UK applies spray-on waterproofing

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All 80,000m^2 of the Hindhead highway tunnel arch in the UK is fitted with a spray-applied waterproofing system. *TunnelTalk* visited the project to see it in application and to know how it provided the basis for accruing other value-engineering savings on the 1.8km long twin-tube tunnel contract.

The tunnel was described as particularly dry during excavation with few areas of ground-water dampness and no instances of dripping water ingress. Even under the shallowest 18m cover on the diagonal to the rim of what is known as the Devil's Punchbowl in southeast England, the predominantly weak sandstone geology exhibited competent characteristics.

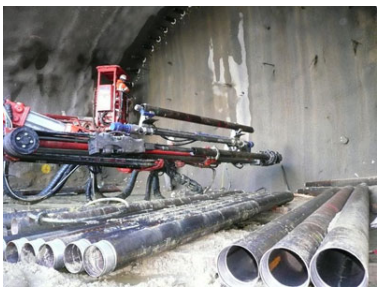
"The weakest ground is at the portals where we used the canopy pipe pre-excavation support system," said Roger Bridge, Tunnel Manager for Balfour Beatty, the construction contractor. "The sandstone is actually sensitive to water and we had to adopt an mist-flushing system for the drill rigs as well as a misting dust suppression system for the tunnel excavator and a self-cleaning scrubber unit for controlling dust at the face and at the sizer that fed the continuous conveyor muck haulage systems."

Twin tube portal

The key variable for maintaining ground stability was adjusting the length of each top heading round from between 1m and 2m, and closing the invert of each bench 3m behind. "Bolting was not required in the weak sandstone and we eliminated the use of lattice girders by adopting reflectorless survey techniques," said Bridge. "We also worked with VMT on the development of a profiling system for accurate excavation. Only steel or poly-fibre reinforced shotcrete was used as the primary support, with GRP spiling applied for extra support where necessary. Steel spiles were installed outside the primary lining profile where required. Face nailing was a nominated face support method but it wasn't needed."

Pipe arch pre-support installation

To pre-support the weakest ground at each portal, the ALWAG pipe umbrella pre-support system was installed. The 25 pipes of 12m long x 139.7mm o.d. across the top-heading span of each 11m wide x 10m high two-lane tube were installed using a Sandvik Axera 8 two-boom jumbo. It took about 30 min to install each pipe including all coupling and decoupling phases, not including the grouting phase. At the south portal, through the weakest of the sandstone, 19 rounds of 12m long pipe-umbrella pre-support were installed with a 4m overlap on each round.



The tunnel is part of a 6.9km section of new highway being built by the UK Highways Agency to replace a section of one-lane bi-directional surface road up and over the hill and restore and protect the local environment. The Devil's Punchbowl is a designated area of outstanding natural beauty in the UK and the single-lane road is a major bottleneck on the otherwise dual-carriage A3 motorway. Maximum cover over the tunnel is about 65m.

Despite predictions of low ground water ingress and a good self-supporting quality of the sandstone, the reference design for the tunnel included a drained PVC-membrane waterproofing system behind an in-situ concrete final lining. But on both scores, there was scope for value engineering.

"Although still controversial for some, we proposed a spray-on waterproofing and a shotcrete final lining," said Ross Dimmock, leader of the Mott MacDonald design team engaged by Balfour Beatty. Within the value-engineering and shared benefit clauses of the design-build contract, "the Highways Agency was receptive to developing these alternatives which illustrated significant time and progress flexibility advantages for the contractor and major time and money savings for the client."

Before needing to order the full arch shutters to progress the reference design, the Highways Agency agreed to adopt the spray-on waterproofing system and to use shotcrete as the final permanent lining in the crown. Cast concrete sidewalls of 6m high, rising 4m above road deck, allow for a painted reflector surface and easier wash-down maintenance. The spray-on system recommended and adopted was Masterseal 345 developed by BASF of Switzerland.

Speaking for the owner, Paul Arnold, Senior Manager and Project Sponsor for the Highways Agency said the decision making process started with accepting the initial shotcrete lining as the structural support and followed the contractor's value engineering proposal to apply poly-fibre shotcrete as the final fire-resistant finish. "This meant we had to use a different method for the waterproofing. It would have been difficult to spray the final shotcrete lining against a sheet membrane in the crown. We knew of spray and paint applied products on the market and since we were well into excavation by that time, and assured that there were no major sources of water ingress, against which the products we were looking at would not have been appropriate, we approved the use of the Masterseal product."

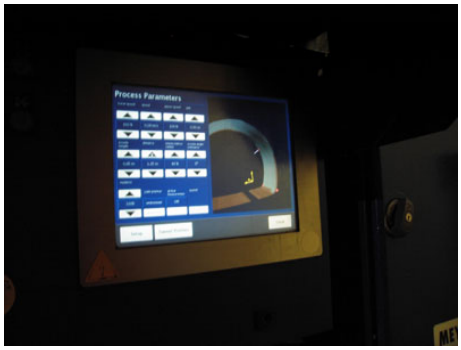
Dry powder product

The Masterseal 345 product is manufactured in the United States and is a polymer rich powder that is basically the same raw material used to produce PVC membranes. It requires only water as a mixing agent and is applied using the contract's existing shotcreting crews and equipment, introduced water to the dry-mix at the nozzle of the spraying boom.

Spray-on waterproofing as part of a composite shotcrete lining

It is described as a significant improvement and quite different to BASF's earlier Masterseal 340 product. It is said to have a faster curing time; needs only one instead of two layers to ensure a consistent 3-5mm layer thickness; and has a more robust bond with the substrate. The 4 bar compressed air application is said to resist pull off forces of between 1.1 to 2kN/m^2 on average. "It is often latent particles and contamination on the surface of cast concrete that cause bond failure," said Dimmock. "Application against a clean, regulated shotcrete surface provides a better key for the spray-applied polymer."

"Masterseal 345 is geared specifically towards application in tunnels," said Richard Foord, the BASF representative in the UK. "It is less sensitive to the climate characteristics and less sensitivity to the quality of the substrate. Unlike two-part spray or paint applied waterproofing systems, it requires no B component catalyst - all of which are typically quite toxic and flammable; no specialist equipment, no specially trained crews; and no special PPE protective gear."



Computer settings....

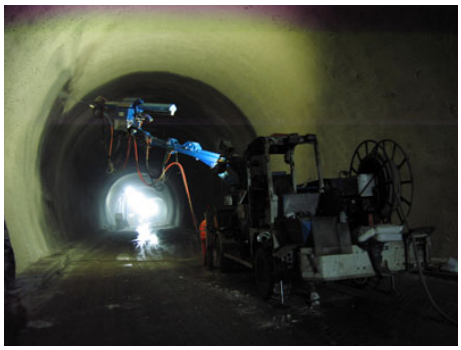
Application cycle

"The ease of using the product is a major advantage on the application side," said Bridge. "We used the same workers as those who applied all the shotcrete needs on the contract and fitted a Meyco Piccola dry spay pump to the Potenza robots to bypass the integral wet mix pump. This retained the Logica computer-controlled action of the spraying boom to apply a 5mm layer of waterproofing against the primary shotcreted surfaces."

In the tunnel, a crew of three was watched applying the product during the visit - one operating the robot, another emptying the bagged product into the dry-mix rotor pump hopper, and the third responsible for quality assurance.

Each waterproofing cycle started with the Potenza robot air-blasting the substrate to remove dust and other latants and spraying the surface with water. "Some dampness is needed for optimum application and it suppresses dust," said Foord. Once the spraying parameters are entered into the Logica's computer system, a 2.5m long round of 5mm thick application across the full 11m arch span of the two-lane profile took about one hour. This speed of application is one of the greatest economic advantages of the system.

The total 40,000m^2 arch of 5mm thick Masterseal 345 was applied to the northbound tube in 4.5 weeks using two robots on a 24h/day, 7 days/week availability and working around other activities in the tunnels.



....for the waterproof spraying cycle

The experience

Hindhead is the largest application of spray-on Masterseal 345 waterproofing in the world to date. Its 80,000m^2 application overtakes the 60,000m^2 applied in the open cut and conventional excavation approaches of the North-South Bypass Clem Jones highway tunnel in Brisbane, Australia, to the point where the segmentally lined TBM drives take over for the passage under the river. Following the Hindhead experience, the system is being considered by designers for application in the SCL (spray concrete lined) underground stations and intermediate access/ventilation/emergency exit shafts on London's Crossrail project.

During the visit to Hindhead, the limitations of the system were acknowledged. "Like all spray or paint applied products, it is not possible to spray directly against highly saturated substrates or against running water ingress," said Dimmock. "Any such situation would have to be pretreated to stem or divert excessive inflow." "This is less significant than it was with the previous more sensitive Masterseal 340 product," said Foord, "but still a limitation that requires active management prior to the membrane application".

Preparation of the substrate was also a matter of differing opinions. "We did recommend application of a smoothing layer," said Dimmock, "but this would have cost time and money and the arguments for bypassing the smoothing layer won the day. There was the acceptance that the tunnel is basically a 'dry tunnel' and its need for a full, comprehensive waterproofing system is marginal compared to other possible applications. There is also the argument that the permeability specification of 1 x 10^{-12}m/s for the primary shotcrete provides a waterproofing barrier of quality itself." The use of maximum 6mm aggregate in all sprayed concrete was also considered sufficient for application of the spray-applied waterproofing to the structural poly-fibre shotcrete without an additional smoothing layer.

When in the tunnel however though, it was noticed that the long strands of poly-fibre protruding through primary shotcrete provided traps on which shotcrete matrix accumulated. In other areas poly-fibres matted on the shotcrete surface. This was overcome, it was said, by adopting a mechanical/hydro cleaning process similar to that used for in-service tunnel cleaning and by the air-blast cleaning immediately prior to application of the waterproofing layer.

Questions about the durability of the product were covered quickly with the explanation that, apart from accelerated aging tests on the membrane, similar polymers have been in existence for 50 years or more in the civil engineering waterproofing industry, and their durability and resistance to biological breakdown is notorious. "There is no reason to doubt that the same long-term durability is not guaranteed in this application," said Dimmock.

Another point of concern was the affect of persistent, saturating rainfall. While the sandstone exhibited good qualities during excavation and it is true that sources of minor seepage can seal hermetically, new fractures and joints can develop as the strata adjusts to the excavation and the possibility of rainwater percolating into the tunnel is real. The performance characteristics of the spray-on waterproofing membrane however is said to be able to address these concerns.

Compliance with regulations

Other innovations incorporated into the Hindhead SCL/NATM construction cycle were driven by new European regulations for exposure to Nitrogen oxides and sandstone silica particles in the workplace.

At one stage it was anticipated that electrically driven tunnelling shields of large diameter would be needed to avoid the use of diesel-driven drilling, excavating and muck hauling machines. The European Union safety regulations for the Control of Substances Hazardous to Health and the CHANS (Chemical Hazard Alert Notices) that must accompany any occupations that might contravene such regulations, required a reduction of exposure to NO^2 from the permitted 25ppm to the new regulation's 1ppm. Exposure to silica had to reduce from 0.3mg/m^3 to 0.1mg/m^3 in a 8hr time weighted average.

A study revealed that applying shields to excavate the twin 1.8km long x 11m wide two-lane tunnels would have increased the cost significantly and put the viability of the project in doubt. As it was, a working group of the British Tunnelling Society was instrumental in having the regulations for exposure to NO^2 in a tunnel working environment relaxed to 'as low as reasonably practicable' (ALARP) and set at a 5ppm maximum and a working target of 3ppm.(2) This allowed the use of some diesel driven plant and resorted the availability of conventional excavation and construction for the project.

To achieve the NO^2 and silica exposure limits in a conventional open-faced excavation process, Balfour Beatty

- used electrical equipment rather than diesel equipment wherever possible;
- employed a Leibherr 944C tunnel excavator with new low-emission diesel engines for top-heading excavation;
- used the electric version of Terrex ITC Schaeff 210 units for bench and cross passage excavation;
- adopted a ripper bucket for use with the excavator over the preferred transverse drum cutter option to minimise dust generation;
- used Leibherr 566 loading shovels with the same low-emission diesel engine specification as the tunnel excavator;
- applied a continuous conveyor system instead of trucks for muck-haulage in both tunnel tubes;
- installed increased ventilation capacity at the portal of each tube from a planned 60kW per tube to two x 250kW fans/tunnel;
- used self-cleaning de-dusting units at the face in each tube with a capacity to treat a total 50m^3/sec/tube.

References

1. UK Health and Safety Executive guidance on COSHH regulations
2. BTS guidelines on the exposure to Nitrogen Oxides

Independent test results are available to confirm that the product, once applied, has an ability to expand 100% times it own thickness. "This provides an integrity to bridge any cracks in the substrate" said Dimmock. Answers came from two directions when asked about future cracks developing in the composite lining, creating a serious channel for water ingress through the 200mm primary support, the 3-5mm waterproof membrane, and the 150mm final lining.

"In the first instance, the lining design specification limits cracks in the primary lining, to a maximum of 0.5mm for example, using fibre reinforcement and high quality shotcrete specifications," explained Dimmock. "Secondly, we need to ensure our specifications call for membranes with crack bridging properties well in excess of the design crack widths. Typically the 345 spray membrane can cope with crack widths equal to its thickness of application, for design purposes. This safety margin allows us to cover cracks that are outside those that can be controlled in the design specifications." Literature that accompanies the product also explains that

Cast side walls for reflector pain and easier wash down

there can be no migration of water between the membrane and the substrate. Should a leak appear in the composite structure, that is exactly where the leak is occurring. As a result there is no chasing the source of a leak and, despite the fact that using grout injection to seal water leaks can be problematic, the leak can be seen and readily repaired with the most effective of modern epoxy and polyurethane resins.

When asked, it was confirmed that there is no long term insurance applied specifically to the waterproofing system of the tunnel and that Balfour Beatty has the contractual three-year maintenance liability period after the opening of the new road. "There are no standards as such for waterproofing in highway tunnels in the UK, and EU regulations don't apply," said Arnold.

"There are standards for waterproofing bridges in the UK but as we have so few road tunnels, alternatives go through a rigorous assessment process within the Agency to be approved for application."

When *TunnelTalk* visited the site, all application of the spray-on waterproofing membrane was within a week or so of finishing and casting of the in-situ concrete walls was advancing. Behind these shutters, the final 150mm of final shotcrete lining in the crown of each tube was also progressing, attention being paid to provide a smooth connection between the final shotcrete lining and the cast walls.

From the start of the waterproofing process, the final lining in both tunnels was completed in six months. The road deck and the final M&E services are now being installed towards the scheduled mid-2011 opening date.

"Given the right conditions it's a very good system," said Arnold for the Highways Agency. "It speeded construction of the tunnel by about three months over the traditional option and worked well. The system has lived through a particularly wet winter here in the UK and has performed as we expected. There were a few additional damp patches on the final lining, breaching the waterproofing, but the contractor has resolved these effectively with a grout injection process."

Since its introduction, the reference list for application of the MASTERSEAL 345 product in new build and tunnel rehabilitation applications has grown. The attraction of the technique is winning advocates but it will be in the monitoring of the product in these different applications that will provide the telling evidence of its long-term suitability and actual performance.

Final lining in the crown

References

Spray-on waterproofing - finding real application - *TunnelTalk*, August 2008

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