Predictable and successful rock injection - the first time around

A new improved system for cost-effective control of water in-leakage during tunnel excavation may reduce the need for expensive sandwich lining systems

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Abstract: New environmental friendly materials and methodology, have lead to the invention of a new cost-effective rock injection system: the MultiGrout System. The use of the system results in a low permeability zone around the tunnel. Experience from a dozen tunnels built during the last 4 years documents that water in-leakage levels hardly seen before can be achieved again and again, without the use of costly, time consuming, repeated injection rounds. The new system meets the requirements to watertight tunnels, the first time around.

Key words: Injection, grouting, leakage, tunnel, microsilica.

Introduction

In Scandinavia the common practice is to prevent water in-leakage in tunnels by the use of pre-injection during excavation. This is much less costly than the use of sandwich lining systems. Previous pre-injection methods have been unpredictable or have required repeated grouting rounds before in-leakage requirements have been met.
In other parts of the world lack of proper methods to control water in-leakage has led to severe flooding and caused excavation problems that result in severe delays, project stop, costly continuation and even bankruptcies.
Water inflow has an impact on groundwater level and ground settlement that can cause damage to buildings, lakes, creeks, wells or water reservoirs. Water leakage into underpassage tunnels must be removed by costly pumping and can also have a negative environmental impact where such water is discharged.
In all tunnel projects the staff should be prepared to apply pre-grouting to reduce water in-leakage or to improve the ground conditions. The improved method described in this paper, has great potential to reduce overall tunneling costs.

Drawbacks of traditional cement grouting

Portland cements of various fineness have always been used for injection, sometimes combined with bentonite or water glass, to improve stability and setting time. Cement injection grouts, despite better penetrability of ultrafine cements, still have several major shortcomings:

Scientific paper

- coarse fraction blockage
- cement filtration
- water/cement separation
- durability/ solubility problems
- uncontrolled setting of some cements
- dilution by ground water
- in situ bleeding
- shrinkage / volume instability

Cement grouts have generally low penetrability, and many grouting holes and repeated grouting are often needed. The costs to meet required impermeability and rock stability are high. A new high performance grouts would eliminate these costly problems.

PREFERRED CHARACTERISTICS OF HIGH PERFORMANCE CEMENT GROUTS

- high penetrability
- environmentally harmless
- economic feasible / attractive
- no separation / particle blockage
- stable at high injection pressure
- stable volume during and after hydration
- durable and difficult to dissolve
- controlled setting so excavation can proceed without delay
- fill all voids in first injection round

A grout with these characteristics will effectively glue the fractured rock together[2], [3]. MultiGrout® is a new high performance, high durability; cementitious grouting system developed to meet this list of wants[1].
Although chemical grouts have the desired penetrability, such products are either very expensive, complicated to use, harmful to environment, poisonous and forbidden, or have unpredictable durability and are therefore an undesired alternative.

THE MATERIALS IN THE MULTIGROUT SYSTEM

GroutAid® penetrator is a proprietary processed silica fume 10-100 times finer than cement. The sub-micron particles create cohesive forces and help to improve the grout mix through:

- eliminated bleeding / separation
- homogenous and stable grout
- reduced filter-cake build up
- increased penetration
- pumping pressure stability
- increased bond strength
- volume stable
- increased durability
- harmless to the environment
- overall better grouting results

GroutAid is used to stabilise the grout in all aspects and such grout is hereinafter named High Performance Grout (HPG).
Portland cements: The water in-leakage criteria (e.g. liter/minute/100 m), the porosity and fracture system determine what cement fineness to be used. Of specific importance is the blocking fraction, the > 97 % fraction.
Blocker grout (BG): A special water blocker grout is applied as a necessary tool for effective grouting in special situations, especially in post-grouting situations for fighting water. In ordinary grouting BG is used to control grout placement and grout volume. GroutAid is

used to enhance stability and durability of the BG. BG meets fast setting requirement without the risk of flash setting in pumps and hoses. When BG mixes with HPG inside the rock formation an immediate reaction of the intermixed grouts leads to blockage of grout outlets.

Grouting methodology

Pre-grouting, drill & blast, mucking, shotcreting and bolting are all important parts of the repeating excavation sequence. Testing of probe-holes determines when and how pre-grouting must be applied. The grouting work is specified by a number of parameters that has to be designed by trained engineers. Normally only HPG is used, but in some situations with high grout take, BG is used to stop runaway grouts[4],[5].

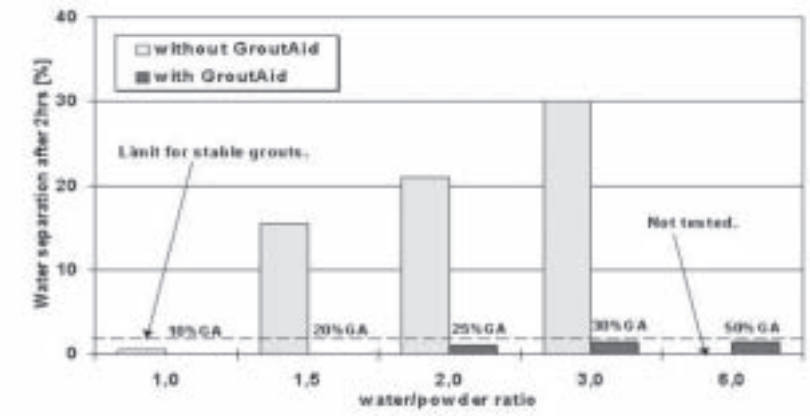

Figure 1. Bleeding in grouts with and without GroutAid[1]

In shallow overburden situations, in very fractured rocks or in water-rich areas, a primary grout curtain is made by the use of BG: High pressure grouting with HPG is then applied on the inside of the curtain to seal up fine fissures. This methodology can also be applied effectively from a TBM if it is equipped for pre-grouting.

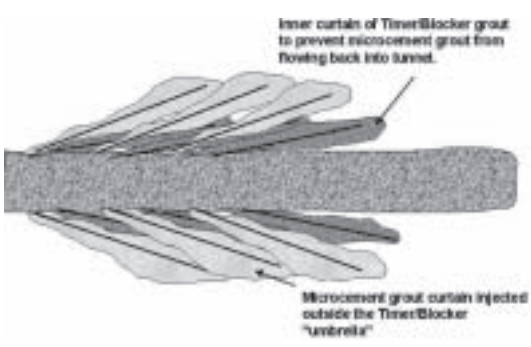

Figure 2. Blocker Grout placed to create a grout curtain outside of the tunnel profile and the area of High Performance Grout

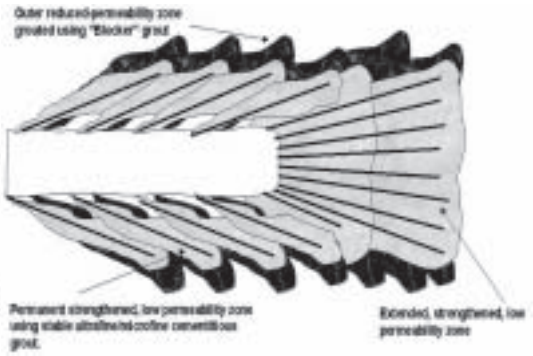

Figure 3. Post-grouting with BG to prevent grout from flowing back into the tunnel

In **Post-grouting** HPG should also be used. HPG is ideal to fight water due to its cohesiveness, especially when used in combination with BG to form a blocking membrane to stop grout from flowing back into the tunnel. This new system makes post-grouting fast and cost effective.

REFERENCE PROJECTS

Table 1 describes some of the projects where the MultiGrout System has been used with success. Many of these projects represent special challenges, such as post-grouting after other systems have failed, stopping of severe water in-flow, using high pressure in shallow areas without surface jacking, etc.

Project		Challenges	In-leakage, litre/min/100m			Method
Location	Type		Before	After	Spec.	
Romeriksporten, Nor.	Railway	Surface damage	50	20	20	post+blocker
Akrafjorden, Norway	Highway	High press.,46 bar	3-5m^3/mi	10	20	post+blocker
Bomlafjord, Norway	Highway	-220m, sub-sea	leaking	20	20	post+pre
Storhaug, Norway	Highway	Shallow/fissures	70	1	6	pre+curtain
Baneheia, Norway	Highway	Sensitive area	170	1,7	6	pre
Lunner, Norway	Highway	Protected nature	leaking	4	6	pre + post
T-baneringen, Norw.	Metro	Urban		4	8	pre
Hagan, Norway	Highway	Suburban		4	4	pre
Sines, Portugal	Cavern	Propane storage	20m^3/hr	12m^3	12m^3	post
Salmisaari, Finland	Cavern	Coal storage	leaking	dry		post+pre
Hong Kong	Sewage	Subsea, fractured	leaking			post+pre
Sydney, Australia	Cable	Fractured zones	leaking	dry	dry	post+pre
Skaugum, Norway	Railway	Suburban		<goal	4-8-16	pre

CONCLUSIONS

When used according to the recommended procedures the MultiGrout system has an unrivalled track record – no failures to date. Statistics show that more than 99 % of all grouting rounds are successful first time around, saving time and money.

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