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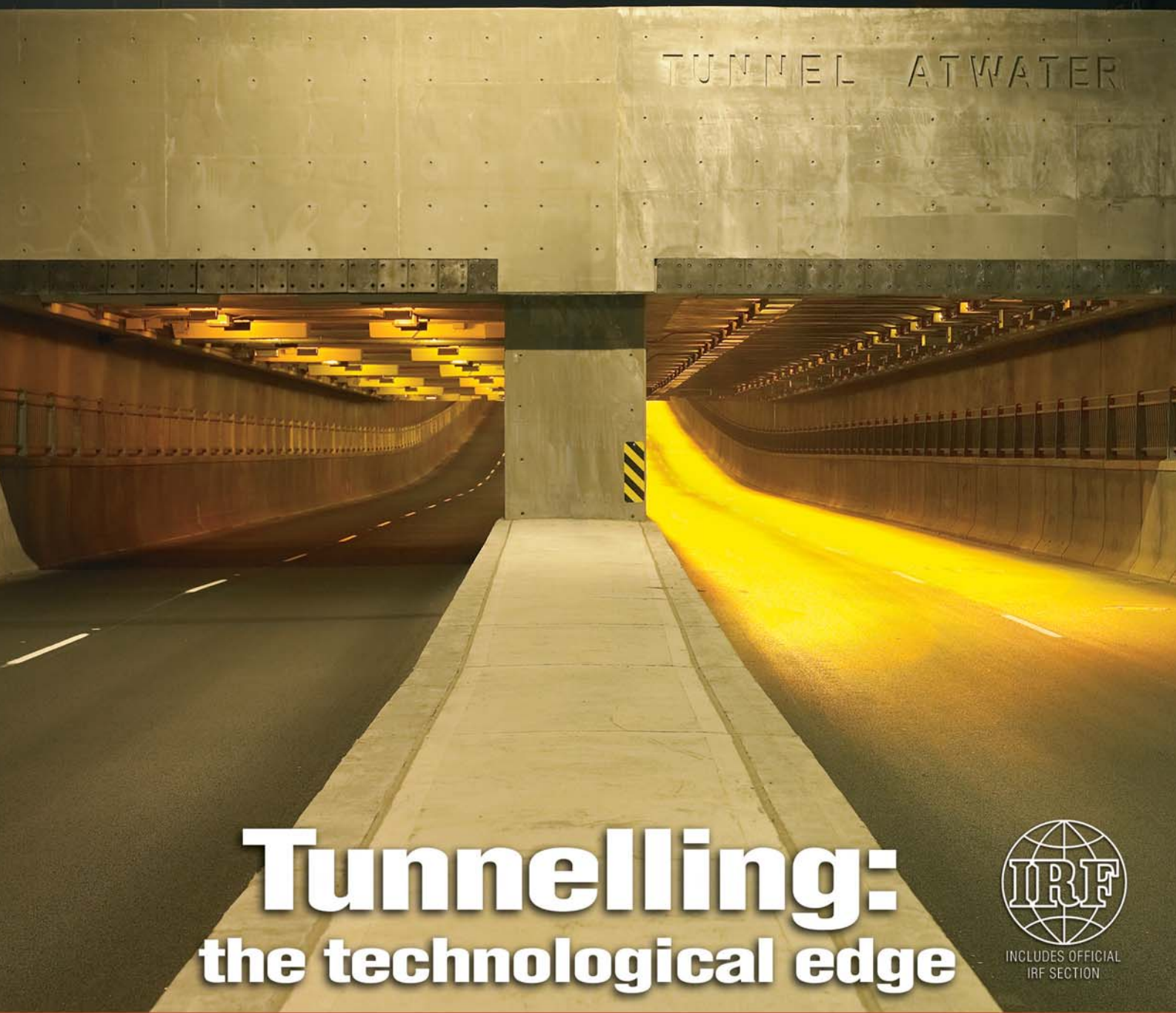

Tunnelling: the technological edge

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Out of sight

Mike Woof reports on the technological innovations being made in tunnelling

With Boston's Big Dig project complete, one of the world's most impressive tunnelling jobs is now in full use.

The construction of the Central Artery/Tunnel in Boston. It has involved the removal of some 12.2 million m³ of earth and the placing of around 2.9 million m³ of concrete, and has been one of the most impressive single transport infrastructure projects in the history of the US. However the job has not been free from controversy. Costs spiralled during construction far above the original estimates and even though the tunnels are brand new, leaks in slurry panels in some sections resulted in the need for repairs.

But in Boston the benefits will be enormous as the previous elevated road link was badly congested, with a high accident rate. Moreover, the Federal Highway Administration (FHWA) has said that the Big Dig tunnels are structurally sound and remain safe for traffic and that the small percentage of slurry panels affected by low level leaks can be repaired, easily.

The project included innovative engineering solutions. The tunnel was dug directly underneath the old elevated expressway while it was still in use, requiring the installation of new temporary supports. The novel slurry wall technique was employed to underpin the elevated highway, while much of the excavating equipment used to dig out the tunnel was originally developed in Europe.

> **"GPS specialist Trimble is playing a key role in earthmoving through local distributor Ultimate Positioning, which has supplied 3D machine guidance and survey systems"**

Boston is by no means the only city to be benefiting from new underground road links. Work has already started on an urban road in Melbourne in Australia, while a road tunnel for Chile's capital Santiago is being planned. The proposed 10km six-lane tunnel will be a major project and is expected to cost some $150 million. The Vespucio Oriente highway is to start at the Grecia roundabout in the Peñalolén district and connect with the Ñuñoa, Providencia and Las Condes parts of the city, finishing at the Centenario Bridge in Vitacura, in the city's north east. Traffic congestion is a serious problem in Santiago as the city's population is growing along with the strong Chilean economy. The tunnel tolls will be collected electronically and it will connect with the city's existing Costanera Norte Vespucio Sur and Vespucio Norte Express urban highways, as well as the El Salto-Kennedy and Nor-Oriente highways under construction.

In Australia, work on the major A$2.5 billion ($1.9 billion) EastLink toll road project in Melbourne is well underway with Thiess John Holland acting as lead contractor on this three and a half year job. The work includes 2 million m² of road, over 80 bridges, 17 interchanges and twin 1.6km three-lane tunnels. The project is providing Melbourne with its second fully-electronic tollway and some 45km of freeway-standard road when it is complete in late 2008. Some 7.5 million m³ of dirt has to be moved, so the contractor is relying heavily on smart technology to deliver the project on time and on budget. Stakeless surveying is crucial and GPS specialist Trimble is playing a key role in earthmoving through local distributor Ultimate Positioning, which has supplied 3D machine guidance and survey systems. Thiess is using Trimble four NetRS and an SNB 900 radio network. However a wide array of Trimble tools is being including two BladePro 3D systems for graders, four BladePro 3D GPS systems for graders and four dual-antenna SiteVision systems for dozers.

Tools

Tunnelling technologies continue to evolve, right from drill and blast equipment and methodology though to support, communications, controls, lighting and repairs. Once a tunnel get the go-ahead for construction drilling and blasting (or continuous boring) provide the first stage of construction. The pace of development is particularly fast in drilling and blasting and Nordic firms such as Atlas Copco, Dyno Nobel and Sandvik, as well as it subsidiary Sandvik Tamrock, are among those leading the field.

Computerised drill rigs may have been around for some years but the newest models offer more accurate hole collaring, higher penetration

rates and vast increases in overall productivity. Advanced controls allow high levels of automation, with rigs capable of drilling a whole pattern on automatic. More powerful drifters have further helped increase performance, though this advance has exposed the limitations of conventional drilling components.

However a Korean contractor used new drill rod technology, developed initially for the mining industry, to boost productivity on a difficult tunnelling job. The firm, Sung Bo Development, says these drill components lasted 30% longer than standard units in the difficult, fragmented rock. Sung Bo says that by switching to Sandvik's recently introduced Alpha tools, gooseneck failures in the rods were eliminated.

The 2.3km long tunnel is part of South Korea's new Pyeoungtak-West Ansung Highway 40, from the port of Pyeoungtak. The road runs parallel to the heavily congested Highway 50 some 20km to the north and the new link will reduce congestion as traffic flow will be split equally. The first 32km has already been completed, stretching from the interchange with the north-south Highway 15 some 50km south of capital Seoul and crossing the north-south Highways 1 and 35. Work is now underway on the remaining 32km between West Ansung and Eumsung.

Sung Bo's Section 7 contract includes the 1,150m western portion of a 2,300m tunnel, with NanSun Construction building the eastern end of the tunnel. Section 7 also features three elevated bridges and rises steadily from an average altitude above sea level of around 150m at the Highway 15 interchange.

Both contractors faced difficulties in building the tunnel and Sung Bo's project manager, Mr Lee, said the poor condition of the black biotite gneiss rock was at the centre of these problems. As the rock is non homogenous, the contractors drove the twin dual lane tunnels, each 14m wide by 8.5m high, in two sections. Sung Bo first excavated the tunnel across a 12m x 7m high profile, then took a second cut that was 14m wide and 1.5m deep. The firm used a three-boom Sandvik Tamrock Axera rig with computer controls and fitted with the Alpha 330 tools for the job, having used this equipment successfully on an earlier project. Although the Alpha drill rods were developed for mining applications to cope with the extra power delivered by new generation rockdrills, these components are now being used in tunnelling too. The rods feature different joint profiles with bigger cross-sections and special guides to reduce bending and breakage problems seen on conventional R32 units when used with 20kW drills.

Using 4.9m long rod type T38-H35 Alpha 330, the system also gave clean, high quality holes and the firm achieved an average 4,000m/rod. The top profile design required 120 face holes, drilled to a depth of 2.2m using 48mm Alpha 330 bits. Each hole took around 1.5 minutes with the profile requiring some 80minutes to drill and despite the abrasive rock, Sung Bo said bit life was good. Contour holes at the outer edge were spaced 600mm apart, with the second line 800mm apart and line spacing of 740mm. Sung Bo did not use reamer holes and employed 14 V-cut holes at 60° angles to achieve optimum pull rate. Blasting was carried out twice/day, with each shot producing around 810tonnes of rock that needed 54 cycles of the firm's 15tonne payload trucks.

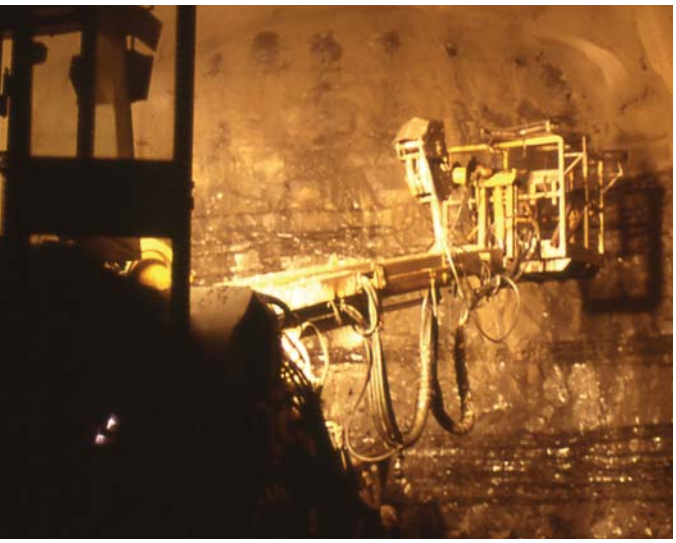
The fragmented nature of the rock meant shotcreting was required immediately afterwards for roof support. Only then could Sung Bo could drill the lower part of the profile in an operation taking some 30 minutes and producing around 180tonne of rock. Because of the weak rock, overbreak and underbreak problems were encountered and Sung Bo had to make extensive use of bolting and additional reinforcement bars. For each advance, the rig was used to place 16 x 4m long bolts across the profile.

Supporting the tunnel effectively is crucial, particularly in weak rock conditions. Bolting technology has advanced considerably, with Atlas Copco having made particular gains with its growing line of Swellex products. The well-proven Swellex bolts range was initially limited in the number of suitable applications but constant development has broadened the range, with new types suiting a huge array of duties. Broken and fragmented rock types or sites with high acidity can now be reinforced effectively using special types of Swellex bolts for example.

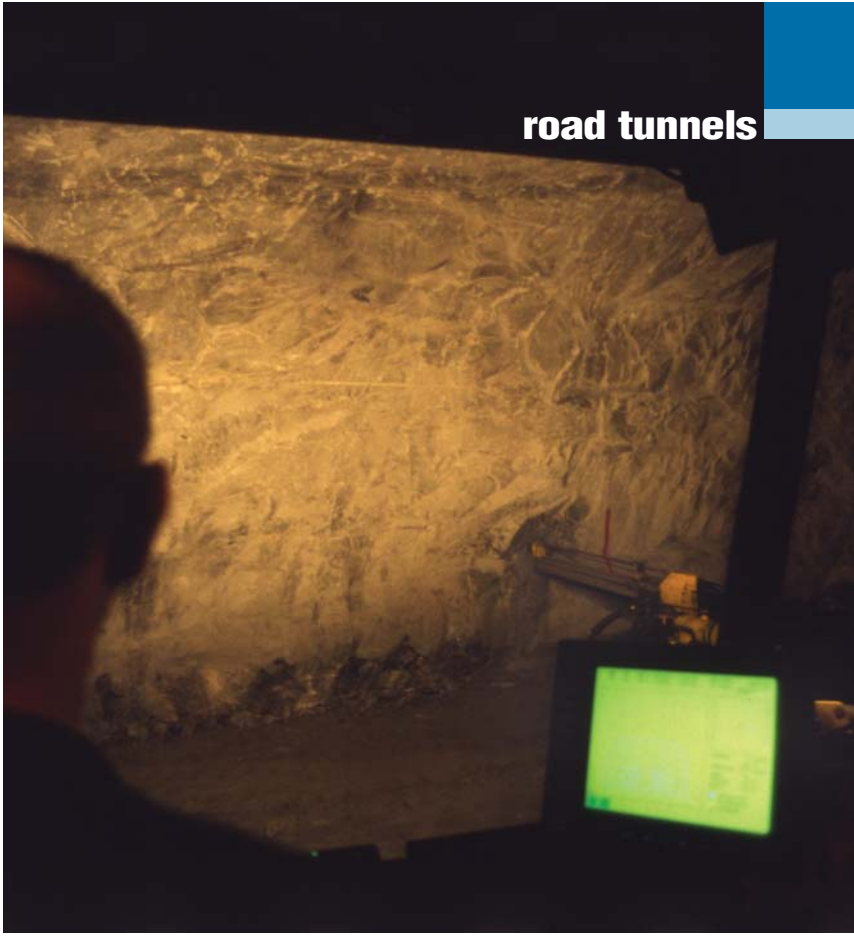
During tunnel construction formwork plays a key role and specialist Peri has supplied custom-tailored units to the impressive Lötschberg project in Switzerland. This is the third longest tunnel in the world and measures 15.74m wide by 12.54m high and World Highways will look at Peri's input into the Lötschberg Tunnel in greater detail next month.

Tunnel lining methodology has

New communications systems will boost safety for the Rotherhithe Tunnel



New drill rigs boost productivity



also advanced. Italian company FIP claims its Biblock system provides fast segment installation and is well-suited to use in tunnels bored with TBMs. Biblock provides precise segment location and is quick to use, in comparison with conventional connection technologies. Aligning the lining segments correctly is crucial to ensure the structure provides its maximum design strength and also to minimise water leakage. Compared with a conventional bolt connection, Biblock offers a smooth tunnel surface, minimal gap or offset and a reduction in segment cracking due to misalignment according to the firm. Because offset is reduced, smaller and less costly gaskets are used. As there is no need to screw or unscrew bolts, segment positioning time is reduced. FIP says Biblock the system can be used on tunnels with diameters up to 12m and has recently scored a major contract for an Italian tunnelling project. The contractor decided to switch to Biblock after work had started so the segment moulds had to be modified but FIP says its technology will still deliver major cost savings.

Once a tunnel has been constructed, lighting and safety systems have to be installed and these can also be retrofitted to update existing tunnels. The Idris incident detection package offered by Diamond Consulting provides a smart, low-cost solution that boosts safety standards, particularly in tunnels where space is limited. By installing the Idris system, emergency services can receive immediate alerts that the tunnel has an obstruction, whether through a crash or breakdown, and this technology also minimises the risk of additional incidents.

Bolting is crucial for roof support while computers in the cab improve accuracy

> **"The algorithm that detects a stopped vehicle requires high quality data"**

Based on proven technology, Idris can detect single stopped vehicles anywhere in the tunnel and is said to be just as effective whether there is heavy congestion or free-flowing traffic. Idris uses outstation units to collect and process data from inductive loops, which then indicate hazards such as slow-moving traffic, a single slow or stopped vehicle, queues or vehicles travelling in the wrong direction. The algorithm that detects a stopped vehicle requires high quality data as it depends on accurate counts and vehicle identification. The system uses data from one outstation to predict when a vehicle will arrive at the next and if it fails to arrive when predicted, an alarm is raised. With such predictions made for each vehicle at each outstation, identification and correlation is critical to minimise risk of false alarms.

Diamond Consulting says Idris features accurate detection technology that can distinguish between vehicles straddling a lane and two vehicles side by side. The system can also differentiate signals generated when a large vehicle is alongside a smaller one, or between vehicles that are tailgating or towing. The system is based on RS485/Ethernet technology and features a maximum cable distance between stations of 500m, using 2m square loops placed in pairs 2-2.5m apart and with each pair located 80-200m apart.

Tyco Integrated Systems has supplied sophisticated technology for the Rotherhithe Tunnel in London that provides a radio-based public address system. This is the first time DAB digital radio has been fitted in a UK tunnel. In addition to its loudspeaker function, the technology can also broadcast emergency messages over car radios, as well as providing radio coverage for emergency services, tunnel maintenance crews and London buses. The radio network also provides mobile phone coverage to help with breakdowns and incidents, while automatic monitoring ensures reliability.

The system can cut in to car radios, whether they are tuned to AM, FM, LW or DAB channels and Tyco reckons this may be the first application of such re-broadcast, emergency break-in technology anywhere in the world. The network broadcasts through 21 analogue stations and all DAB stations throughout the tunnel, over-riding any radio in use. The loudspeaker system means that pedestrians, cyclists and people who have car radios switched off can also hear either pre-recorded or live messages.

Because the system supports mobile phone use it can speed breakdown or accident response and its compatibility with the radios used by emergency services, bus companies and maintenance crews boosts its effectiveness. Meanwhile automatic monitoring increases reliability and allows speedy maintenance if required.

Quixote's Nuart Lighting subsidiary has supplied its latest fluorescent or low-pressure sodium lighting systems to major US tunnelling projects including the Big Dig in Boston and more recently, the new Eisenhower Tunnel in Colorado. However, the firm continues to develop its technology and says it has just completed the design work for an advanced tunnel lighting package based on induction lamp technology. The firm says this system is extremely well-suited to tunnel applications as it provides a powerful white light as soon as it is switched on, while lamp life is up to 120,000hours. Safety is maximised due to the rapid lighting effect, while the induction lamp system is also very durable and can be switched on in extremely low temperatures without problems. Because it features no electrode, the lamp system is rugged and resistant to vibration damage and is said to offer 50% of its lumen output at 120,000 hours. The units are available in ratings from 35-125W and can be fitted with multiple lamps in each fixture depending on the application.

Holding on

Tunnel structural integrity has to be maintained too and UK firm Resitech has provided an effective sealing solution for the Limehouse Link Tunnel in London. Water ingress into tunnels is a problem in London, due to the rising water table as well as the shrink and swell of the clay-like soil caused by rain, settlement and compaction of alluvial deposits. If this shrink and swell is not controlled effectively, damage can occur to tunnel structures. The Limehouse Link, opened in 1993, is one of many tunnels under London that have had to be modified.

Although attending to these is a normal part of tunnel maintenance, contractors have to minimise costs by ensuring there is no need to tackle repairs more than once. Specialist Resitech and the tunnel operators developed a localised solution to the leaks, with a repair programme implemented where required in line with routine maintenance. This novel process seals existing pathways and prevents water ingress using a combination of accurate assessment and diagnosis, careful selection of appropriate resins and water reactive gels, and the use of advanced injection techniques.

However, there is no standard technique for application. The method of injection, drill pattern and material selection depends on the conditions. Surface leakage at the crack location is generally sealed using quick setting hydraulic cement and 12mm holes are then drilled through the concrete at 1m spacings and at an angle of around 45° to intercept the joint. Next, the holes are countersunk to 50mm and the injection lances are inserted. Resin is then injected and mixes with water present in the crack and forms a homogenous acrylic flexible gel. Packers are then removed and the remaining holes filled with a polymer modified cementitious concrete repair material. According to Resitech's sealing expert Mike Guy, this can offer an effective solution for many applications where ground water is causing water ingress ■

Efficient lighting boosts safety, with modern systems also proving cheaper to run

Dellux lighting package offers greater safety

Canadian firm Dellux Technologies reckons its LED-based Intelligent Tunnel Lighting package offers greater safety than earlier systems. The lights are monitored remotely by computer, with the controller able to examine the network section by section using a web interface to highlight problem areas.

According to Dellux, there are several reasons why LEDs are more cost-efficient than previously available lighting. The LEDs draw anything from 40-80% less electrical power than conventional fluorescent or sodium lights Each LED uses around 32W, while a standard HPS lamp will use some 150W. Component life is also said to be long with Dellux claiming a maintenance-free, 15-year/130,000hour average working life for the LED units. Even when the LED units fail, they are cheap, non-toxic and can be disposed of easily, with replacement taking little time. Running costs are predictable while the simple wiring and uniform light levels generated (even in case of power failure), make maintenance easier and improve safety. The computer control can identify when individual LEDs fail, though Dellux says the units are durable and resistant to moisture, huge changes in temperature (as well as the freeze-thaw effect) and high salt levels. Compared with conventional lighting systems, Dellux reckons its LEDs offer a fast return on investment. The firm has developed a software package that can model a system layout and show how its LEDs will reduce running costs.

One of the first applications was for the Atwater tunnel in Montreal, a twin-bore cut and cover tunnel running over 200m beneath a canal in the southwest of the city. Completed in 1929, the tunnel was fitted with available fluorescent lighting technology at that time and re-equipped with a more modern HPS system in the 1980s. The HPS system provided good service but when it came due for replacement the city engineers opted to use Dellux's LEDs. The performance of this installation matched expectations so the city opted to use Dellux's LED technology for the 220m long Saint Marc and du Fort tunnels and also plans to use the system on the Saint Remi tunnel, while a client in Norway is now installing the LEDs as well.

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