Active or Passive?

Could the combination of passive and active fire protection measures lead to better value solutions for road tunnels? Kristina Smith reports.

Top right: PassiveTec fire protection boards installed by BAM Nuttall and BBV at Heathrow Airport's main road tunnel.

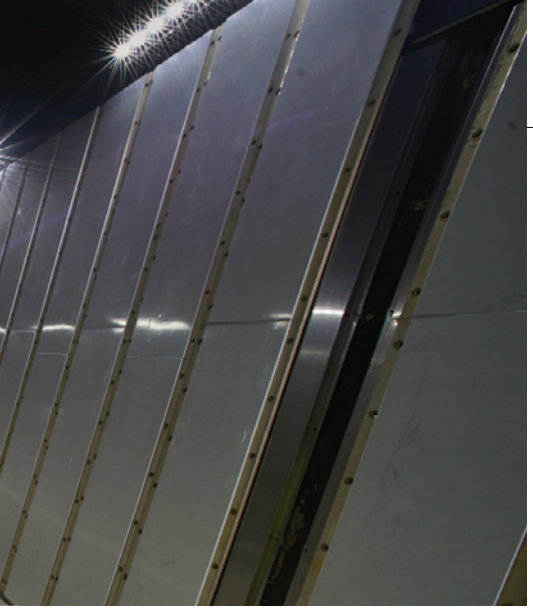
Middle right: Fogtec installation at the Dartford Tunnel

Below: PassiveTec installed at the Tåsen Tunnel in Norway

THE RUNEHAMAR ROAD TUNNEL in Åndalsnes, Norway, has been the scene of several major fires over the last 15 years. While some have been controlled by fixed fire-fighting systems (FFFS) others have burned on, reaching temperatures of almost 1400°C.

These fires have been no accident, however. The Runehamar tunnel is disused and the fires are experimental ones, aimed to give insight into how fires in road tunnels behave and how they should be tackled.

Some of the latest tests have been carried out on behalf of the Swedish Transport Administration which has been developing a new valve to fight fires on the Stockholm Bypass. Currently under construction, the bypass runs underground for 18km of its 21km length and with heavy traffic expected, an un-



checked fire could spread fast from vehicle to vehicle.

Active systems, such as water spray and mist systems are relative newcomers to the tunnel designer's arsenal of fire protection measures in most parts of the world. They can control or suppress a fire, allowing people time to escape and allowing fire fighters safe access. They can also allow the designer to downsize ventilation and passive requirements, although this is a point of some contention.

"The big question at the moment is how can we consider reducing fire sizes and proposals to trade off other critical systems," says Paul Sparrow, global support manager, tunnels, at Promat. "But active systems should be an addition to passive ones, not as an opportunity to reduce passive protection. Designers should design for tomorrow not today, by using current worst case scenarios, not looking to try to reduce the size of fires."

The latest guidance on fire protection relating to refurbishment of existing tunnels from Working Group 6 of the International Tunnelling and Underground Space Association (ITA) – covered on pages 43-47 – ducks this questions altogether. It is titled 'Structural Fire Protection for Road Tunnels' and sticks firmly to that brief, saying nothing about the interaction of active and passive systems.

"It was a lost opportunity to address these issues: do we really need that much passive fire protection or not," asks Dr Fathi Tarada, managing director of specialist consultancy Mosen. "The issue of cost versus being safe is always there. That gives us engineers a challenge that means we cannot always go down the prescriptive route. We have to develop new ways to optimise things, and look at whether the investment in safety has provided the right benefit-to-cost ratio."

Life and livelihood

Fire in road tunnels are not a rare occurrence – they happen often and are dealt with safely and effectively. Serious fires are rare, but when they do happen the impacts can be devastating in terms of loss of life and connectivity.

Such events can act as a catalyst for tunnel owners and engineers to re-examine their approaches to fire protection, control and management systems. The infamous Mont Blanc Tunnel fire in 1999, and another one later that year in the Tauern Tunnel in Austria triggered a raft of testing – including tests in the Runehamar tunnel – and work on various guidance documents.

Tunnel owners and insurers are also looking beyond the initial capital cost to assess what the wider costs of closure would be. For instance, the Swedish Transport Agency has calculated that every time they close the South Link in Stockholm it costs society €70M a day.

Passive measures, such as boards and spray-applied materials, are the most established and understood means of fire protection. Promat has been involved in tunnel fire protection since the 1960s, according to Sparrow, and has fitted its board systems in over 300 tunnels. Promat also supplies sprayed protection, having joined forces though acquisition with Cafco International ten years ago.

Promat's biggest current project will see it supply a massive 330,000 sq m of Promatect-H board to the immersed tube tunnel sections of the Zhuhai to Macau link which will link Hong Kong and China. "That's equivalent to around three years' normal activity in one project," says Sparrow.

Refurbishment projects account for an important – and growing – proportion of Promat's workload. "We are seeing more and more refurbishments coming on stream," says Sparrow. "When tunnel owners are looking to replace ventilation and lights and upgrade other things, they are beginning to incorporate fire protection where they previously had not done. There is a growing global awareness that fire protection in tunnels needs to be addressed, principally because of the high-profile disasters we have seen."

The growing awareness and market means that new passive protection suppliers are emerging, hoping to steal a slice of the pie from Promat, which has somewhat dominated the market. One new brand is PassiveTec, owned jointly by SIG and PFP Group, which came to the market in 2014.

"We are providing better fire insulation with a thinner product," says Iain Giffen, business development director at PFP Fire Systems. "We had to take a different approach, we're battling against a 20 or 30-year legacy. We offer a better value proposition with better fire protection and a better margin for the contractor. That's our niche."

Giffen says that PassiveTec boards are betted suited to damp tunnel environments. They are made from fibre reinforced magnesium and allow water to pass through them, whereas the most widely-used calcium silicate boards absorb water.

However, Tarada explains that for calcium silicate boards, their absorption of water is integral to how they work. "We have developed a model for the movement of water and steam within passive fire protection boards themselves in order to work out their level of resistance," he says. "It's not the fact that these fire protection bards don't conduct heat very well, that they are good insulators, it's the fact that they have got a lot of water in them and

Road tunnel fires

Road tunnel	Date of fire	Brief description	Of note
Mont Blanc, Italy/France	1999	39 people died after a truck carrying flour and margarine caught fire, with the driver failing to notice initially. The fire burned for two days.	There was no fire protection in the tunnel and many of the deaths were due to people staying in their vehicles rather than going to refuges. The tunnel was closed for three years for repairs and upgrades.
Tauern, Austria	1999	12 people died and over 40 were injured when a truck ran into a queue of stationary vehicles.	The tunnel was closed for three months. Repairs included upgrades to the walls and ventilation system.
Gotthard, Switzerland	2001	11 people were killed when a collision between two trucks created a fire.	The tunnel was closed for two months for repair and cleaning. The number of trucks in tunnel is now limited.
Fréjus, France/Italy	2005	2 people were killed after a fire in a tyre truck spread to other vehicles.	A safety tunnel and connection cross-passages is currently being constructed at a cost of €408m
Burnley, Australia	2007	3 people died after multiple vehicles crashed into a stopped truck.	Deluge fixed fire fighting system limited fire to allow fire fighters in and safe evacuation of other drivers
Brynglas Tunnel, UK	2011	A truck caught fire causing extensive damage to the tunnel, although there were no fatalities.	Upgrade work, currently underway, includes tunnel lining and M&E repairs costing £40m

that's how they resist the heat flow.

"Magnesium oxide-based materials rely on the fact that they are such a poor conductor of heat," he adds. "One of their downsides is that they are very difficult to drill and cut – they can blunt your blades."

Working for Heathrow Airport, BAM Nuttall, BBV and Mott MacDonald are using 24mm PassiveTec tunnel liner boards on the refurbishment of the main road tunnel at the airport. The work, which is taking place with some night-time tunnel closures, includes upgrades to the ventilation, FFFS, detection and alarm, electrical and fire mains as well as the fire protection element.

The modular sandwich panels, which BAM is installing in a framing system on the walls of the road tunnel, have undergone independent testing to RWS 120. RWS is one of a number of time-temperature curves which was developed by the Netherlands' ministry of transport, the Rijkswaterstaat, as a result of tests carried out in 1979.

The RWS curve, which is referred to in current guidance documents, is based on the heat that would come from a fire in a petrol tanker in an enclosed space. The temperature of the fire rises quickly to reach 1350°C after 60 minutes, falling to 1200°C at 120 minutes.

PassiveTec boards have also been installed in the Tåsen Tunnel in Norway. The panels were cut to size and coated off site.

"Norway is one of the countries where we are concentrating our efforts because there are over a thousand tunnels, all of which have to come up to EN standards before the end of 2025," says Giffen. "They all have to be upgraded, not just for fire protection, for signage and protection of services too." PFP and SIG are also pursuing projects in Asia, the Middle East, North America South America and Australasia.

Sparrow, who was a primary contributor to the ITA Working Group 6 document, highlights the fact that the group's new guidance warns against the use of magnesium oxide boards. The guidance states that 'magnesium oxy-chloride materials' which it says are also known as 'fibre reinforced magnesium' and 'magnesium oxide, silicates and other additives' contain chlorides and that these can be detrimental to durability and to life safety in the event of a fire.

The rise of water

It has taken a long time for the US, Western Europe and elsewhere to reach the conclusion that Japan did 40 years ago and Australia more recently with respect to FFFS. That is that water spray and mist systems limit the impact of a fire by lowering the temperature and/or preventing it spreading as far.

Water spray systems tend to work at lower pressures, typically less than 12 bar, producing larger water droplets. Mist systems operate at over 35 bar and produce smaller, higher volume drops.

Very broadly speaking, water spray systems tend to operate by cooling and wetting fuel surfaces whereas mist works on the gases of the fire. The available space, water volume, size and use of tunnel all impact on what is the best choice of system.

PIARC, the world road association, has moved gradually from a position in 1995 where it said that sprinkler systems should not be used in tunnels – citing problems such as the danger of steam and impacts of water on smoke – to a position today where it recognises their use. In 2008 it published 'Fixed fire fighting systems in road tunnels: current practices and recommendations', a document it updated in 2016.

"PIARC have changed their view from a rather negative one in the 1990s to being really positive in the latest edition," says Armin Feltmann, business manager – tunnel systems for Fogtec.

As well as recognising the impact of FFFS on protection of life, the 2016 update recognises that active systems can enable a reduction in passive systems. In Section 3.5 on asset protection, the PIARC document says: "FFFS may be considered as a compensatory measure in fire-engineering design. It is recognised that passive measures are normally considered to be the most reliable, nevertheless, in some circumstances, it may be possible to reduce the level of passive fire protection."

In the US, the National Fire Protection Association (NFPA) has also changed its stance on FFFS. In the 2014 edition of its guidance document NFPA 502 'Standard for Road Tunnels, Bridges and Other Limited Access Highways' information on fixed systems appeared in the appendix and in the latest edition, issued in May last year, there is a whole chapter devoted to the subject.

The latest NFPA 502 says that the effect of fixed water-based fire-fighting systems should be taken into account when sizing ventilation. And it says that such systems can be taken into account with respect to structural protection, if there is appropriate evidence and if approved by the relevant authority.

For Fogtec, refurbishment is a growing sector: "For tunnel refurbishment projects, there's a tendency more and more to go to active fire protection systems," says Feltmann. "With FFFS, you can easily upgrade the fire safety standard of a tunnel with limited investment and only very minor interruptions to traffic during installation. In some cases, the insurance costs for tunnel operators can be reduced significantly."

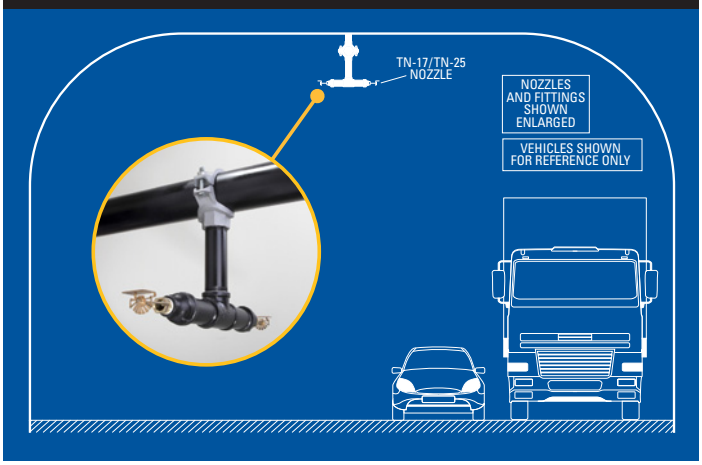
With more and more projects, FFFS keep developing, says Feltmann. "The technology is improving constantly, we learn from each and every project we are doing."

For instance, Fogtec has developed a system which can remotely test the section valves which separate the various sections of the mist systems along the tunnel's length. This remote testing capability has been installed in several tunnels including the Dartford Tunnels on the M25, East of London, which were upgraded in 2011-2012.

For the Dartford Tunnels, the water mist system was integrated into a SIL2 (safety integrity level 2) certified tunnel control system, which made it the world's first SIL2 FFFS, says Feltmann.

Currently Fogtec is installing a water mist system into the Tunnel Wald in Austria. "The main reason for its installation there is to protect the infrastructure and to keep the highway running," says Feltmann. "It carries one of the main North-South highways which connect Germany to Slovenia."

Tyco Nozzles designed by Johnson Controls



The Swedish experience

The construction of the Stockholm Bypass has triggered an extensive research and development programme by the Swedish Transport Authority, Trafikverket.

The main goal of the programme was to develop new nozzles for deluge systems, with a view to specifying them for the Stockholm Bypass and other planned projects such as the Göta Tunnel in Gothenberg. That goal has been achieved, with a system that is effective and costs around one-third of the cost to install, when compared to standard deluge and mist systems.

The work, carried out jointly with research body Science Partner (SP) – now Research Institute of Sweden (RISE)) - included two series of large-scale tests in the Runehamar tunnel. The first tests in 2013 looked at TYCO TN-25 nozzles, designed by Johnson Controls (formerly Tyco Fire Protection Systems), based on a design by consultants Brandyskyddslaget

– which in turn were based on Tyco's existing SW-24 open sprinklers.

The TN-25 is a horizontal spray nozzle with a wide opening; it has a K-factor of 25.2 (K360). The K-factor describes the flow rate through the nozzle.

The 2013 tests mimicked the sort of fire you might expect from a fuel tanker and the aim for the water system was to keep the heat release rate below 50MW and to prevent the fire spreading to a target 5m away from the main fire. The nozzles were positioned back-to-back, suspended from the centre line of the tunnel ceiling at 5m intervals.

The 50MW value is the level below which the Swedish fire fighting teams can enter the tunnel to perform search and rescue and manually fight fires. The TN-25 performed well, easily beating the target.

The 2016 tests were set up in the same way as their predecessors but this time the researchers were looking at the TN-25 with lower water pressure, a smaller version called the TN-17. Johnson Controls' existing SW-24 sprinkler was also put through its paces.

The SW-24 has been installed in Sweden's Northern Link, since the tunnel was designed before the findings from this research which meant that an existing product had to be specified. Recently it was activated successfully during a car fire of around 5MW.

The second tests set a lower target of 30MW for the heat release rate. All the nozzles met the targets, the TN-25 being the most effective and the SW-24 the least. One interesting point to note was that the TN-25 with lower water pressure worked better than when higher pressure was used.

"The smaller pressure leads to bigger water droplets which means there is a better impact on fire," explains Arjan Ten Broeke, Johnson Controls' business development manager for water-based systems, Benelux and UK. "We were able to meet the goals of the test and prove that with reducing the amount of water and pressure on nozzle, we got better results on the fire."

The TN-17, says Henrik Johansson, Johnson Controls business development manager for Nordic countries, will be useful in longer tunnels or in situations where water supply is limited since it requires a lower flowrate than its sister. "If you have wider tunnels, the TN-17 will flow further than TN-25 and it can also be set to discharge less water per nozzle."

For all types of FFFS, early detection and activation is essential if the fire is to be suppressed or controlled. In the tests, the activation of the systems was delayed. First, the researchers waited until the temperature of the fire reached 141°C, which took around four minutes, and then delayed a further four minutes before activating the nozzles.

In a 'live' situation, the detection system should set the nozzles into play much sooner. Johnson Controls would recommend a laser cable detection system, such as its ZETTLER MZX SensorLaser Plus, because the laser is very accurate and not affected by wind. Water flow and pressure to the nozzles is also important; Johnson Controls uses its deluge valve DV-5 which can be reset remotely after being activated.

Photo showing full scale fire test carried out by Mosen used to verify its 3D computational fluid dynamics modelling in developing the MoJet vent system

From an investment perspective, the new nozzles have advantages over existing systems, largely due to the fact that Johnson Controls has designed them to operate from the same pipework that feeds the hydrant systems for fire fighters. "With TN-17 and TN-25, we have reduced the installation costs of the system by between 70 and 75 percent compared to traditional water-based systems by using less pipes and different type of pipes," says Johansson.

According to Johansson, calculations from Trafikverket put the capital cost for systems using the TN-25 nozzle at €500,000 per km, compared to €1.5m to €2m for high-pressure water mist systems and €1m to €1.5 m for traditional water spray systems.

The first tunnel to benefit from the development of the new nozzles is the Rantatunneli tunnel in the city of Tampere in Finland. The 2.3km tunnel, Finland's longest toad tunnel, opened in late 2016 and has Johnson Control systems which features the TN-25 nozzles.

Standardisation

A lack of standards for fire protection, in terms of both requirements and testing, is seen as one of the biggest challenges in this market. Although PIARC's guidance is well-respected around the world, it is only guidance – rather than a standard.

Sparrow hopes the new ITA document, which he says was peer-reviewed by PIARC before publication, will create some clarity, highlighting the link it makes between temperature curves and heat release rates: "Different engineers use different measures in their specification. Some reference heat release rates, some use time temperature curves, but there has never been a connection between the two before. If the specification asks for fire protection to meet a 50MW fire, what time temperature curve is that?"

We need more research and guidance related to FFFS, and how they interact with other systems, says Johansson. "Test protocols differ for each manufacturer and system as there is no globally recognised standard," he adds. "This makes it difficult for tunnel owners to compare systems, as well as the trade-off with passive fire protection measures."

Firms such as Mosen are using advanced 3D computational fluid dynamics (CFD) modelling and computation to look at tunnel systems in their entirety. "It's a bit of a tall order but you have to get the picture of the whole tunnel, all at the same time," says Tarada. It used this approach, verified by full-scale testing, to develop its MoJet ventilation system.

Sparrow cautions against a reliance on modelling and calls for better full-scale testing. "Don't try to be clever with CFD modelling to say fires are not as hot as they used to be because we don't know," he says. "Most testing conducted on FFFS is with pool fires - fuel on a tray - or single vehicles. We need to be more accurate in our full-scale testing, not run the risk of becoming too heavily reliant on desk top modelling."

Giffen thinks that testing is vital, particularly where high-strength concrete is involved. "If I could make one change it would be to require full-scale tests on concrete samples on every single project because of spalling in new types of concrete – 55MPa and higher – which spall at lower temperatures," he says.

Testing, of course, adds to the capital cost of fire protection. So we come back to the question of cost versus benefit. This is a dynamic subject, which can only become more so with the advent of autonomous and semi-autonomous vehicles and connected cars; these can only reduce the risks due to erratic driver behaviour during incidents.

If we want to see more roads going underground, reducing congestion and air pollution in urban areas, belt-and-braces solutions do not help make the economic case.

"If you make tunnels unattractive because they are far too expensive to construct and maintain, you will clog up the surface routes, potentially creating additional safety and environmental risks, and hinder economic progress," says Tarada. "We don't have fires every single year and those that affect the structure are even rarer. We have to account for that."