinavia
Frank Leismann, STUVA e. V., Germany

13 september 2023

12.15 - 13.30 Lunch

13.30 Presentation from general sponsor: Master Builders Solutions
Patrik Wåhlstrand
Session 5: Grouting equipment
Moderator: Rebecca Hellby, WSP
Pressure losses along the delivery lines during rock grouting using polyurethane resins (PUR)
Robert Penczek, DSI Underground, Poland
Dynamic grouting - Feedback resonance
Peter Ulriksen, Lund University LTH, Sweden
Dynamic grouting - Water hammer
Peter Ulriksen, Lund University LTH, Sweden
Grout-free Expandable Standpipes for Pre-excavation Grouting
Joel Adams, IPI Packers, USA
Presentation from general sponsor: Keller Grundläggning
Tünde Lorinczi

15.00 Closure of NGS 2023
After Grout - Mingle with friends and colleagues at Eken Bar, Hilton (Optional)

Nordic Grouting Symposium is endorsed by:

International Tunnelling and Underground Space Association

International Society for Rock Mechanics and Rock Engineering

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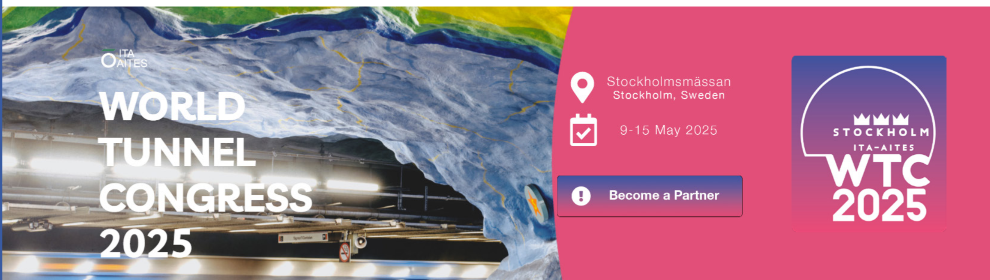
Rock Engineering Research Foundation

Swedish Transport Administration

Upcoming events

Bergdagarna 2024
21-22 mars, Cirkus Arena, Stockholm

Call for abstracts deadline 15 september 2023
For more information visit: svbergteknik.se



World Tunnel congress 2025
9-15 may, Stockholmsmässan, Stockholm
For more information visit: wtc2025.se

Abstract of the presented papers at NGS 2023

The full papers are published at the Swedish Rock Engineering Association's website

www.svbergteknik.se/publikationer_

Transformation of grouting from black magic to art of engineering

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Abstract: Rock grouting is a multidisciplinary engineering science.
The last decade has deepened the understanding of hydrogeology, rock mass response, material science rheology and theories of grout spread in rock fractures. Grouting has moved from craftmanship to engineering – a paradigm in the approach to design and execution. Design of the basic geotechnical structures is a defined objective of the consultant's work. The design work has changed over time, however, from primarily based on application of prescriptive measures to calculations. It is a transformation from black magic to art of engineering.

On the use of pressure relief holes in remedial grouting of rock foundations under existing dams

Suihan Zhang, KTH- Royal Institute of Technology, Sweden*
Fredrik Johansson, KTH- Royal Institute of Technology, Sweden
Johan Funehag, Luleå University of Technology, Sweden
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Abstract: Remedial grouting under existing dams founded on rock is often conducted under unfavorable hydraulic conditions with high gradients and fast-flowing water in the rock fractures. The fast-flowing water may push the grout downstream, change the shape of the grout spread, and erode the fresh grout. All these issues can jeopardize the outcome of the grouting work. To deal with the fast-flowing water, drilling pressure relief holes upstream of the grout holes can be one of the alternatives. These pressure relief holes function as additional drainage. They can reduce the velocity of the water in the fractures near the grout holes, thus reducing the risk of erosion of the grout. However, the usage of pressure relief holes in remedial grouting practices has not been widely documented, and different opinions still exist on their effectiveness. Meanwhile, few studies have analyzed the effectiveness of the relief holes. In this paper, the usage of pressure relief holes in remedial grouting of rock foundations under existing dams is analyzed. The effectiveness of the relief holes is evaluated using both analytical calculations and numerical simulations. The analysis results show that the pressure relief holes can reduce the downstream hydraulic gradient and facilitate the remedial grouting. Based on these results, discussions are made on their effectiveness together with suggestions on how to deal with excessive groundwater flow in remedial grouting.

Data-driven control of compensation grouting measures

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Florian Weber, Züblin Spezialtiefbau Ges.m.b.H., Austria
Florian Rathenböck, eguana GmbH, Austria
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Abstract: Compensation grouting measures are being used to assure that buildings situated close to the construction site are not affected by consolidations because of tunneling works. From shafts several horizontal boreholes are being drilled as preparation for the actual buildings and tunnels. Via a tube-a-manchette system a cement suspension is being grouted to achieve a form of pre-consolidation. If due to construction activities, such as tunneling, a settlement or consolidation occurs, heaving grouting can be used to react. To ensure that no damage occurs, sensitive infrastructure is constantly monitored through a real-time gauge system and the data is being transmitted to a data management system. This system monitors the complete construction site and triggers several measures. If a specific settlement or heaving level has been reached, the system notifies the users about the reach of a pre-defined alarming level. Moreover, it automatically generates a grouting strategy proposal based on the monitored data and situation. Therefore, the system not only checks specific data from single measurements, but all relevant and available data on the construction site. The grouting strategy proposal is reviewed by the involved stakeholders like site manager or geotechnical engineers and then send directly to the grouting plant. The operator selects the specific grouting point and starts the automated grouting process. The grouting data is automatically uploaded to the data management system, where it is analyzed in terms of data integrity and quality. Each grouting process is recorded, transmitted and visualized in real time. Every project stakeholder (client, contractor and designer) can access not only the construction data but also the gauge measurements at any time via web platform, thus creating a novel, automized method for grouting.

Digital and mechanical development in grouting

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Abstract: Grouting, meaning injections of a fluid in strata/soil/rock formations, has been used for more than 100 years. In Scandinavia, pre-grouting is very common and often required by the project owner. This is to avoid water ingress and to ensure that the ground water level is not affected negatively. The data that are produced by the quite advanced machinery today are extensive, it starts before the operator reach the drilling unit. Drill plans are created in an office environment and are then loaded into the drilling unit. This drill plan will be used during operation and the result will be stored as a quality log. A tool that is becoming common in Scandinavia is the Measurement While Drilling (MWD). It still requires allot of calibration in order to have a tool that produces a prognosis of some rock parameters at hand. Lately, interpretation of the drill parameters for prognosis of the grouting has been studied and can be fitted for the project at hand. To be able to connect and link all produced data is to enable communication between different system. With Underground Manager (UM), where the code is written in IREEDES ensures needed possibilities of data transfer. This will support the operator from one operation sequence to the next. The data can be seen as the glue in-between the different machinery that acts in the tunnel. The link between design and the operationl progamme Underground Manager (UM) is the Rig Controlled System (RCS)-controlled machines when performing the excavation. The Rig Control System will also record all MWD (Measuring While Drilling) data which is used by the operator and for quality control. For the specific operation like grouting is can be controlled as today, more manual operations or with the Automated Grouting Control is controlled by the machinery, the pressure time and necessary adjustment are done automated. This paper clarifies the different steps of automation as well describing a field test executed using the different systems.

Pre-investigation data in grouting design: recommendations regarding fracture transmissivity distributions

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Abstract: In grouting design a design methodology can be used where transmissivity and fracture aperture distributions form the basis for selecting grouting parameters. The calculations are based on section transmissivity data calculated from hydraulic tests in boreholes. These are linked to individual, mapped fractures using a statistical distribution function called the Pareto distribution. The design methodology has been used in several research and infrastructure projects in the Nordic countries.
However, there are still uncertainties regarding requirements for pre-investigation data and how data should be handled in the calculation process. This article presents a study of how different types of test set-ups and interpretations of mapped geological domains can affect a Pareto-analysed fracture aperture distribution. Sensitivity analyses have been performed by testing various existing datasets from tunnel projects and modifying parameters such as measurement limit, section length, number of fractures and geological domains. The sensitivity analyses form a basis for recommendations regarding the applicability of the calculation method, test set-ups and model assumptions. Fundamental to producing
reliable fracture transmissivity distributions is the collection of sufficient and representative amounts of data. Mapping of drill cores and execution of hydraulic tests must be of good quality, and it is recommended that weakness zones, the boundary between shallow rock and host rock and recorded flows near the measuring capacity of the test equipment are the subject of deeper analyses.

Technological Insights into Hybrid Grouting

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Manuel Entfellner, Implenia Österreich GmbH, Austria
Helmut Wannenmacher, Implenia Österreich GmbH, Austria
Dr. Thorsten Kratz, Thyssen Schachtbau GmbH, Germany
Sewerin Sabew, Oberbauleiter Spezialtiefbau, Hochtief Infrastructure GmbH, Germany since August 2022 and former Product Manager, Häny AG, Switzerland
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Abstract: Grouting has a long history in tunnel and shaft construction and emphasises sealing or consolidating weak or water-bearing ground conditions. Organic grouting is mainly carried out within complex ground conditions or areas of heavy water inflow. However, standard grouting equipment is limited to cement-based grout mixes or organic materials since these materials demand different equipment and grouting criteria. With recent developments in grouting technology, both grouting materials can be utilised in various ways - either individually or with different mixing ratios depending on the objective of the grouting works. The unique system's advantages are apparent when used to stop water inflow. Polyurethane resins accelerate the adhesion and hardening process of the cementbased grout, thus significantly reducing the dispersion of the grout mix in groundwater. This technology has been dubbed Hybrid Grouting (combined Cement-Polyurethane Grout Mix) because it garners both the advantages of economical cement-based grouting and the advantages of highly reactive resin injections. Furthermore, the processes of combined cement-polyurethane grouting are carried out fully automated. Therefore, the usage of combined cement-polyurethane grouting enables controlled and efficient grouting operations in tunnel and shaft construction. The paper explains the equipment and the technology of combined cement-polyurethane grouting. The system's effect and intensity are demonstrated by reviewing various actual grouting works.

Theoretical analysis of rock grouting with varying injection pressure

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Abstract: Cement grouting has been widely used in underground rock engineering projects for groundwater flow management. Analysis of cement grout propagation in rock fractures is important for the design, execution and monitoring of rock grouting in practice. At present, analysis of rock grouting mainly relies on theoretical models or methods, such as the real time grouting control (RTGC) method. Specifically, in the RTGC method, it is assumed that the cement grout is injected into an idealized fracture consisting of smooth parallel plates or disks with constant injection pressure. In reality, the injection pressure can vary over time, and it is in many cases not necessarily constant during the entire grouting process. In this work, we extend the RTGC method with consideration of varying the injection pressure over time, by assuming that the propagation process of cement grout in rock fractures is under a pseudo steady state. Illustration and application examples for cement grout propagation in fractures with varying injection pressures are analyzed by using this extended method. The results generally show that the extended method can predict the propagation of cement grout in fractures and the evolution of injection flowrate with varying injection pressures in typical rock grouting applications. Therefore, the extended method can be readily used for the theoretical analysis of rock grouting in practice.

Optimizing the fan layout with respect to the grouting boreholes and identified geological structures

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Abstract: The basic idea early stated in the Swedish building codes (AMA) is that the boreholes should be directed as perpendicular to the water bearing fractures as possible.
In general, the grouting design with respect to the fan layout results in a fan having a certain length, inclination outside the tunnel contour, a predetermined spacing between boreholes and specified number of rounds per fan. Knowing the fracture orientation and the flow dimensionality one can optimize the layout of the fan to have a best "hit-rate" of the fractures at hand.
The "hit-rate" in this article is defined as the ratio between the area that if formed at the intersection between the borehole and a fracture and the borehole area itself.
This paper brings up a theoretical approach how to assess the best "hit-rate" together with a practical case-scenarios where boreholes has been added in the areas where the systematic fan layout has a very low "hit-rate".
If the borehole is perpendicular the shape of the intersection will be circular, equivalent to the cross section of the bore hole. This would be referred to as the best "hit-rate" giving that the ratio between the borehole area and the circular area of intersection 1, a "hit-rate" of 100 %. If the borehole is not perpendicular to the fracture, the boundary of intersection would instead be elliptic, resulting in a larger area of intersection. The worst "hit-rate" would occur when the borehole is parallel to the fracture and the "hit-rate" would asymptote towards 0 %.
In the practical case showcases a scenario where a minor change of drill direction or borehole layout can be carried out to improve the "hit-rate" without compromising the simplicity of the grouting fan this is an option that should be considered, especially for areas of the tunnel where the prognosed "hit-rate" is low.

Shear modulus as a new parameter to characterize grout

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Abstract: When tunnels are excavated by drill and blast there are several processes that generates forces/tensions on the grout, such as vibrations, blast induced forces, water flow etc. Extensive laboratory work was conducted to find crucial parameters on grout to assess a fundamental understanding on how a grout can be characterized to cope with future demands on grout.
The work comprised of advanced laboratory testing on cement compared more traditional testing.
The shear modulus is measured in this study for cement grout over five hours of hardening time. It is shown that grout with lower w/c hardens faster i.e., more rapid growth of shear modulus. Cement grout has a relatively high shear modulus which increases over time, where the viscous and elastic shear moduli intersect at a point which is believed to correlate to a change in failure mechanism Rheological tests are performed to study the first five hours of the hardening process of the grout. The setup was with oscillating concentric cylinder, with both constant amplitude and frequency. The shear moduli over time can be computed, which in this case can be seen as a first attempt to describe a shear moduli of cement grout. This could help to describe the characteristics of a grout, to understand the forces that the grout encounters during a full drill-and blast cycle.

Classification of rock masses for adjustments of the grouting procedure

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Abstract: Pre-grouting is an essential part in the low-cost tunnel concept. It is also work to be carried out on the critical line. It is therefore important to correctly describe the conditions for the works in the technical specification. Intense research has clarified the theoretical base for pre-grouting. However, describing the water bearing structures of the rock mass is still a challenge. It has in many projects been found that estimation of the grouting effort regarding number of grouting fans, hole spacing, grouting sequences, grouting pressure and number of re- grouting fans is to a large extent related to geology. The tunnels in the Stockholm By-Pass are pre-grouted. Totally more than 2500 grouting fans have been carried out. The grouting efforts have been followed up and adapted to geology in order to fulfill the requirements of acceptable groundwater ingress to the tunnels. The objective of this paper is to describe the achieved experiences from the follow up.

The follow up, shows and confirms the intuitive conclusion that the achieved sealing efficiency and tightness depends on the grouting effort, more specifically to a significant extent on the number of grouting rounds. It has also been found that the need for grouting also to a large extent depends on the geology. We have found that the hydrogeological conditions of the rock mass can be divided into 3 classes as simple, open and complex flow paths. Simple flow paths are characterized by open unfilled fractures in massive rock with relatively few discontinuities more or less perpendicular to the tunnel alignment. Complex flow paths are characterized by channels (1D flow) possible together with 2D flow in less connected networks. The fractures are often filled. Geologically, the rock can in many cases be described as fault or fracture zones. Open flow paths are often connected with large grout takes but with 2D flow and generally good grout results. In the paper it is suggested how to analyze the grout take to identify the hydrogeological conditions and to verify the grouting results. It is also suggested how to use the data during the execution of the work to decide whether to continue excavation or when an additional complementary grouting round is mandatory.

Challenges of Grouting for groundwater control in Hard Rock Tunneling

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Abstract: Reasons for challenges in groundwater ingress control are highly variable ground conditions, numerous alternative grouting methods, and materials properties. Consequently, strategies abound, and opinions are quite divergent. This paper covers strict ingress limits for systematic pre-excavation grouting (PEG). The paper points to a disconnect between theoretical models and the demands of at-the-face decision making. The focus should be on the lowest possible PEG cost and execution time. It is highly beneficial to utilize information from drilling ahead and pumping of grout. No theoretical model will replace this. Inject only the necessary volume of grout. For an example PEG fan in crystalline hard rock, the targeted rock volume of 7465 m3 contains 22 L of fracture volume. The relevant empirical grout volume would be 1000 times this fracture volume. To properly seal off such a rock volume, 22 L of grout is way too little, but it does indicate that the practical volume can is less. Huge condu-ctivity contrasts have significant effects on PEG, which needs more attention. Water and grout take the path of least resistance and grouting simultaneous-ly into highly conductive channels and smaller joints will not work. This was well established decades ago for dam foundations, limiting hole-sections for grouting to 3-5 m length. The paper continues to discuss maximum pumping pressure, stop criteria, the frequent priority on stop-on-pressure, attempts at saving time by one-round PEG and the benefits of the two-round strategy. The paper explains the controlled setting of cement grout by adding accelerator and benefits identified. Process management at the face requires a fully implemented living document method statement. Finally, find a new method for grout spread control presented as a challenge for on-site testing.

Sealing under artesian circumstances to stop water causing collapse

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Abstract: Many geotechnical surveys are conducted each year, and sometimes total soundings cause artesian leaks. Minor leaks can be successfully sealed with bentonite rods pushed into the hole by a wooden pole. However, artesian leakage with high flows can be very difficult to seal. The consequence of a leaking borehole can be severe, especially if it is not discovered in time and particularly if the water flow causes erosion within the soil. Undiscovered sink holes can be dangerous for the public and the landscape can suffer detrimental changes due to the water flowing up through the ground. NPRA report nr. 704 "Sealing leaking boreholes with grout" (2021) describes how Norwegian Public Roads Administration in 2018-2019 conducted a research program where one of the aims was to find a practical and robust method for sealing leaking boreholes caused by total soundings, with the same drilling equipment that penetrated the artesian aquifer in the first place. Drilling mud of bentonite and barite was tested but failed, since the resulting gel did not sustain the pressure over time. Instead cement for underwater repair works was grouted directly into the leaking formation. Huth & Wien Engineering AS (HWE) has used a one-component water reactive polyurethane grout to seal against artesian water pressure at several locations in Norway. The first time was in 2015, when a total sounding for new Rv. 23 in Linnes, Lier, had penetrated a layer with artesian pressure below 18 m of quick clay. The sealing with polyurethane was successful and took less than two days to perform. Several other projects with leakage due to artesian pressure have since been sealed with this method. This paper describes some of these cases, presents the success criteria, and problems encountered. It can be concluded that successful sealing of leakages due to artesian pressure, can be performed by grouting with polyurethane. There is a correlation between the time after puncture and the effort needed to seal the borehole. Leakages that have been difficult or impossible to seal will be presented, together with plausible explanations. Such examples are usually more interesting, and an analysis can be used to improve of the planning and execution of the sealing.

Pre-grouting from a TBM. The Follo Line EPC TBM project (Oslo, Norway)

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Abstract: This paper will be developed under section 4. Grouting equipment. Development of grouting equipment. Norway has one of the hardest rock in the world, with granite up to 350 MPa. The Follo Line Project is one of the most ambitious infrastructure projects in Scandinavia, where four double shield hard rock TBMs have excavated 40 km of tunnel through that rock, from Oslo to Ski. The presence on the alignment of weakness zones and high-pressure water has made this excavation a challenge, as no reduction on the water level was allowed during excavation. Due to encounter ground conditions, it was required the execution of approx. 8 km of pregrouting. Pregrouting from a TBM is an innovative solution that has never been used in Norway. With this tunnel support technology, it has been possible to minimize environmental hazards, like lowering the pore pressure & ground water level and avoid settlements on surface.
This paper will describe the drilling rigs installed in the TBMs, the systematic probe drilling done to detect water leakages ahead of the TBM, trigger values for leakages, design formulas for injection and the maintenance and improvement of the equipment, achieving at the same time good TBM production. The paper will reflect how through innovative and sustainable solutions pre-grouting from TBMs becomes a feasible solution even in highly complex underground projects, affecting the TBM excavation in a much more reduce manner than ever before, and allowing the pregrouting cycles to be fully implemented into the TBMs cycle works. Those innovations are being embedded into a highly complex underground project and it has been possible to minimize environmental hazards and to protect the urban landscape for sustainable urban development.

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.

The Anneberg-Skanstull high voltage cable tunnel, Stockholm, Sweden. Challenges and possibilities performing pre-excavation grouting in hard crystalline rock from a tunnel boring machine, TBM

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Abstract: The Anneberg-Skanstull tunnel is a new high voltage cable tunnel currently constructed in the rock below the Swedish capital of Stockholm. The purpose of the cable tunnel is to ensure a balanced and reliable Swedish electrical power system by its owner Svenska kraftnät, an authority responsible for the Swedish National Grid. The tunnel for a new 400 kV cable connection is one of many ongoing projects in the Stockholm region to strengthen the national grid and to increase the capacity to meet the growing need for electricity. The tunnel will be 13.4 km long, with a diameter of 5 meters and connected between two substations, Anneberg in the north and Skanstull in the south. The tunnel depth varies between 50 and 100 meters. The tunnel has two passages below sea level, Stocksundet and Strömmen, a bay of the Baltic Sea. There will also be six vertical ventilation shafts along the tunnel, 40 to 100 meters deep. The tunnel is mainly excavated using a TBM, except part of the passage at Strömmen, planned as a conventional drill and blast tunnel. The TBM is an open gripper manufactured for the execution of pre-excavation grouting works, which means it carries equipment for the drilling of grout holes, water pressure testing and pre-excavation grouting. The grouting works is carried out as either selective or systematic pre-excavation grouting by means of rock fracture grouting with cementitious grouts. Curtain grouting is used for the vertical ventilation shafts.

Adjustment of a grouting design during the production phase. Examples from the West Link-project

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Sara Kvartsberg, SGI - Swedish Geotechnical Institute, prev. Norconsult, Sweden
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Abstract: Grouting design is preferably well-founded in adequate pre-investigations and analyses carried out during the design phase. Ideally an array of designs, presented in grouting classes, are prepared to achieve sufficient sealing for varying inflow requirements in various rock conditions. However, there will always remain uncertainties in any underground project, and these are typically handled by actively adapting the final design to suit the actual site conditions encountered during the production phase. The aim of this paper is to present the grouting design adjustments that were made during the initial production phase of the West Link-project (Västlänken), Sweden. The West Linkproject involves the construction of a double-track rail tunnel with three stations under the centre of Gothenburg. The project is divided into six major contracts and this paper focuses on results from the Korsvägen contract (E05). In the West Link-project, the client (Swedish Transport Administration, Trafikverket) has assigned contracts for adjustment of rock design during construction, including grouting. This paper describes the design pre-requisites that formed the basis for the initial grouting concept, as well as the method for collecting relevant information for evaluating the concept. The evaluation has been based on initial production experiences, increased geological knowledge and most important achieved tightness of the rock mass. Examples of adjustments of the concept involve the extent of grouting classes, performance and target value of control boreholes and more efficient use of stop criteria. In this paper, the background and implementation of the adjustments are presented, as well as their subsequent consequences for the production. Finally, technical and contractual factors that have influenced the design adjustments are discussed.

Evaluation of grouting design considering favourable and unfavourable geological conditions

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Abstract: In Scandinavia, continuous pregrouting is performed to seal the rock fractures and lower down the leakage of water after the rock excavation. The requirements for leakage are based on the assessment of adverse effect on environment due to the lowering of ground water level and decided by the environmental court. The requirements for leakage in urban areas can be strict, e.g., 2-5 l/min for 100 m tunnel. This makes pregrouting a very significant part of tunnelling in hard rock conditions considering the time and budget of the construction work. In Sweden, pregrouting design is performed based on geological and hydrogeological field investigations and the difficulty level of grouting to reach the requirement for leakage. The steering parameters for the grouting stop criteria are the pumping time under constant pressure and the grout volume. The design of the stop criteria is performed based on scientific research and experience from previous projects. In this paper, the evaluation of the grouting data from certain access tunnels of the extension of the Blue metro line in Stockholm are presented. The extension of the Blue line of the Stockholm Metro project involves six underground metro stations, which are approximately 11 km of tunnelling in total. The aim of this work was to come up with recommendations for the optimization of grouting stop criteria, which can be used in future projects with similar geological conditions. For this purpose, evaluations were performed for different parameters of the stop criteria, e.g., grouting time, volume, flow etc. The whole evaluation was based on the grouting data from 115 grouting fans which were compared with the design work. Data from 50 fans are presented in this paper for two access tunnels Londonviadukten AT1 (31 fans) and Järla Östra (19 fans). The achieved sealing efficiency based on the measured leakage into the tunnel was estimated due to many inaccuracy and external factors. The estimated achieved sealing efficiency was then compared with required sealing efficiency set to reach the requirement for leakage according to the leakage prognosis. The geological and hydrogeological field investigations during the design phase were summarized and later been compared to the actual geological field mapping that was performed during the construction work. Finally, recommendations were made to optimize the stop criteria for grouting design, considering favourable and unfavourable geological conditions. *This article is based on the work carried out during a master thesis at KTH Royal Institute of Technology, Sweden.

Real-time analysis during pre-excavation rock mass grouting -methods and benefits

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Abstract: During pre-excavation grouting (PEG) a considerable amount of data is continuously generated, but just a small part of this data is used actively during the PEG operation. A high potential remains in the unused data regarding optimization of the grouting operation.

Today most of the grouting procedures are designed before excavation start-up and with little flexibility to adapt to the site conditions during the grouting itself. The Logic Grouting project, has collected data from several Norwegian projects and developed methods for real-time interpretation, suited as decision basis during PEG. The main attributes of these methods are notification of unexpected flow and pressure behaviour that has a high likelihood to be hydraulic jacking of fractures in the rock mass, and warning for holes with risk of high grout consumption. Both these indicators should lead to adjustments in the grouting procedure or grout mix, to ensure a successful grouting without excessive use of grout and time.

Graphic display of flow and pressure during grouting has been available for many years but is seldom actively used by the operators, as it has no practical impact on their work. Optimization of the digital interface for the operators also need to be improved to fully utilize the potential of real-time interpretation during PEG. This paper presents the basis for the developed methods, statistics from Norwegian tunnelling projects and practical examples from on-site real-time analysis at the Sollihøgda tunnel in Norway.

Potentials and limitations of using artificial intelligence to predict grouting parameters – Results of a case study in a tunnel project in Scandinavia

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Abstract: During tunnel excavation, support measures may be required to seal or stabilize the ground. Since these sometimes significantly reduce the advance rate, their efficient design is of great importance. Injections are often chosen for this purpose because they can be flexible with comparatively simple equipment technology. Along with this flexibility, it is possible to continuously adjust the grouting parameters during execution. This can mean regular modifications of the drilling grid and length as well as the grouting parameters, grouting materials and stop criteria.
Digital data recording systems have increasingly found their way into drilling and grouting technology. Currently these systems are used almost exclusively for documentation in the framework of quality management. The potential to consider this data in the further construction process and to optimize it has remained practically unused until now. The reason for this is not least the complexity of grouting work and the interactions with the subsoil, so that grouting measures are carried out using the observation method. The project ”AVANT - Adaptive Planning of grouting measures in tunnel construction using Artificial Intelligence” has set itself the goal of using grouting data to set up a dynamic real-time process in which artificial intelligence methods are used at several levels. Since grouting data is available in digital form for all major construction projects, the foundations have already been laid for combining these data with AI approaches. As this paper showed it is possible to train artificial neural networks (ANN) in such a way that they can reliably predict the evolution of pressure-volume records and the volume of grout injected at the end. The case study shows that observed deviations are less than 20 % after only a quarter of the grouting has been completed. In terms of construction site efficiency, this is a very satisfactory amount.

Pressure losses along the delivery lines during rock grouting using polyurethane resins (PUR)

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Abstract: In the case of polyurethane resins, the viscosity value is 5-30 higher than cementitious suspensions, increasing due to a hockey-stick model and, in contrary to slurries, taking several dozen seconds up to a few minutes only. As a reminder, the viscosity component determines the rate at which a grout travels from the grout hole into the rock crack system under the given pressure and for a certain thickness of an open joint. In other words, a certain pressure at the pump, proportional to the material's viscosity and, in addition, due to resistance along delivery lines (of small internal diameter like ø =10 mm), is necessary to keep resin flowing. Even a low pumping rate of as few litres/min causes significant pressure losses between the values shown by manometers at the pump and the end of the extension pipes in the borehole, i.e. in the rock crack system. The maximum/critical injection pressure not exceeding the in-situ rock strength is crucial to avoid hydraulic fracturing and jacking the rock mass. In turn, the operator can estimate the value of the safety pressure at the pump based on the knowledge of the pressure losses between the pump and at the end of the grout set. This paper presents the flow resistance/pressure losses comparison of the commonly used accessories like packers, static mixers, hoses and extension pipes required for resin injection. The measurement data are collected for two polyurethane systems with different viscosity ("normal" and low). Furthermore, the temperature effects are considered, conducting the measurements at different ambient temperatures. Finally, the pressure drop is reflected in the function of the resin flow rate, i.e. pumping rate. Data generated during the experiment subsequently provides fresh insight into injection pressure drop to better understand the grout's impact on the rock for safely performing grouting operations.

Dynamic grouting - Feedback resonance

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Abstract: The idea behind dynamic grouting is to counter increasing viscosity due to plug-flow and build-up of filters in narrow cross sections of the fracture system that would obstruct grout flow.
The viscosity in a thixotropic fluid can be kept low by oscillating the pressure in the grout-flow. This will cause a back-and forth movement of the cement particles, which of course must be combined with a positive static pressure which produces a net flow of grout.
The same oscillations can have the effect to keep the build-up of filters down. The idea behind this is that if the pressure up-streams a filter is reduced, the pressure down-streams of the filter will remain high and cause a filter break-down from the downstream side. When working properly the filter build-up process will be kept very low and no real filters will develop.
A system of grout pump, oscillator, rubber hose and injection pipes and fractures have a combined resonance frequency. If the oscillator is made to work at that frequency very high pressure variations can be obtained with a small force. This is because new energy is continually added to the oscillating system. The resonance is most obvious in the steel-reinforced grouting tube but the counter pressure in the rock could perhaps also influence the resonance frequency and amplitude.
These assumptions have been verified by experiments in which the oscillations are produced by an electrically controllable hydraulic cylinder, which in turn operates on a grouting pump cylinder. The system allows any type of pressure or flow function to be established. It is e.g. possible to create transient pressure pulses as well as sinusoidal pressure variations.

Dynamic grouting - Water hammer

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Abstract: The idea behind dynamic grouting is to counter increasing viscosity due to plug-flow and build-up of filters in narrow cross sections of the fracture system. In this case also some cement particle aggregates may be dispersed.
An inexpensive way of producing pressure variations in the grout is to make use of the water hammer effect. This occurs when a flow of liquid is abruptly shut off with a valve. The liquid up-streams the valve will want to continue flowing, but is stopped, producing a strong positive pressure-wave propagating in the up-stream direction. Down-stream, similarly, the liquid will want to continue flowing, but no new liquid is added from up-streams. Thus a negative pressure pulse is created down-stream the valve and it is propagating in the down-stream direction.
The negative down-stream pressure pulse will agitate the thixotropic grout and keep its low viscosity although a plug-flow may be present. It will also create a backward gradient when it reaches a place in the fractures where a filter is building up. Down-stream of the filter a high pressure will be present when the low pressure impulse reaches the filter. Thus the high pressure gradient will destroy the filter.
The low pressures obtainable with this method can be very low. Close to the valve we have measured negative pressures in water. Negative pressure cannot exist in a gas, but in a liquid they may do that a short time before cavitation develops. There are two problems with this method and it is that the higher the valve-closure rate is, the lower will be the average flow. The other problem is that the efficiency of the valve closing depends on the rate of flow, thus the method is only useful when the flow is high.

Grout-free Expandable Standpipes for Preexcavation Grouting

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Abstract: Underground construction in areas of high groundwater inflow necessitates the installation of standpipes to provide a secure wellhead for both groundwater control and high-pressure preexcavation grouting.
The common method of standpipe installation is to drill a short pilot hole into which a standpipe with centralizers is inserted and subsequently grouted in place. Once the grout is fully cured, the standpipes can be pressure tested according to project specifications. If the pressure test is successful, drilling can be advanced through the standpipes as planned. However, if the pressure test fails, the standpipes must either be re-grouted and re-tested; or abandoned and replaced with a new standpipe and the drilling/grouting/testing procedure is repeated. The time required for grout curing results in non-productive time (NPT) that can be significant, depending on the type of grout applied. The grouting process can be particularly challenging in horizontal and up-angled holes that are common in underground construction. A new grout-free method of standpipe installation has been developed that can significantly reduce NPT associated with grouted standpipes. The method utilizes a steel pipe that is covered by a thin (6mm) elastomeric cover and is expanded using a compact hydraulic setting tool based on high-pressure inflatable packer technology. The expanded standpipe is self-centralizing, and the elastomeric cover provides an effective seal and anchor conforming to the borehole wall. Once placed in the pilot borehole, the expansion process takes approximately 3 minutes, after which the standpipe can be pressure tested immediately. A pilot project has been conducted in which standpipes were installed in an advancing tunnel. The grout-free expandable standpipes were pressure tested to 83 bar directly after installation and subsequently utilized for pre-excavation grouting. In contrast, in this particular project, grouted standpipes required 24hr cure time prior to pressure testing.

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