Proceedings of the NROCK 2023
The IV Nordic Symposium on
Rock Mechanics and Rock Engineering
ISBN 978-9935-9436-2-0
DOI 10.33112/nrock2023

Extended ABSTRACT 22
Session 4.5

TIGHT – A research project on modern rock mass grouting techniques

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One important element of tunnelling in urban areas or elsewhere where a strict requirement applies for water control is the technique of rock mass grouting. Norway is one of the countries globally that has been the driver for this development whilst on the other hand the technology is mainly empirical based.

Different approaches exist in the tunnelling industry to reduce groundwater ingress to tunnels to achieve specified leakage limits. The project TIGHT was established to improve Pre-Excavation Grouting techniques though a research-based approach and to take forward detailed understanding of improving high-pressure grouting in tunnels through a combination of work by academics, a PhD, and site-based studies on construction projects. TIGHT aimed at building upon empirical field experience to scientifically optimise the approach to pre-excavation grouting (PEG).

Rock mass grouting is a common method for reducing water inflow in tunnelling projects in hard rock, using cementitious grouts being carried out during excavation. The cost related to grouting constitute 20-30% of the tunnelling costs in projects where the groundwater level must be maintained at a certain level due to urban areas and/or in order to prevent damage to the environment. However, there is a significant unforeseeable aspect of grouting for all parties involved which needs to reduced. Increased knowledge is therefore crucial for optimising the existing grouting methods by reducing the amount of grouting materials used and the time spent on grouting operations. The future in tunnelling would likely implement pre-excavation grouting or rock mass grouting as a standard procedure integrated into the tunnelling cycle.

The official report from TIGHT was issued in Norwegian in 2020, presented to the country's national tunnelling industry over recent months, and its findings have been shared with the national and international tunnelling societies in various ways.

Some of the key outcomes of TIGHT are that even with the risk of jacking the use of high pressure grouting will continue but with an apparent reduction and increased caution to obtain effective spread of the injection. In this context the need of addressing properly cost, time and environmental concerns has an impact on the decision on grout pressure to be applied. While some may view high flow rates of grout to be a good thing due to jacking, it may not therefore always be so effective.

The outcome of the research suggest that the Norwegian approach to grouting would preferably be shifted to have more focused, site-specific designs and procedures. By that, high pressure is a need, but the pressure needs to be balanced with circumstances like in-situ stress, rock overburden and other elements that cause resistance on the grout penetration.

The TIGHT project aimed at combining studies of both theory, laboratory testing and practical tunnelling work to analyse, and better understand, the interplay of multiple variables in the task of high-pressure grouting of rock mass. Researchers looked at variables in particular such as materials, geology, rock mechanics and experience in the field. A vital threshold zone in the studies was the tipping point where hydraulic jacking by the high pressure suddenly opens up cracks wider in a local rock mass, leading to much greater grout consumption.

From numerical simulation it was found that the angle of borehole incidence to crack orientation has little influence on the spread of grout, whilst viscosity has more bearing. The penetration point needs to be open enough to permit and not throttle flow. Water in cracks has some positive effect on grout dispersion.

Enlarged cracks allow the viscous properties of cement to become more dominant to flow behaviour with ensuing consequences for pressure control, especially in small cracks. Grout, then, is also partly diverted from the intended zones, but there can be instances where jacking opens up filled cracks in aid of grouting.

Further, there is no doubt that finding the optimal cement mix is challenging and products with seemingly the same properties behave differently. Therefore, a much more intensive testing would be needed both before commencing the grout works as well as during the works to control that the wanted behaviour of the grout mix is actually achieved and also maintained during the execution of the works.

The research project TIGHT (True Improvement in Grouting High pressure Technology for tunnelling) has improved the understanding and procedures for pre-excavation grouting in such a way that it produces more cost- and time-effective grouting methods that benefit all the participants in this research project, including the public owners who finance the building of road- and railway tunnels through the national budget. Other owners and operators of tunnels and underground openings will benefit from the results of TIGHT as well.

Based on the results from TIGHT, the project-specific solutions should seek local, site-specific approaches to grouting based on a comprehensive design approach covering all elements of the grouting system and controls and held to consistently. By continuously employing the same cement mix design for grout, the same mixing method and equipment, and a faster more rigorous management of jacking risk the workflow processes would have better opportunity to minimise variations in grouting performance. Including the understanding that high or moderate pressure is required to be able to insert cement into cracks and joints in the rock mass, but still have control on the flow. Jacking may not be the key of the problem, rather control of the grouting procedures that follow immediately upon such

instances being triggered and this is where research is currently ongoing, ie. how to detect an incident and how to react on the alarms that go off. Widespread and uniform methods from a general solution would not be the expected outcome, whilst project-specific solutions will continue to be required.

TIGHT may have led to development of technology and also benefit projects on time and cost aspects of grouting, however the field of pre-excavation grouting of the rock mass is a huge theme to investigate. There are still lots of issues that could have been developed and dealt with in other research projects; like the understanding on how contract conditions could better reflect grouting quality and quantity; how can the industry better establish relevant laboratory testing on grout penetration on cracks and joints in the rock mass to mention a few, and last but not least, how can we take benefit and learn from the endless amounts of data that is collected at the drilling jumbo and the grouting rig for each grouted hole in the rock mass.

TIGHT is a project that has been financed by the Norwegian Research Council as a competence building project (KPN-BIA) involving a number of participants from the tunnelling industry in Norway; Statens Vegvesen, Jernbaneverket, BASF, Mapei, Geovita, LNS, ITS, Normet, Bever Control, AMV and Veidekke together with NGI, NTNU and SINTEF.

Picture shows preparations for pre-excavation grouting at Implenia/Acciona tunnel face in Moss. Picture by AMV