The future for fire protection

The world of fire engineering is always changing. TJ asked a group of industry players what new challenges they are now facing.

In June this year, a hydrogen refuelling station just outside Oslo in Norway exploded. The cause of the blast was later identified as a leak due to an incorrectly mounted plug in a high-pressure hydrogen tank.

Over in Los Gatos, California, in December last year, a Tesla Model S car caught fire at a tyre repair garage and was extinguished by fire fighters. Hours later, while being transported to a tow yard, the car re-ignited, one of many such incidents reported in the US.

Though dramatic examples, these incidents underline the ever-changing landscape faced by those responsible for fire safety in tunnels. "The biggest challenges we face as safety engineers are the increasingly complex interfaces," says Dr Marco Bettelini, director for ventilation and safety at Amberg Engineering. "We have changing technology, users whose needs evolve over time, costly maintenance and operation, fire-fighting teams and growing public concerns over the environment and pollution."

We asked fire engineers and suppliers of fire protection and ventilation equipment what emerging challenges they were encountering. A growing emphasis on environmental impacts is already evident; concerns over new energy carriers (NEC) for vehicles are looming fast; and, on the flip side, digital technologies offer opportunities to improve operation and safety in tunnels.

FlaktGroup fan in the factory

Environmental demands

"It's not a step-change, but there is definitely a firm move towards more efficient solutions in countries such as Singapore," says Paul Wenden, director, tunnel & metro at FläktGroup. "That does require a lot of work on our part, because there's a conflict between efficiency and the other performance requirements for a fan."

FläktGroup supplies fans to both road and metro tunnels around the world. Recent projects include Riyadh Metro, the Thomson-East Coast Line in Singapore and Sydney's North Connex road tunnel.

In metro tunnels, the role of fans is largely to remove excess heat created by the trains; in road tunnels, they provide fresh air and smoke management. But the fans must also be capable of operating under very high temperatures in the case of a fire and they must be reversible to cope with different potential fire locations within a tunnel. These latter capabilities tend to decrease the fans' efficiency.

"We have been working on the development of our impeller geometry to create the best possible compromise," says Wenden.

Impeller geometry, with a combination of static and rotating parts, is also under scrutiny in the bid to reduce noise levels, which is a growing requirement for road tunnels. "The traditional approach is to add a silencer or attenuator to the end of fan," says Wenden. "But then they get longer and longer. We are looking at more integral solutions where you attenuate the noise at source."

Such changes produce marginal rather than dramatic noise reductions, says Wenden, but are useful never-the-less.

Dr Fathi Tarada, managing director at specialist consultancy Mosen, also reports an increasing interest in energy efficiency and sustainability. "It's a global trend, although the application is very uneven," he says.

Mosen developed its MoJet technology, which produces more thrust with less power, in response to this trend, says Tarada. The MoJet combines a conventional jet fan with shaped silencers which direct the fan's flow towards the tunnel centreline, preventing some of the thrust being lost as the flow drags along the tunnel wall.

Researchers found that conventional fans fitted with MoJet silencers installed in the Montgomery

Tunnel in Brussels, which has undergone a repair and upgrade programme, produced twice the thrust of fans without them, says Mosen. Université Libre de Bruxelles carried out the research on the MoJet silencers which were fitted to fans from FläktGroup.

A focus on lifetime costs and impacts has led Promat's development of a new generation of Calcium Silicate Board, which was launched earlier this year at the World Tunnelling Congress in Naples. The PROMATECT® TF-X board, as well as meeting requirements under international fire curve tests, has additionally been designed to cope with extreme climatic conditions.

"We already have products that have high performance in a fire situation, but we wanted to address long-term durability too," says Paul Sparrow, head of tunnels at Promat. "These boards are completely inorganic so they won't degrade. They can survive water ingress and freeze-thaw cycles. And, unlike active systems, they do not require power, water or human intervention to operate."

Whereas a tunnel may expect to be refurbished four or five times over a 100 or 125-year lifetime, PROMATECT® TF-X boards won't need to be renewed at all, says Sparrow, as long as they aren't disturbed or damaged, significantly reducing whole-life maintenance costs.

New vehicles, new risks

How do you design a tunnel that will be in use for 100 years, when it's not clear how the vehicles using it will be powered? "It is very difficult," says Armin Feltmann, business manager – tunnel systems, for Fogtec. "The number of vehicles with new energy carriers is increasing and that means that the fire loads and the fire risks are changing. It will have a big impact on how we manage fire safety in tunnels."

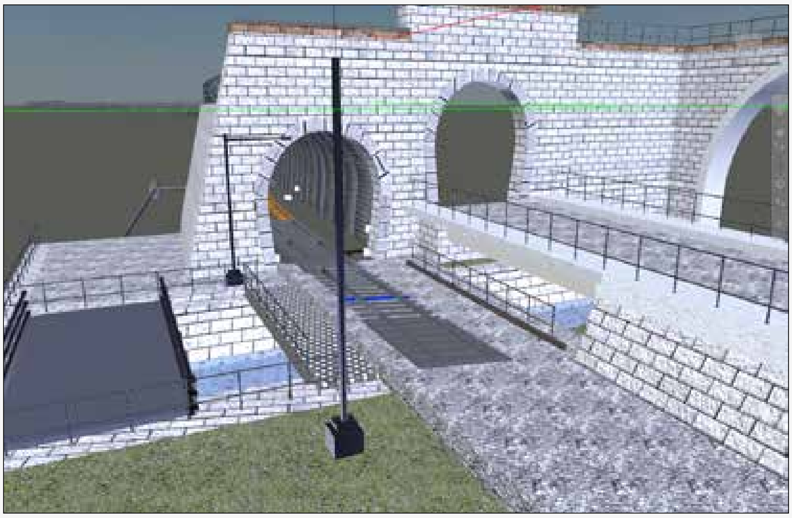
As well as the risk of reignition, lithium-ion batteries can experience thermal runaway where they release all their energy at once. This can lead to very high temperatures, up to 400 degrees C. Such fires also release toxic gases, even before the point of ignition.

For fuel cell electric vehicles, the biggest risk comes from hydrogen leaking from the highly-pressurised tank, either through a valve or due to damage. Hydrogen ignites easily, even at low concentrations, and burns with a flame that is difficult to see.

Uncontrolled escape of gases is also the biggest potential hazard for vehicles that run on natural gas such as CNG (compressed natural gas) or LNG (liquid natural gas). With the presence of a spark or fire, experts warn that this could lead to explosions.

Current fire safety regulations and guidelines for road tunnels were created after a series of terrible fires in the Mont Blanc, Tauern and Gotthard Tunnels at the turn of the century. "Those fires changed our way of thinking in road tunnels," says Bettelini who worked on the reconstruction of the Mont Blanc and Gotthard tunnels. "These tragic incidents urged us to develop new concepts, systems and scenarios to permanently improve the safety of tunnels. It was a time of learning for the whole tunnel safety community."

However, fire engineers don't want to wait for catastrophic fires before they formulate new rules to cope with NECs. A number of research projects are underway, including Suveren (Safety of City Underground Structures).



Top: The MoJet system in side view

Below: Amberg Engineering has worked on specific software using digital modelling of infrastructure

The Suveren research project, led by Bundesanstalt für Materialwirtschaft (BAM), Studiengesellschaft für Tunnel und Verkehrsanlagen (Stuva) and Fogtec aims to assess the risks that NECs create and propose ways of mitigating those risks. As well as carrying out a series of fire tests, researchers will develop models, new standards and regulations and training programmes for tunnel operators.

Suveren carried out fire tests with lithium ion batteries and CNG flames earlier this year and looked at high-pressure water mist for supressing thermal runaway. An initial release reported that "within the testing environment, the thermal runaway of the tested lithium ion batteries could be suppressed by high-pressure water mist". More detailed analysis of the tests is expected later this year.

Other organisations are looking at this issue too. February this year saw a joint meeting of the ITA COSUF, which looks at the operational safety of underground structures, the world road association PIARC and the Knowledge Platform for Tunnel Safety (KPT) of the Netherlands to look at the issue of new energy carrier vehicles.

One of the conclusions of the meeting was that more data on the thermal loads of fires with NEC vehicles was required, as well as information on the NEC vehicles themselves.

Digital opportunities

Though new technology for energy sources is causing headaches, advances in digital technology offer huge opportunities for improvements and optimisation, says Bettelini. Intelligent tunnel control systems will improve the interaction between different systems and help cope with human and technical errors.

"Ventilation design has already reached quite a high level of intelligence, but there is the opportunity to do much more with self-learning systems," says Bettelini. "In the future, control systems will have built-in digital tunnel models and will be able to control themselves in an optimum manner. There is huge potential, and the future is not that far away." Intelligent components, such as advanced sensors in jet fans that help monitor how they run, send alarms or maintenance messages, are also just around the corner, he adds.

Amberg Engineering is working on specialist simulation software that speeds up commissioning of software systems within a tunnel, by using a digital model of the infrastructure. "This means we can do the commissioning in less time with reduced pressure," says Bettelini.

'Digital twins' for new and existing tunnels will play a key role in the planning of maintenance, upgrades and optimisation of tunnel systems, says Bettelini. He would also like to see real-time information on fire development and smoke propagation in underground infrastructure, such as tunnels, provided to fire-fighters and other first responders in the case of an emergency.

"Advanced real-time simulation models could also provide forecasts for the most likely evolution of all the key safety parameters relevant for the intervention, with appropriate recommendations on the best possible strategies," says Bettelini.

Dutch infrastructure authority RWS performs fire tests in tunnels after laboratory tests produced surprising results.

In 2017, Rijkswaterstaat, the executive agency of the Dutch Ministry of Infrastructure and Water Management (RWS) made some potentially worrying findings about the concrete being used to construct its road tunnels. Although it had been tested back in 2000 and deemed to be 'non-spalling', the concrete did, indeed, spall when exposed to a fire according to the RWS fire curve.

In retrospect, performing only one fire test back in 2000 might have been too little to form the basis for new regulations, says Bart Hendrix, technical adviser, tunnels at RWS. "The concrete mixture that was used in the fire test was poorly documented compared to today's tests," explains Hendrix. He adds that a change in the constituent parts of concrete could be one of the reasons why spalling occurs today.

To find out whether any of its tunnels had been constructed from concrete that would show spalling in the event of a large fire, RWS embarked on a programme of testing, both in the laboratory and in existing tunnels. As a result, some tunnels might have to be retrofitted with passive fire protection such as boards or sprayed fire protection, and specifications for future tunnels will be revised.

A history of fire protection

Up to 1981, tunnels in the Netherlands were not equipped with any kind of fire protection. However, a fire in the Velsertunnel in 1978 which caused the loss of five lives, caused RWS to review its strategy. From 1981, all new tunnels were fitted with boards or sprayed fire-proofing and existing tunnels were retrofitted.


The RWS test panel before testing (left) and after testing (right)

In 2000, RWS commissioned a fire test to find out how the concrete being used in tunnels behaved in a fire. The test showed that there was no spalling, just surface damage of a few millimetres, and so RWS deemed it non-spalling concrete suitable for use in tunnel construction.

The mix, called ROK, was <C30/37 with no fillers, a water/cement ratio of 0.5, no fly ash and restrictions on the use of plasticisers. This specification allowed contractors to choose from a 'family' of mixes that met these constraints.

In 2015, questions about the fire performance of the ROK specification concrete started to arise. "On some tunnelling projects, both the contractors and our own project teams asked questions on the ROK requirements regarding fire safety," says Hendrix. "On top of that, an article was published in which a research laboratory showed that concrete according to ROK requirements did show spalling. After that, we decided to start a research program to verify the fire resistance of our standard concrete mixture."

RWS's testing programme, which started in 2017, saw test slabs with three concrete mixtures tested at three months and 12 months old. One mix aimed to mimic as closely as possible the 2000 concrete, one was a present-day concrete and the third contained limestone as a coarse aggregate.

Each mix was tested twice under RWS fire loading conditions with all six tests showing severe spalling. The limestone mix, which the researchers expected to behave better, actually showed the same severity of spalling as the others, possibly even worse.

Although it wasn't part of this test programme, Hendrix also reports that around one year later, fire tests on concrete containing polypropylene fibres were performed for a new tunnel and it appeared that this concrete mixture also exhibited spalling.

This test result came as something of a surprise: "We realised that the 'magic' formula of adding polypropylene fibres is not always safe," says Hendrix. The purpose of adding very small polypropylene fibres to mixes is to prevent spalling, since the fibres melt, creating space for the expanding water vapour.

Pierre Pimienta, vice head of the Fire

Continued

This is something that Amberg Engineering and other leading European institutions worked on as part of a European research programme called EMILI (Emergency Management in Large Infrastructure) which looked at how historic and real-time data could be used and reported during emergencies involving airports, rail and metro systems and further complex underground infrastructures. The programme ran in 2011 and 2013 with Amberg Engineering (through its subsidiary ASIT) working jointly with Fraunhofer on the development of iSEM, a simulation tool that helped work out in real-time the best response to underground emergencies.

"It was something radically innovative and powerful that we tried to push from proof of concept to a commercial implementation, but it was not yet the right time," comments Bettelini.

Digital technology, or rather social media, is also altering the behaviour of drivers and passengers. One of the speakers at the ITA COSUF, PIARC and KPT meeting remarked that people seeing a fire in a tunnel today might stop to take photos and videos, rather than flee as fast as possible.

These are interesting times for those specifying fire safety systems for tunnels, for operators and for first responders. The race is on to find new ways to deal with these new risks – and the funding to help develop them – before any major incidents occur.

Studies and Tests Division at French research organisation CSTB (Scientific and Technical Center for Building) sheds some light on the subject of spalling. He has been studying the phenomenon for the past 20 years, recently carrying out fire testing on the segments for the Ismailia and Port Said tunnels which run under the Suez Canal.

"Spalling is a very complex phenomenon. There are several mechanisms that are involved and several parameters to which spalling is sensitive," says Pimienta, adding that some have been quite well investigated and defined. "Others are less well understood because they are difficult to test for and the experimental research programmes are expensive."

Pimienta explains that the higher the following parameters are, the higher the likelihood of spalling: concrete strength, water content, compressive stress in the concrete and the temperature curve of the fire itself. Conversely, adding polypropylene fibres has been shown to reduce the risk of spalling.

In tunnels, the heat of a fire rises quickly due to the confined space. RWS' time-temperature curve is based on the heat that would come from a petrol tanker fire and shows the temperature rising steeply to reach 1350 degrees C after 60 minutes, falling to 1200 degrees at 120 minutes. In France, the model curve used in similar, says Pimienta, although the maximum temperature is 1300 degrees C. In Germany, the curve is a similar shape but reaches a plateau with a lower temperature of 1200 degrees.

Combining such a fire with high-strength concrete, high water content and a high compressive load raises the possibility of spalling, even with polypropylene fibres, explains Pimienta. And then there are other parameters: the cement type, the aggregate, the variation in mixes. The shape of the concrete element being tested - such as beam, column, slab or segment – also has a significant impact on spalling.

"With spalling, you must be very careful not to generalise from one result," warns Pimienta. "You need a lot of data before you can generalise."

New specification

Having made its discoveries in the lab, RWS's next step was to examine its existing tunnels to find out whether their concrete was at risk of spalling. Since there had been a flag raised in 2008, RWS focused on the four tunnels built since then, planning a series of in-situ tests to the RWS fire curve using a mobile furnace.

"After a study on the different concrete mixtures used in the tunnels, the presence or absence of fireproofing, the compressive stress in the cross-section, we chose locations for a fire test," explains Hendrix.

First the concrete was tested as it was. If spalling occurred, a further test was carried out with a dummy fire protection board, measuring the temperature of the concrete behind the board.

"We chose the thickness of the dummy board so that spalling would occur within the required fire resistance time, either 60 or 120 minutes depending on whether a tunnel is located under open water or not. The interface temperature at which spalling occurs is then an input value for the design of the repair measure, which is then tested in a verification test," says Hendrix.

To date the four tunnels built since 2008 have been tested. "The results did not make us happy, it became obvious that repair measures are required for these tunnels." says Hendrix. At this moment repair plans for these four tunnels are being developed.

RWS is thinking about formulating future specifications regarding fire safety in tunnels and is considering two options. The first option is to test concrete mixes for a project before construction to find when spalling occurs to inform the fire safety design. The same mix, with exactly the same constituents, would then have to be used for the entire project.

"That's quite a hurdle for contractors," says Hendrix. "They have to run the tests and find a supplier who can commit to delivering huge amounts of the same concrete, with the same sand, gravel and chemical additives, maybe for a number of years."

The second option could be to specify fire protection – boards or sprayed – which prevents the surface of the concrete reaching a temperature where water vapour, and hence spalling, occurs.

"That means that suppliers only have to test the performance of their products once every so many years to ensure that their products still meet the thermal insulation requirements to insulate to a certain temperature on the non-fire side," says Hendrix. Contractors could then choose a solution which is the most suitable for the project regarding fire safety, time and costs.

Part of RWS's ongoing work will be to determine the best options for passive fire protection in new – and existing – tunnels, a similar exercise to the one that took place in the early 1980s. "It's an insurance fee," says Hendrix. "If you need it, it's always cheaper to have installed it, rather than to build a new tunnel.