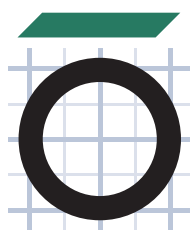


ITAtech GUIDELINES ON BEST PRACTICES FOR SEGMENT BACKFILLING

ITAtech Activity Group
Excavation

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1 >> INTRODUCTION AND IMPORTANCE OF BACKFILLING

This document is a guideline to the best practices on backfill grouting. It is intended to address the various considerations when applying backfill grout. It does not address the theory or details of applying, or mixtures of, the backfill grout itself, but does give reference for such theory and application. The document gives general guidelines: site and machine-specific guidelines should be developed based on this document as well as the project specifications.

The operation of boring a tunnel and current practice of setting of segmental lining necessitates the practice of backfill grouting. The actual lining and backfill grouting are inseparable from the operation of the Shielded Tunnel Boring Machine (TBM). Because of their interface they must be designed in parallel and become interdependent with the TBM operation. Backfilling of segments is an essential operation in order to prevent ground convergence and surface settlement, as well as stabilize the segments themselves.

When boring with a shield TBM two effective voids (annular gaps) occur. There is the void from the overcut; that is, the cut diameter in relationship to the outside diameter (O.D.) of the shield. The second effective void is the space from the shield O.D. to the tunnel lining segment O.D. and normally becomes an integral part of the final void.

The first void can vary in size due to cutting tool wear. In soil the initial overcut or void is usually smaller in area than when cutting rock. The reason for this is to allow clearance for shield turning in hard rock, as there is more plasticity in soft ground. Also in soil, "copy-cutters" are often used to assure a minimum of cutting diameter and to cut the additional clearance required on one side to make sharp curves. The filling of these voids is a very important part of successful tunnel operation and involves numerous considerations.

In open mode as well as on some closed mode machines (especially with stepped shields) in soil and rock conditions, an excluder ring, typically in the form of fish scale seal, is mounted on the O.D. of the tail shield. This excluder ring is designed to keep the grout around the last few rings of segmental lining that is extruded

out of the shield and effectively prevent grout from moving forward over the tail shield. Such grout could effectively harden and cement the tail shield to the surrounding soil or rock.

Injection of grout into the annular space in pressurized tunneling has a direct influence on the settlement or heave behavior of the surface and the quality of the tunnelling process. The void injection serves as a backfill and a foundation for the individual tunnel segments. The injection pressure must be sufficient to fill these voids completely. However the maximum predetermined pressure should not be exceeded to prevent leakage of the grout through the tail seals of the TBM and/or ground heaving. Therefore the applied injection pressures and injection volumes must be maintained and controlled during the injection process.

Control of the grouting system is based upon dual stop criteria, which involves controlling the injection pressure and injected volume of the grout. In EPB and Slurry TBMs the segment grout injection pressure is the leading factor and should be based on a geostatic calculation, slightly greater than the face pressure, but below a point that would create heaving on the surface. The injected volume is more difficult to predict in soft ground but depends upon the void created between the segment outer diameter and in situ soil, as well as the soil type. The volume should be monitored continuously and any changes from the normal level should be indicated or should trigger an alarm.

Backfill grouting can be applied using two methods: through ports in the shield or through grout ports in the segment lining. Grouting through the shield ports, known as tail tube grouting, occurs at the point between the tail shield and the start of the segments, providing immediate stabilization and a lower risk of settlement. The risk of tail tube clogging is, however, a drawback of this method. Grouting through the segments requires grout to be applied behind the machine shield, meaning the annular gap remains unfilled for a longer time and the risk of settlement is higher. However, there is no risk of clogging.

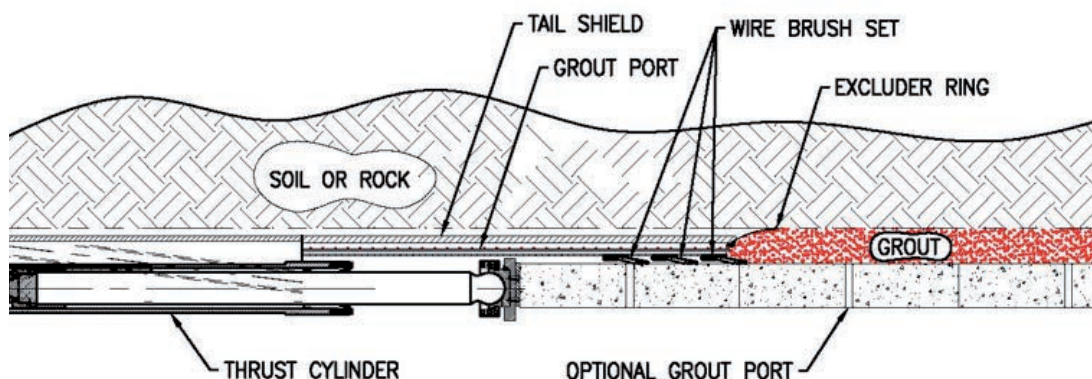


Figure 1 : Shows the basic principle of backfill grouting through the tail shield in a pressurized tunnel.

2 >> GROUT SELECTION CRITERIA (SINGLE Vs TWO-COMPONENT)

The properties and characteristics of each grout mix depend on the ingredients added and the method of grouting. Changes to the composition of the mixture will create effects and property changes in the grout. The mix design will determine the exact properties and behaviors of the grout to be used. Typically, single component grout consists of cement, fly ash, sand, and bentonite. Grout material is mixed and transported into the tunnel, then pressurized with an injection pump and injected into the annular gap. Two-component grout consists of an A Liquid and B Liquid. The A liquid is typically cement and Bentonite, while the B liquid is an accelerator derived from sodium silicate. In two-liquid grouting, the A and B liquid are kept in separate lines and mixed at the injection point into the annular gap.

In some cases, non-active or inert grout may also be used, consisting of sandy materials. While this type of grout will not be explored in this paper, it is an alternative in certain ground conditions. The section below introduces some important grout properties and features.

2.1 SUMMARY OF GROUT TYPE ADVANTAGES AND DISADVANTAGES

Following is a chart comparing the two systems.

GROUT TYPE ADVANTAGES CHART		
CONSIDERATION	SINGLE COMPONENT	TWO - COMPONENT
Strength	X	
Cost	X	
Transportation		X
Groundwater		X
Early Set Time		X
Early Support		X
Fluidity		X
Batching		X
Maintenance		X

Grout properties and further elaboration on grout selection and grout use can be found below and in reference documents.

2.2 STRENGTH

The strength of grout depends on the mix design and the time that the grout is allowed to set up. Single component grouts have the ability to be designed with high strength due to the mixture properties. Two-component grouts do not form as strongly as single component grouts in part due to the lack of aggregates in the mixture. Both single and two component grout types must be mixed and tested for the specific ground at the tunnel location in order to ensure the optimal mixture. The guiding principle for contractors should be that the grout strength is sufficient to support the tunnel lining as it exits from the support of the tail skin. In addition, the strength should be sufficient to support imposed loads from the TBM back-up.

2.3 COST

The contractor has the choice of single component grout or two-component grout. Single component grout is much lower in initial cost in many markets, though its overall cost can be more expensive than two component grout when the volume of grout mix and the amount of the mix thrown out are taken into account. The choice of grouting method can also greatly affect the cost of the bore, as the bigger the void the more cost for grout. Grouting through the segments does not increase the bore diameter, making the method more cost effective. However, this method increases the risk of settlement in pressurized face tunneling operations, mainly because grouting cannot start until the grout hole in the segment has cleared the tail shield, leaving the void exposed. This can be minimized by having multiple grout ports in each segment. Conversely, providing tail tubes for tail tube grouting will increase the bore diameter, resulting in a larger bore, but the method's settlement minimization is superior. The increased cost of a larger bore diameter (and therefore larger backfill volume) must be weighed against the increased risk for segment grouting.

2.4 TRANSPORTATION

The transport of the mixture plays a large role in the construction and timing consideration. Single component grout is most commonly brought into the tunnel in grout cars, while two-component grout can be pumped in from the batch plant through the tunnel. There are benefits and draw backs to each, depending on the construction methods. The recommended transport method requires a full study of the tunnel depth, length, size and other factors.

2 >> GROUT SELECTION CRITERIA (SINGLE VS TWO-COMPONENT)

2.5 GROUNDWATER EFFECTS

In tunnels under the groundwater table the groundwater will interact with the grout in a variety of ways. A problem that is associated with grouting under the groundwater table is the dilution of the grout as the groundwater mixes with the grout.

This is only an issue in single component grout as two-component type grout is less influenced by outside water. Anti-washout agents can be added to single component grouts in an extra step.

2.6 EARLY SUPPORT OF LINING

The early support of the lining can play a significant role in the early strength capabilities of the grout. The ability for the grout-in-place material to resist loads is important, and this comes not only from the loads of the ground. It is important to resist forces acting from the lining and the stresses incurred from thrusting the machine forward or moving the trailing gear (back-up) over the newly set rings. The stresses placed on the lining will try to move the ring and reduce stress loads throughout the lining, creating the possibility of movement in all directions. A good supporting pressure and ability to lock the ring in place as soon as possible is desirable. This setup can help to reduce maintenance costs and repair work over the whole tunnel drive. The two-component grout and quick setting time also allows for minimizing of ground settlement, and, in high stress conditions, it will reduce the ground convergence.

The early set strength plays an important role in the ability of the segments to avoid movement and stepping between joints. The faster the set time the better the chances ring deformation will not occur. One-component grout has a slow set time associated with the ability of the cement to hydrate. Two-component grout has a high early strength due to the acceleration of the gelling by the B-Liquid.

2.7 FLUIDITY/PUMPABILITY

The fluidity of the grout will play a role in the transport and final placement of the grout around the segments. The greater the fluidity of the grout, the easier it is to transport and inject around the ring structure. Single component grout, being more paste-like, is much harder to transport and pump than two-component grout. Two-component grout has a very high fluidity of both the A and B liquids.

2.8 BATCHING

The logistics and properties of the grout can be influenced by the batching process. The ability to quickly batch uniform grout mixtures is essential for large projects and rapid construction. Good mixture ratios can be achieved with one-component grout, but this is dependent on the experience of the contractor and implementation of an effective batching system. Both types of grout are fairly easy to mix and can be done by automated grout plants with small equipment.

2.9 MAINTENANCE

Two-component grout remains fluid and pump-able till the components mix at the nozzle. This is in contrast with single component grout, which can set in the lines if the mixture remains there for an extended time and can require replacement of the lines in the machine.

3 >> GROUTING PORT NUMBER AND GROUT PORT FLUSHING

The number of grouting ports used on a machine depends on a variety of factors. The factors include types of grout provided, anticipated advance rates, machine size, and type of ground to be excavated.

In soft ground machines less than 10 m in diameter, two-component grout can effectively be used with only two grout ports with proper grout and injection procedures. This is because of the ability for the fluid grout mixture to maneuver around the segments to completely fill the annulus. It is very normal for only two ports to be used at one time in practice. Single component grouting normally requires four ports on TBMs in the 6 to 8 m diameter range to allow the correct placement of the mortar grout around the ring. Mortar is less fluid than the two-component type, so more placement locations are needed to allow complete filling of the annulus.

The anticipated advance rates also play a part in the selection as faster advances require more grout, which may make it economical to provide more ports rather than larger pumps. Each port should have an independent pump to better control the injected volume and help prevent clogging. Another factor that influences the grouting ports is the size of grout ports that can be used. In soft ground/soil the ports can be placed on the exterior of the shield and size is not a critical matter. In rock or mixed ground the ports need to be imbedded in the tail shield structure. In this case it is desirable to keep the port relatively small so as not to increase shield thickness, thus increasing the actual void.

In addition, when designing the injection system it is important to have an effective flushing system to prevent clogging and ensure ease of cleaning. Smaller diameter grout ports can also assist in the prevention of blockages as the velocity can be maintained in the lines, reducing the chance of pipe clogging. A good cleanout regime with flushing systems and established procedures for daily and weekly cleaning is essential. This is true for two-component grout as well as single component—for example, it is usual to fill the last 100 mm of advance with an un-accelerated component A-only mix to ensure the ends of the tubes do not clog in two-component grouting.

4 >> USE OF PEA GRAVEL

Pea gravel is another form of segment backfill, often used while boring in rock with a double or single shield TBM. This type of TBM permits segment setting during mining. The pea gravel is used to immediately stabilize the segments. The pea gravel is usually screened alluvial pebbles, which are preferable, or crushed rock. The pea gravel is pneumatically pumped into the void through holes in the segments (normally the same holes used for the segment lifting device) or by blow pipes inserted between the tail shield and crown segment. The pea gravel normally is not applied in a pressurized tunnel.

During application the void is not completely full but is filled to the angle of repose. The void with the injected pea gravel is then normally cement grouted as a secondary operation a few segments back from the tail shield. Please reference Figures 5 & 6 for the

operational sequence. As can be seen in these figures, the gravel is injected through a port at the crown of the tunnel and flows to the sides. This is due to the fact that in many cases the segments in double shield tunneling machines placed in rock (without ground water pressure) are placed directly on the tunnel invert and the annular space is larger at the crown of the tunnel as compared to the invert. Also this arrangement allows the pea gravel to be placed by gravitational forces. In the case of using single shield machines in rock, with ground water presence at the shield where a seal should be maintained from time to time, the segments are installed in the tail shield and not laid on the ground. The resulting gap of the annular space is still higher at the crown than it is at the floor of the tunnel.

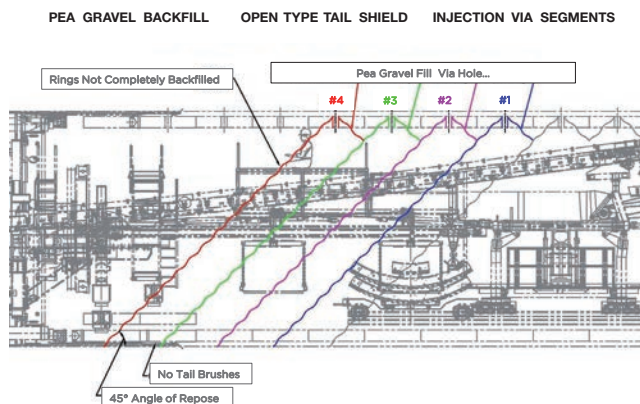


Figure 5 : Pea Gravel backfill injection via segments
For clarity on detail see reference 4, slide 11

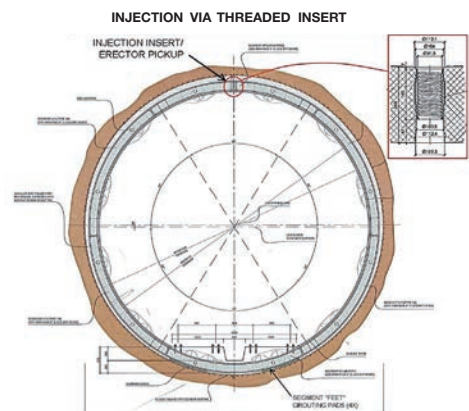


Figure 6 : Pea Gravel backfill injection via segments-detail
For clarity on detail see reference 4, slide 14

5 >> GENERAL RECOMMENDATIONS

It is recommended that the various companies that manufacture the backfill grout and other related components be consulted when finalizing the design and concluding operational practices. At this stage the anticipated ground deformation should be calculated versus time based on the tunnel depth, size of the tunnel, in situ stresses, rock mass or soil properties and modulus of deformation, and finally the presence of groundwater and its related pressure and flow rate. This information allows for realistic design of the grout to cope with the site specific conditions. The final selection of the grout time and its implementation should be done in conjunction with a coordinated meeting of all involved parties, including the TBM manufacturers, to ensure total compatibility of equipment and materials.

The following reference documents were used when preparing this document. These documents provide additional detail on most of the major topics.

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