Course in Tunnelling and Tunnel Boring Machine
Kurs w zakresie drążenia tuneli oraz maszyny drążącej

BACK FILLING

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The instantaneous filling of the “annulus” which is created, due to the excavation procedure, behind the segment lining during the TBM advance is an operation of paramount importance for mechanized tunnelling in urban area to minimize settlements.
Back-filling main goals

to lock the segment lining into position, avoiding movement owing to both segmental self-weight and the thrust forces generated by the shield
to bear the loads transmitted by the shield back-up weight
to ensure a uniform, homogeneous and immediate contact between ground and segment lining
to avoid puncture loads by ensuring the application of symmetrical and homogeneous loading along the lining
complement the waterproofing of the tunnel with the concrete lining and gasketry
Type of materials

Inert mix based on sand transported in water with some other constituents such as filler, fly ash. In rock mass it is possible to use a mix of sand and gravel (pea gravel). That can be injected after some time.

Cheap system. The absence of cement avoids the rock of clogging the pipes. It is usually pumped behind the tail skin through the segments. Setting is retarded or it never occurs. Low strength.
Cementitious mix is constituted by water, cement, bentonite and chemical admixtures (it is also named mortar). Active mix with a very high fluidity. It has to be easily pumpable and it is usually retarded to avoid risk of choking the pipes during transport and injection. The presence of cement helps the development of mechanical strength after 28 days of curing.

It is usually pumped using the tail skin.
**Type of materials**

Two-component mix is a super fluid mortar stabilized in order to guarantee its workability for a long time usually at least 72 hours. An accelerated admixture is added at the injection point. The mix gels a few seconds after the addition of the accelerator (normally 10-12 s) during which the machine advance of 10-15mm.

The gel starts to develop mechanical resistance almost immediately a value of 50kPa at 1h is typical.
**Type of materials**

The mix is injected under pressure and it is able to penetrate into the voids that are present and, depending on soil permeability, can also penetrate into the surrounding ground.

The accelerator admixture is based on sodium silicate and its addition to the fluid mortar leads to an almost immediate gel formation which starts developing mechanical strength.

Using a proper mix design and specifically designed equipment the risk of choking can be minimized. The bentonite increases significantly the homogeneity and impermeability of the hardened mix and minimizes the bleeding.

The permeability of the system is less than $10^{-8}$ m/s.
Grouting through the Segment

There is a void gap between the shield and the grouted part, which may lead to local ground collapses and/or subsidences.

This method is unsuitable in unstable ground but is effective in rock masses.
Simultaneous backfilling
The simultaneous back-filling system and the injected material should satisfy the following technical, operational and performance characteristics:

- The back-filling has to be ideally instantaneous in order to avoid the presence of voids in the “annulus” while advancing with the TBM. For this reason, back-filling is typically carried out through pipes built into the TBM tail skin.

- The “annulus” must be regularly and completely filled so that the lining is regularly linked to the surrounding ground.

- The reliability of the system must be guaranteed in terms of transportability of the mix. The grout must therefore be designed to avoid choking of the injection pipes and pumps segregation and bleeding in collaboration with the time the grout is being transported and distance from batching to injection.
the injected material has to gel very quickly after injection but without choking the injection pipes and nozzles

the injection can be re-started and integrated with any previously injected material at any time

the injected material should be homogeneous in respect to physical characteristics and mechanical behavior throughout the "annulus"

the injection must be always carried out until either achieving the maximum pressure that depends on the TBM face pressure or the theoretical volume of the annulus
Example of backfill annulus with two components in Naples metro tunnel
Performance analysis of the two component system

As the injected material for two-component system is an ultra-fluid slurry which, thanks to the addition of an accelerator admixture just before its injection, gets a thixotropic consistency in a few seconds, and as it is made up of a huge amount of water

it is without doubt an uncompressible fluid, just like water.

The consequence is that the annulus void that is created, after the shield tailskin passage, has to be considered as a closed annular bubble that is filled, instant per instant, with an uncompressible fluid.
Injection pressure

The injection pressure should be chosen to prevent that the mix escapes between the tail and the excavation profile. This goal is achieved with a correct balance between the face pressure and the injection pressure.

The injection pressure should be usually 0.2 bar bigger than the face pressure.
Rome Metro C tunnels

The main geological formations encountered by the tunnels are volcanic soils with different granulometry and mechanical properties ranging from loose soils to soft rock mass. Practically the whole length of the tunnels are below the water table that can be higher than 15 m over the tunnel roof.

For the construction of the tunnels where used 4 EPB machines with an excavation diameter of 6.71 m.

The lining has an outer diameter of 6.40 m and the average thickness of the backfilling annulus is of about 150 mm.
Application at Rome Metro C tunnels

The backfilling was carried out with two component mix.

This mix was studied by Metro C also with special tests and researches carried out by the Department of Land Environment and Geoengineering of Politecnico di Torino.

Mix design (m$^3$ of hardened mix)

Water : 770-820 kg
Bentonite : 30-60 kg
Cement: 310-350 kg
Retarding agent: 3-7 l
Accellerator admixture: 50-100 l
Application at Rome Metro C tunnels

The main properties of the mix are:

gelification time: 5-15 s

monoaxial compression strength
after 1h: ≥ 50 kPa
after 8 h: ≥ 100 kPa
after 24 ore: ≥ 450 kPa

permeability coefficient: ≤ 1,0 x 10^{-8} m/s.
Application at Rome Metro C tunnels

Mixing the accelerator
Application at Rome Metro C tunnels

Monoaxial compression tests at different time

- after 1h: ≥ 50 kPa
- after 8 h: ≥ 100 kPa
- after 24 ore: ≥ 450 kPa

Test carried out after 1 year has shown that no significant loss of strength can be observed
Application at Rome Metro C tunnels

Durability

The durability of the gel which fills totally the annular bubble is guaranteed in the normal humidity conditions of the ground (even more when the tunnel is drilled under the water table).

During the construction of many Metro Lines in Singapore where the two-component system has started to be used more than ten years ago there has only been a positive indication of the grouts durability.

Some tests after curing the samples in the soil with its natural humidity were carried out
Testing
A special attention was given to the check of the complete filling of the gap particularly over the crown of the segment lining.

Many monitoring tests, also requested by the tender documents, were carried out to check both the quality of the hardened mix and the thickness of the annulus.

direct core drilling of the lining and the backfilling

visual check where the tunnel was demolished in the station areas.
direct core drilling of the lining and the backfilling
georadar tests
georadar tests

Steel bars
Steel bars that were detected only locally
Backfilling zone. The detected backfilling is homogeneous
Tunnel boundary
Disturbance induced by the boundary of the segment
Disturbance induced by the boundary of the segment
Segment boundary
visual check where the tunnel was demolished in the station areas
Conclusions

The two-component system injection for the back-filling while excavating with face counter pressure applied by shielded TBMs is progressively diffusing in substitution of the traditional use of cementitious mortars for two main reasons:

- it reduces the risks of choking pipes and pumps (typical when pumping cementitious systems)

- it guarantees a complete filling at pressure of all the annular voids created after the TBM tail passage, thus avoiding surrounding ground movements.
Conclusions

The example of application of Rome metro-Line C shows clearly the advantages of back-filling using ultra-fluid two-component mixes, activated with an accelerator.

This type of fluid is able to correctly completely fill the annulus due to the fluidity of the mix and of the speed of hardening thus permitting a correct management and control of the surface settlements that are really important when tunneling in urban area.

The carried out investigations showed a very good backfilling along the whole line.