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Injection

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Introduction to grouting in hard rock tunneling

Grouting in hard rock tunneling has primarily two purposes:

- Groundwater ingress control
- Improvement of rock mass properties and tunnel stability

The first purpose is clearly dominating with focus on avoiding that too much water ingress creates difficult working conditions inside the tunnel, or that ingress must be significantly limited to prevent damage on surface due to settlements or environmental damage like loss of water resources. The improved stability will in any case be an additional and positive side effect of grouting for groundwater control.

Pressure grouting in rock is executed by drilling boreholes of suitable diameter, spacing, length and direction and placing packers typically 2-3 m into the boreholes. The packers have an expander at the end, that provides a pressure-tight block against the rock wall of the borehole, allowing grout to be pressurized and forced into cracks and joints of the surrounding rock mass.

In tunnel grouting there are two main methods to consider:

- Pre-excavation Grouting (PEG), where the boreholes are drilled forward of the tunnel face into virgin ground. Cementitious grout is injected (mostly) and allowed to set, before the tunnel is advanced into the treated rock volume. PEG may alternatively be executed from surface.
- Post-grouting (PG) includes the same basic steps, but takes place along areas of the tunnel already excavated. Be aware that drilling and grouting through the tunnel face, sometimes experiences back-flow of a major part of the pumped grout through connected leakage points through the face or elsewhere. In terms of required practical steps and final results, this situation can best be classified as PG.

Pressure grouting around tunnels has existed for more than 70 years, with a rapid development especially during the last 30-40 years. Successful examples now cover a wide range of rock types and against hydrostatic groundwater head of up to 85 bar, as well as urban tunnels with water head in the range of 1 to 4 bar. The targeted maximum allowed water ingress depends on local requirements and most projects will show limits in the range of drip-free (For example 1-3 L/min/100 m of tunnel) to 40 L/min/100 m.

If a strict maximum allowed water ingress is specified, it is not advisable trying to achieve the result by PG only. Focus should be on fulfilling requirements with PEG for reasons of achieving results with lowest possible time and cost.

A more thorough description of grouting is given in publication "Rock mass grouting" from [Norwegian Tunnelling Society](#) NFF.



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Pretec injection

There are many types of packers used for rock grouting and it might be confusing what exactly is the meaning of the expressions used. The packer types presented in this catalogue are all mechanical packers (as opposed to pneumatic, or inflatable packers)

In this publication the various parts of a packer and grouting tool are described together with some practical aspects of packer selection and useage.



Pretec grouting tool with mounted rubber packer ready for insertion into the borehole.

System components

1. Packer is the rubber part with an outer diameter somewhat smaller than the borehole diameter. It can be inserted to the decided depth and then expanded against the rockwall of the borehole. The Tab washers slides forward only on the packer tube during expansion, that allows removal of the grouting tool while maintaining the expansion force on the packer.
2. The grouting tool is a double walled insertion pipe. The inner pipe of tool is connected to the rear end of the packer and to the grout hose from the grouting pump. Purpose of grouting tool is to transport grout under pressure through the packer into the sealed off borehole in front of the packer. The outer pipe of tool connects to the locking washers of the packer and allows compression of the rubber by pushing the outer pipe forwards, relative to the inner pipe, causing shortening of the packer and expansion of the rubber.
3. The tightening nut, can be rotated on the outside threads of the inner pipe to shorten and expand the rubber expander.
4. The hook-up assembly for the grout hose at the tunnel end, with quick connect coupling and valve to open for or close the grout flow.
5. Safety hook for securing of tool to rock wall.

Grouting equipment

It is beyond the scope of this catalogue to present a complete listing of grouting manufacturers and their various products. This is a large subject because of the huge variation in project requirements, work strategies, time schedules etc. Below is a short summary of different equipment necessary for rock mass grouting.

Mixer for cement-grout

Such mixers are mostly named colloidal mixers, which more correctly should be called high-shear or high turbulence mixers. Choice of a top-quality mixer is important for best possible particle distribution and ability of the grout to penetrate. rotation speed is typically 1500 rpm. Any kind of slowly rotating paddle mixer is not acceptable, which is well demonstrated by checking bleeding of the mix.

Holding tank / agitator

Mixing of a normal batch of cement grout takes about 3 minutes of mixing time. To avoid heating up the batch due to high mixing energy, the batch must immediately be transferred to the holding tank, that will hold several batches from the mixer. Continuously slow moving paddles will keep the grout 'fresh' and prevent gelling or viscosity increase.



Figure 1: Modern injection rig and truck mounted storage of grout mass. *Courtesy of AMV Norway.*

Injection pumps

In Scandinavian practice, only piston- or plunger pumps are used for tunnel grouting. They are electro-hydraulic with maximum pressure capacity of 100 bar. Most of the grouting will be executed from a few bar and up to stop at 50 to 80 bar according to project requirements.

Modern high-capacity grouting systems

As the volume of PEG in tunnels has increased due to many long sub-sea road tunnels and also long urban area tunnels requiring basically drip free tunnel advance, modern units may today have 4 pumps allowing simultaneous grouting of 4 holes. To serve the 4 pumps, there will be at least 2 mixers and holding tanks. Cement will be delivered in big-bags or in bulk and a sophisticated digital system will help out in the mixing process as well as logging all grouting parameters and quantities pumped on individual boreholes.

Furthermore, there should be dosage facilities for addition of accelerator, for modification of viscosity and setting time of the cement grout. The dosage pump must be linked to the cement pump so that a wanted dosage percentage stays constant if the cement pump output is changed. The mentioned dosage system will allow two-component pumping of Colloidal Silica (CS) using the cement grouting equipment, allowing adjustment of gel time during pumping. Additionally, the grout hose from pump to packer, the necessary couplings, manometers and valves must be pressure rated for safe operation.

Pretec single use Packers

Pretec grout packers are available for single or multiple use. The grouting tool has two different hook up assemblies depending on injection pressure and flow rate. Standard length of grouting tool is 1-6m.

Single-Use (disposable) packers

All Pretec Single Use (PSU) packers have two special features:

1. Sliding locking rings / tab washers that keeps the rubber permanently expanded, even when the spanner is released and the insertion pipe is removed.
2. One-way non-return valve that opens for pumping of grout into the borehole, but closes against return flow when the grout pressure on the tunnel side gets lower than in the borehole.

These two features allow immediate unhooking of the pump hose and removal of the grouting tool, leaving the packer in the hole, while maintaining the pressure for the grout to set.

The grouting tool containing fresh and soft grout can easily be cleaned and reused.

The PSU packer is available with two different non-return valves. Conical cross cut (type P) for high flow rate and high pressure (HP), or the non-return valve (type PX) for better control at lower flow and lower grouting pressure (LP).



PSU packer type P



PSU packer type PX

The two packer versions are identical in all respects except the non-return valve. There is no defined pressure level above or below which HP or LP version must be used. Generally, preferences are as indicated above by HP or LP, but local tests and experiences should determine the final choice.



Locking washers
PSU packer

The rubber length of packer is 140 mm and the necessary torque to be applied to the tightening nut is 80-100 Nm for good anchoring in the borehole and to prevent grout leakage between wall of bore hole and packer.

Multiple use Packers (PMU)

The Pretec Multiple Use packer (PMU) have the same rubber length as the PSU packers but no return valve or locking rings. This means that fully expanded packer can be released and removed from the borehole by counter-rotating the tightening nut, which let the rubber go back to its original shape. The PMU packer is available in the same dimensions as the PSU packers.

Grouting procedures will normally require that water ingress from probe- or grout holes is measured and recorded. PMU packers which will collect all the water from the hole are often used for this purpose since they make it possible to accurately measure the flow rate.



At stop of pumping, the valve of the hook-up assembly must be closed before disconnecting the grout hose. The complete packer with the PMU packer cannot be removed from the borehole until the injected grout has developed enough stiffness to retain the groundwater pressure without the support of the packer. This requires careful management of packer removal time to be able to clean the grouting tool and packer. Too early removal will cause backflow of grout and water.

PMU packers can be re-used several times, providing proper cleaning of assembly and lubrication of threaded and moving parts is done.

Packer Type	Drill diameter (mm)	Recommended borehole diameter (mm)	Color Code
PSU-P / PSU-PX / PMU 45	45	44-47	Red
PSU-P / PSU-PX / PMU 48	48	47-50	White
PSU-P / PSU-PX / PMU 51	51	50-53	Pink
PSU-P / PSU-PX / PMU 54	54	53-56	Yellow
PSU-P / PSU-PX / PMU 57	57	56-59	Blue
PSU-P / PSU-PX / PMU 60	60	58-62	Orange
PSU-P / PSU-PX / PMU 63	63	61-65	Green

Grout packer standard dimensions

Grouting tool and hook-up

Pretec grouting tool can be used both for Pretec Single Use (PSU) and Pretec Multiple Use (PMU) packers. Depending on the intended placement depth of the packer within the borehole, the grouting tools are available in standard lengths from 1 to 6m. The injection pipe of grouting tool is designed for maximum 100 bar grouting pressure.

Hook-up

The Hook-up assembly consists of connection coupling for grout hose and valve for controlling grout flow.

There are two different assemblies available and the user must consciously select one or the other depending on what maximum grout pressure that is allowed:

- High pressure (HP) hook-up: Maximum 100 bar operating pressure. All components of the packer assembly can be used at 100 bar grouting pressure.
- Low pressure (LP) hook-up: Maximum 50 bar. Assembly is design for CAM-lock quick coupler with pressure rating (PN50). It is the only part of the grouting system that cannot safely be used up to 100 bar, so the grout pump must be locked and sealed against delivering more than 50 bar.



Hydraulic quick coupling (JIC 1 1/16") with ball valve pressure rating PN 500 and dimension DN15



Quick coupling with ball valve pressure rating PN 63 and dimension DN15

Note: All Pretec packers are designed for up to 100 bar injection pressure. If more than 50 bar injection pressure may occur, the HP hook-up assembly is required.



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Injection in practice

For a normal case of hard rock tunneling and PEG, the typical borehole diameter will be about 63 mm, which fits well with borehole lengths up to maximum 30 m and maintenance of reasonable borehole deviation. If maximum hole length is shorter and drilling equipment for any reason would work better with reduced drill bit diameter, Ø48 or Ø51 mm could be an alternative.

In most cases, the PSU-HP would be the main packer choice with diameter Ø63 or Ø51 mm. This choice saves time and cost and will under normal conditions anchor and seal well in the borehole. For normal conditions the grouting tool can be re-used up to 10 times, if it is properly cleaned and greased after each use.

However, in zones of poor rock, the 140 mm long packer may not manage to seal all boreholes effectively and sometimes 2 or 3 packers in the same hole are required. It is therefore reasonable to have alternative ways to mitigate the problem:

1. Prepare some PMU-HP packers on 4 m (or longer grouting tool) allowing testing of locations in the borehole to find one where the packer will seal properly.
2. Have available some mechanical or pneumatic packers with rubber length of 0.5 to 1.0 m, which will substantially improve the chance of satisfactory sealing the borehole. Also in this case, the total assembly length should be 4 m or more.

Even in good quality rock, there can be water and grout conductive channels that cross both the borehole and the tunnel face. If the packer has been placed outside of this channel, the path of least resistance during grouting will be back to the tunnel, which may cause substantial loss of pumped grout.

For such situations usage of a removable packer may be a good alternative (not the PSU-version). Alternatively, place a PSU-packer inside of the channel and finish grouting. If necessary, then place a packer outside of the channel and execute grouting using accelerator dosage at the packer to block the backflow through the tunnel face.

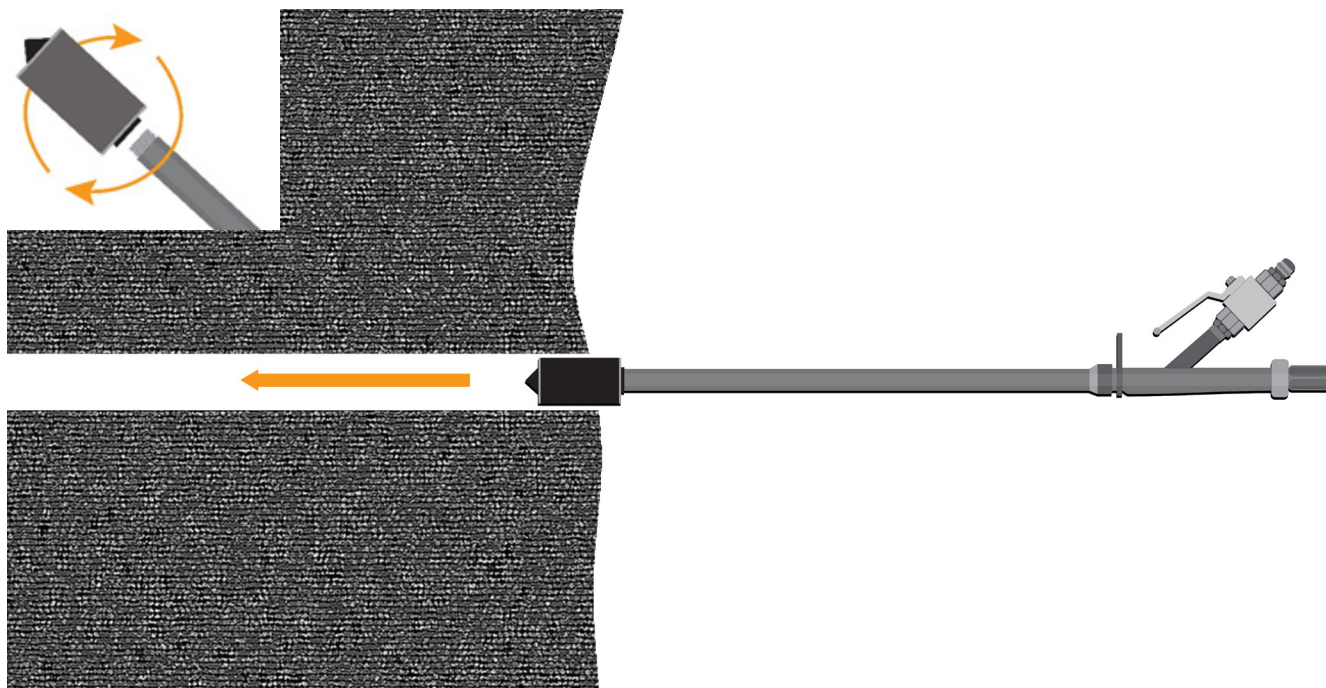
Selection of grout material

Cementitious grouts are always the first choice for tunnel grouting and there are currently no available alternatives to cement. At the same time, the large number of cement types and the variation in rock conditions and ground water ingress limits for various projects, turn project selection of cement and specification of grout properties into a complicated task in itself.

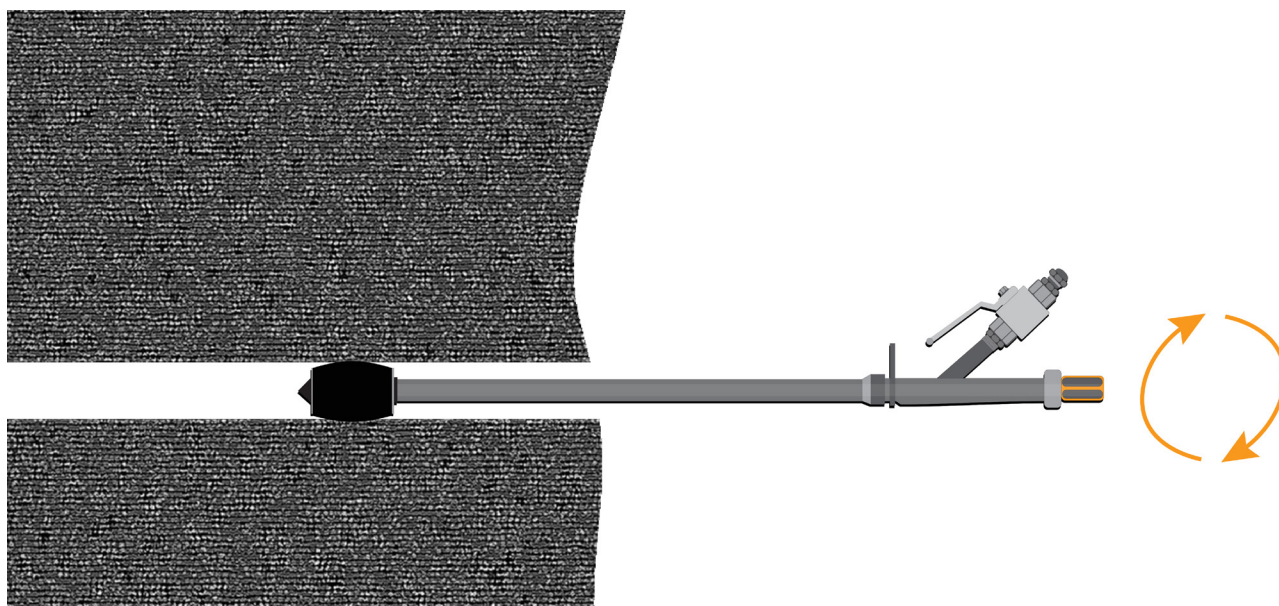
The Pretec packers and grouting tool are all suitable for the normal cementitious grout products as well as for use of various chemical grouts and colloidal silica mineral grout.

Packer Installation and grouting

1. Select the right packer and the correct length of grouting tool with the decided hook-up assembly (High Pressure or Low Pressure). Screw the packer onto the inner tube of grouting tool and push the packer into the cleaned borehole to the intended depth for the packer.



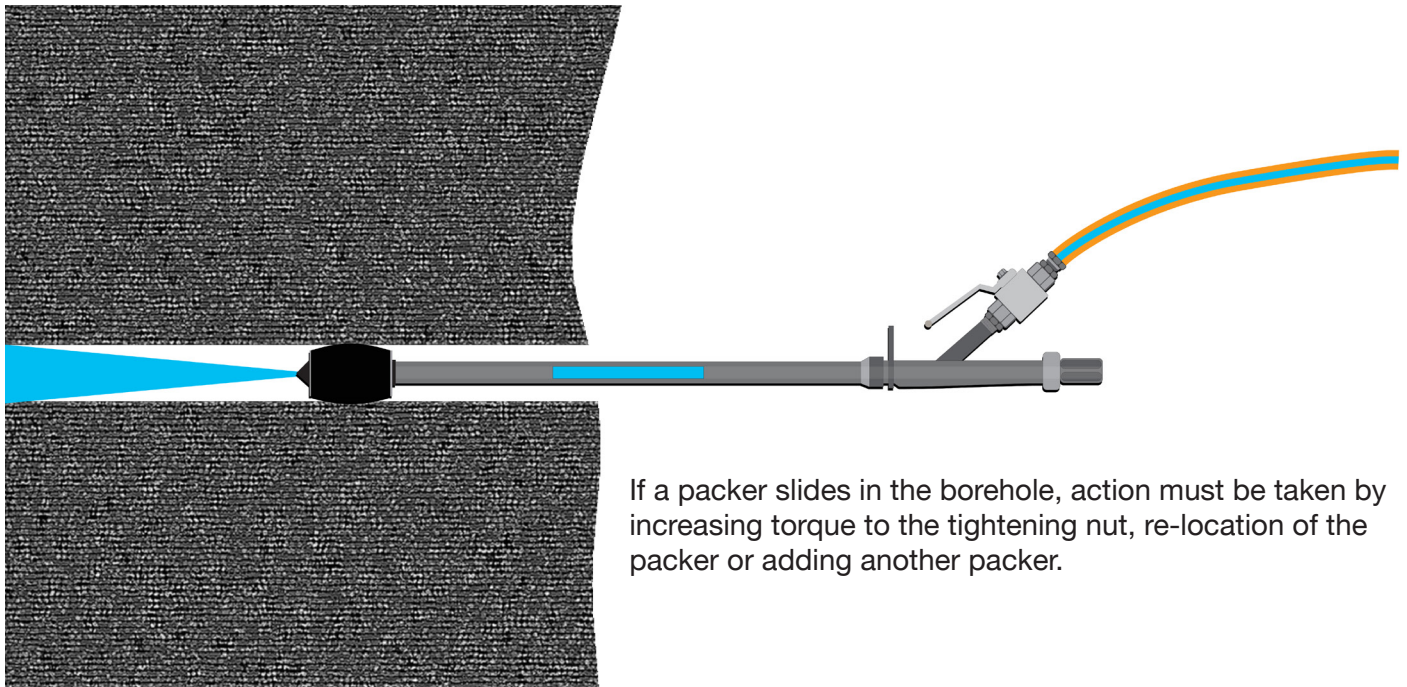
2. Rotate the tightening nut to expand and anchor the packer, using 80-100 Nm of torque. If necessary, check the torque just before start of grouting.



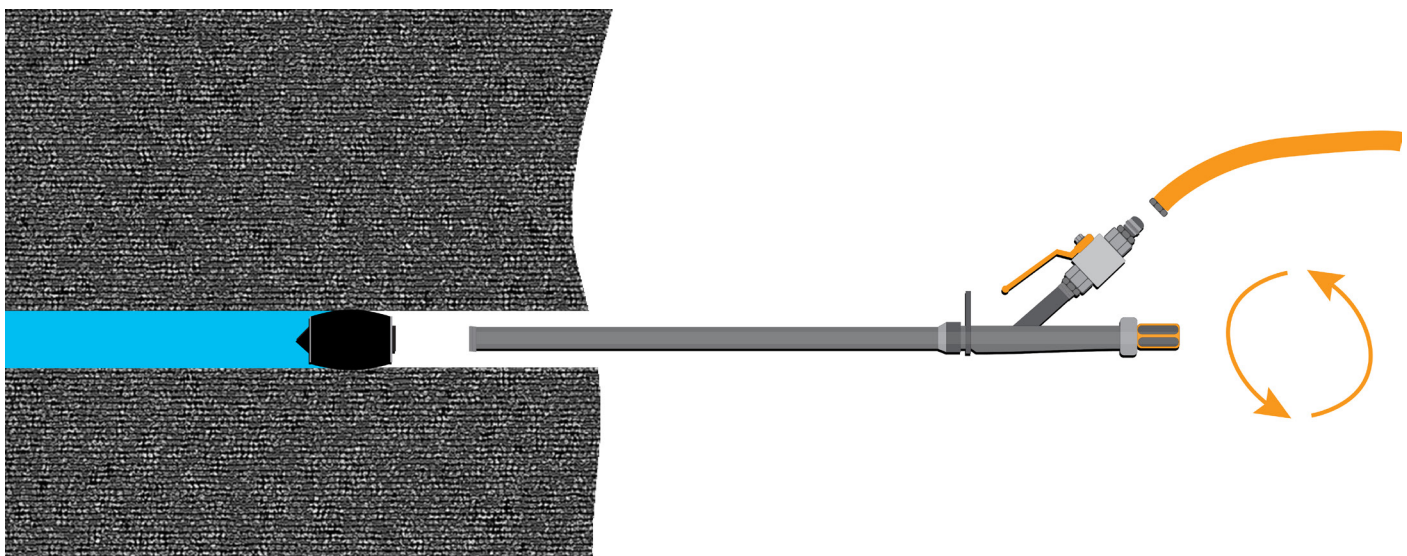
It is not recommended to start injection, if grouting tool is not been anchored to the rock face by an adequate wire or steel chain.

At high grouting pressure, packers may otherwise blow out of the hole and cause injury.

3. When connecting the grout hose, make sure to first pump grout until the hose is full. This must be done to avoid the risk of compressing air that has been trapped in the borehole.



4. As soon as possible after stop of pumping (PSU-packer), unload the tightening nut and remove the grouting tool for immediate careful cleaning and lubrication. If grouting through a PMU-packer, proper timing of grout stiffening must be established to avoid loss of grout due to premature removal, while still being able to clean the packer for re-use.



Health and Safety (HSE)

HSE aspects of grouting in tunnels is an important subject that mostly goes beyond the scope of this catalogue. Some of the risk areas are handling of cement and protection against cement dust, potentially hazardous chemical grouting products, personnel movements around the working area, personal protection gear etc.

The most important risk factor is the high pumping pressure forcing grout through the delivery hose and the packer into the ground. Keep in mind that a pressure of 100 bar pressure equals the pressure of a 1000 m water column.

This whole subject requires a full risk analysis in each case and previous experience has shown that:

- All hoses, fittings, couplings and packer details must be rated for the maximum pumping pressure.
 - Packers may suddenly lose anchorage in the borehole and eject at high speed out of the hole. Packers are therefore required to be secured to the rock face by anchored steel wire or chain.
 - Grout is spreading under pressure on cracks and joints in the rock mass and may cause dislocation and fallout of rock slabs from face, roof and walls of the excavated tunnel. This must restrict personnel movement when pressure grouting is ongoing.
 - To avoid unintended sudden pressure release and dangerous jet of grout.
- All operators must be trained regarding rules of equipment handling, especially aspects of coupling and decoupling of hoses, opening and closing of valves, change of grouting hose hook-up etc.

Packer and tool manufacturing takes place under strict quality control, to ensure that the packers can be safely used within the limits specified for our products. The overall HSE risk analysis and management of general site operations is the responsibility of the product end user.



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