Injection Technologies

Case Study of complex rehabilitation projects

Background:

The article describes the technical solutions and methodology applied to stop the heavy water ingresses in the tunnels of a Metro Line, which have been left incomplete and abandoned since several decades with the natural corrosion and the consequent progressive decay of the tunnels. The waterproofing work was completed successfully over the whole length of 4,8 km by applying compartment injections followed by curtain injections behind the existing lining made either out of cast steel or reinforced concrete segments. In addition to filling the gaps, the extensive curtain injection and, where needed, crack injections guarantee protection from further water ingress. A new inner lining made of waterproof concrete would have been the only feasible alternative to applying the injection method – an expensive and time-consuming measure, which would have furthermore significantly diminished the tunnel's cross-section.

1 Compartment Barriers and Curtain Injections

1.1 Resins and Equipment

● Silicates dual component component resins, quick reacting, flexible foam to high strength elastic products. Used for safe cavity filling to rock consolidation as well as for stopping water ingress in tunnelling, mining and civil engineering works. The homogeneous mixing of the two components results in a viscous emulsion, which does not absorb any water from its surroundings but instead, due to its high density, has the ability to push out the water.

● Use of Duel component, polyurethane urethane based foaming resins, from fast reacting with rapid foaming action, independent of the moisture conditions in the soil formation or in the construction to deeper injection technologies

● PCC Mortars and cementitious grouts were used to respectively patch repair heavy damaged concrete segments and fill large gaps with no flowing water.

● A pneumatic, dual component injection pump was chosen instead of an electric one, this due to the necessity of having a reliable, steady flow of material during the work while maintaining mobility and ease of work in extreme conditions.

● 20 mm and 30 mm diameter steel packers were inserted into the boreholes to convey the injection materials. These packers are equipped with a rubber sleeve and were fastened manually to allow proper compression of the sleeve and pressure-tightness against the walls of the

borehole. More recently, injection needle-like injection packers are available as an alternative to steel packers for the rehabilitation of segment linings.

1.2 Break of Longitudinal Water Conductivity; Curtain Injection of the Segments

To stop the water flow behind the segment lining, the procedure followed a two-step approach. At first, annular resin barriers were created behind the segments at 10 m intervals followed by curtain injections to stop the remaining water ingress between the barriers.

Resin Barriers

To stop or break the longitudinal water flow in the gap between the lining and the ground, rings of expansive resin (silicate or polyurethan resins) were created by placing 20 mm boreholes in radial disposition on a defined section with 50 cm spacing.

Injection then proceeded bottom to top and alternating left and right sides to keep the level of the injected resin even. A steel packer was placed in the lower hole and coupled with the injection head. The injection proceeded until the resin appeared from the borehole immediately above.

To overcome increase of water pressure during injection, segment plugs were left open. In some areas, were pressure was excessive, the rings were placed at closer distance, typically every 4 to 5 segment rings. The reduced distance between two resin barriers greatly simplified the following curtain injections within the newly created compartments in between rings.

In Brief: Curtain Injections

Once two rings were completed and the compartment was built, a series of radial holes were drilled and injected with a thixotropic cement grout or resins (cements are priced based in use, resins are a better long term alternate where ground water is present) to prevent it to flow out of the joints between the cast iron segment linings that had no sealing at all.

A grout injection procedure was performed to create the best possible conditions for completely filling the gaps, which were either void or filled with water. Sealing waterways around the tunnel generally started with sealing the points of major water ingress first. Once these were plugged or filled with grout, the waterproofing works proceeded at the smaller leaks. The first injections often caused new leaks in other segments which had to be taken care of consecutively. The process was repeated until it the whole compartment had been completely injected with grouts.

Complementary Works

Nevertheless, even with the compartmentation and systematic curtain injection, in several parts where the cement grout was used, in spite of its thixotropy and resin barriers, was either washed out or not completely waterproof. In these cases, further complementary resin injections for gap or crack sealing were performed to ensure 100 % tightness of the old tunnel.

2 Backfilling (Curtain Injections)

2.1 Equipment and Material

The backfilling behind the segment lining was made with grout mortar and cement grout via a spiral pump with mixer. Grout injections were performed at all stages with a water-cement ratio of 0.4 including superplasticizer and thixotropizer mix to ensure the ideal creamlike consistency of the cement mix.

If the theoretical injection volume was reached with no significant increase in pressure (<1 bar) a second phase grout with a higher w/c ratio (0,7) was later applied, until the maximum design pressure of 3 bar had been reached.

2.2 Execution

To allow a complete filling, boreholes of 30 mm were drilled in the lining to reach the gap behind. The holes were distributed in radial fashion every 2–3 m, roughly at 12, 2, 4, 6, 8 and 10 o'clock positions and the grouting procedure also followed a bottom to top approach, with alternating injections on the left and right sides.

When the grout appeared in the injection ports located directly above, the injection was discontinued and moved to the successive port to allow the complete gap filling around the entire section perimeter of the compartment.

Eventual leakages of the old cements, concretes and cementitious grouts through the (untight) joints of the cast iron segments and other areas caused work suspension to seal these via resin grouting with silicates or polyurethanes, the selection is purely application based knowledge. The aim in this project was to achieve a block of the flow of grout to complete the curtain injection of the gap behind.

Once the leakage point was sealed, the injection of grout resumed. These operations were carried out systematically at each compartment.

2.3 Monitoring of the Injection Works

The flow rate, volume and pressure of the injected mix, during each injection stage and in all the boreholes, were recorded automatically and digitally. Monitoring also included recording any connection between boreholes and inflows through the lining.

During and after grouting the contractor carried out visual inspections and convergence measurements in tunnel sections of 20 m length to detect possible deformations of the lining.

The hydrogeological environment and water inflows into the tunnels were also monitored by the contractor, by measuring the groundwater level of the surrounding subsoil with piezometers installed in the boreholes at an adequate distance from injection points to prevent the

measurements from being affected by grouting. Furthermore, variations in water inflow rates were measured using gauges in open channels or closed conduits in diverse tunnel sections.

2.4 Completion of Borehole Grouting

The grouting operation was considered completed for a specific compartment, once injections into the upper borehole at the 12 o'clock position reached the maximum design pressure.

3 Complementary Works (Residual Gaps and Crack Injections)

After the segment resin rings and the curtain injection (back filling) of the compartments were fully finished, some places that seemed dry after the grouting works showed renewed water infiltrations, even several days after. These water infiltrations are signs that the work was effective, because they appeared due to the return of ground water level to its original position.

For those areas that still showed water infiltrations to a greater or lesser extent, 20 mm diameter boreholes were drilled for resin grouting to definitively stop the leakages. Additional injection holes were drilled along the resin segment ring barriers that defined the backfill compartments, to perform a secondary resin injection. These injection holes were either left unplugged or equipped with packers with valves left open. When a significant amount of water inflow appeared, the valves were closed in the relevant areas, subsequently injected with chemical grouting and sealed, even with high water pressure and high flow.

4 Final Considerations

This project showed a few interesting insights: A large underground construction, a metro tunnel in a capital city, was in an advanced corrosion process after some 25 years of being left abandoned. The project showed how transient our buildings can be if left alone and it consequently shows the importance of maintenance and prevention of water ingress inside the construction.

The combined application of various resins alternated was an optimum solution to merge the positive qualities of both materials optimizing immediate performance with longer term security.

It is also true that a "purist" of resin grouting may point out, correctly, that the resins used for the segment ring barriers are more suited for gap filling than for crack sealing. However, considering the jobsite conditions, location, distance from supply source and immediate availability, this selection turned out to be the best choice available for this project, combined with the applicator skills that were of paramount importance for the successful completion of the rehabilitation works.