THE HAZARDS OF TRYING TO IMPROVE THE SAFETY OF TUNNELS

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ABSTRACT
In recent years a number of countries have updated their requirements for safety related equipment and facilities in road tunnels and, in 2004, the EU Directive set down minimum safety requirements for all tunnels on the Trans European Road Network. Manufacturers are also responding to this quest to improve tunnel safety by developing and marketing ever more products and systems and tunnel owners are equipping their tunnels with this latest technology.

But are all these safety-related products really improving the situation compared to the systems and equipment which have been used for decades? Are these products actually introducing hazards into the tunnel that increase the risks to tunnel users?

This paper will identify some of the many hazards which are introduced when safety facilities – both old and new – are installed in tunnels, attempt to identify why such massive investments are being made and question whether or not it is the best approach to improve tunnel safety.

Keywords: road tunnel, equipment, safety, hazards

1. INTRODUCTION
The majority of the safety-related facilities and equipment commonly installed in tunnels is concerned with reducing the consequences of fires. The EU Directive (Directive 2004/54/EC) and the design guidelines in many countries are requiring that yet more resources be invested, principally to mitigate the consequences of the fire incident even though it rarely occurs. Little or no investment is being required for either reducing the number of incidents or reducing the consequences of “normal” traffic incidents. This is despite the fact that both the number of casualties and the incident costs are significantly higher for accidents in a tunnel than they are for fires (Day 2003).

The inclusion of all these safety-related facilities and equipment brings with it additional hazards for the tunnel users. Contrary to the belief of some suppliers, equipment for improving safety actually introduces more hazards into the tunnel as is demonstrated below. Some of those hazards are identified for both old and new safety facilities; the approaches used to mitigate the hazards introduced by the “old” systems and facilities are described and those introduced by some of the latest systems and facilities are highlighted.

2. SYSTEMS

2.1. Fire Hydrant System
A pipe network leading from a reservoir to hydrants outlets distributed throughout the tunnel is one of the traditional systems that have been installed in many tunnels. Even this simple system introduces hazards into the tunnel but the associated risks have been minimised. The hydrant outlets are located in niches in the tunnel walls both to prevent them being a hazard to errant vehicles and prevent errant vehicles being a hazard to the hydrant system.
A mechanical failure in the system pipework could result in flooding but the risks from this hazard have been mitigated by sizing the tunnel’s normal drainage system to be capable of receiving any water released.

2.2. Fixed Fire Suppression

Deluge systems have been installed for many years in a number of road tunnels in Japan with the specific aim of protecting the structure. All road tunnels in Australia have deluge systems that are activated manually by the tunnel operator. In Europe and the USA very few tunnels have fixed fire suppression systems but that situation is changing. Systems are going to be installed in a number of tunnels including the A86 tunnel in Paris which is nearing completion, the second Tyne Tunnel currently being designed and the Dartford Tunnel when it is refurbished. The latter two tunnels are submerged tunnels and the need to protect the facility by protecting the structure is obvious. It is unclear when these systems will be discharged – immediately the fire is detected or, like in Japanese tunnels, after some delay period to allow time for people to escape from the fire zone.

Although a fixed fire suppression system in a tunnel reduces the risks resulting from a fire by reducing the consequences it does also introduce additional hazards to the tunnel users. The obvious hazard is the loss of visibility when the system is discharged, particularly with systems based on water mist technology. To mitigate this hazard the Japanese delay the discharge of their systems until some time after the fire is detected in order to allow those trapped in the tunnel to make good their escape.

Another hazard is a false discharge due to either a system fault or a mechanical or material failure of one or other of the components of the system as a result of the aggressive atmosphere known to be present in road tunnels. Such a discharge did occur during May 2005 in the 335 m long tunnel near Boston in the USA (Figure 1) and, although there were no casualties in that instance, it could easily have resulted in an accident and, possibly, fatalities.

![Figure 1: A malfunctioning fire suppression system drenched the tunnel under City Square in Charlestown in May 2005](image)

(The photo seems to indicate that it was not so simple to turn off the water to the sprinkler system!)

2.3. Ventilation Systems

2.3.1. Longitudinal ventilation systems

The principle hazard associated with longitudinal ventilation systems is the security of the jet fans themselves. Failure of their mountings or the unit itself could result in the whole or parts of the fan falling onto the carriageway. To this end many countries now demand that the fixings for all equipment hung in the tunnel are manufactured from a stainless steel with a high molybdenum content, an alloy that has been shown to be resistant to corrosion in the aggressive environment found in a road tunnel.
Once a fire is detected in a tunnel the jet fans are switched on to control the smoke spreading. In a tunnel with uni-directional traffic all of the smoke will be blown to one side of the fire and those trapped in the tunnel upstream of the fire will be protected from it. In a tunnel with bi-directional traffic the jet fans will be used to stop any longitudinal flow to minimise the heat loss from the smoke and promote stratification so maximising the time before it cools and descends. In both cases the operation sequences are short and simple. Multiple jet fans provide a degree of redundancy to ensure that the smoke can be controlled provided, of course, that the electrical power to the fans and control equipment remains intact.

2.3.2. Smoke extraction systems

In many European countries emergency ventilation systems are required exhausting smoke from the tunnel near the fire into an exhaust duct through remotely controlled mechanical dampers. Assuming that the dampers are supported by the exhaust duct and are not hung from it, the hazards directly associated with such systems are the same as with a longitudinal system, i.e. the jet fans that are needed to ensure that fresh air is drawn in from both tunnel portals irrespective of the fire’s location in the tunnel and the prevailing meteorological conditions.

The goal of these new systems is to minimise the smoke spread along the tunnel, reduce the length of the tunnel which is affected by smoke and, as a result, limit the number of people likely to be affected by it. While not questioning the effectiveness of these systems it has to be recognised that this depends on a number of other systems all functioning correctly:

- Rapid detection of a fire by the fire detection system or alternative measures
- Rapid detection of the fire’s location by the fire detection system or by the operator correctly choosing the location based on CCTV images
- Opening of the correct exhaust dampers
- Starting and correct functioning of the exhaust fans
- Detection of the speed of the air coming from each portal
- Correct functioning of the jet fans to control the air speed coming from each portal

If any one of these systems fails to operate or operates incorrectly, the smoke extraction either will not happen, or will be from the wrong location or may not be all of the smoke. Any of these events would significantly increase the numbers of people who would be affected by the smoke hazard.

A similar situation would exist if the smoke extraction system failed during operation because of the inevitable changes in the flow and pressure drop along the exhaust duct. If the fans operating point is close to the stall boundary, these changes may be sufficient for it to go into stall. If the fan has variable pitch blades it is possible to avoid this situation and move the operating point away from the stall boundary by reducing the blade angle. However, if the fan is of the fixed blade, variable speed type powered through frequency converters it is not possible to move the operating point away from the boundary and the fan will have to be stopped. This situation with fixed pitch fans can only be avoided by ensuring that the operating point is well away from the stall boundary so that when the temperature in the duct rises and the pressure drop along the duct increases the operating point does not approach the stall boundary.

Even if the smoke extraction system and the jet fans function perfectly, the effectiveness of the system is dependent on the rapid detection and location of the fire. Failure to achieve this means that the smoke will have propagated well outside the exhaust zone and spread over a considerable length of the tunnel before the exhaust starts functioning, after which the spread of the smoke will be gradually reduced.
2.4. Tunnel closing

The hazard of drivers passing traffic and lane signals at stop as they are approaching tunnels is well known and measures such as physical barriers are being adopted. The EU Directive requires that provisions be made to stop vehicles entering a tunnel and at intervals through long tunnels in order to keep them as far away as possible from the hazards associated with an incident. Barriers can either drop down or swing across the carriageway (Figure 2).

![Figure 2: “Drop down” and “Swing across” barriers](image)

However each type of barrier introduces the hazard of vehicles colliding with them either as they are being closed or once they are closed – presumably by vehicles driven by the same people who “don’t see” the traffic signals!

There is an alternative approach that eliminates that collision hazard. It has been developed for the portals of the Sydney Harbour Tunnel to stop vehicles entering if there is an incident in the tunnel but also to stop over-height vehicles from trying to enter the tunnel. The “Softstop” system developed by Laservision (www.laservision.com.au) projects a laser generated image on to a water screen (Figure 3).

![Figure 3: The “Softstop” system being used at the portal of Sydney Harbour Tunnel](image)

The hazard then associated with this system is the water but any associated risks are easily mitigated using the tunnel’s drainage system.

3. FACILITIES

3.1. Emergency exits

The provision of an escape way through an opening in a tunnel wall is recognised as a hazard to errant vehicles impacting on the corner and the opening is often designed to minimise the consequences of such an incident. Sometimes the door is made flush with the wall; sometimes the “upstream” corner is shaped to deflect the vehicle.
In the past it was thought that just the presence of the emergency exit could be distraction to drivers and hence a hazard. As a result the exits were “hidden” with just a small discrete notice indicating their presence (Figure 4). The problem with that concept was clearly demonstrated in a number of the recent fires – when drivers needed to use them to escape from a fire they did not know the exits were there and, unfortunately, some of them perished. Nowadays the approach is completely different; the emergency exits are being well lit and clearly marked and they are almost impossible not to notice so at least people know they are there (Figure 5).

Figure 4: Typical sign that was used to indicate an emergency exit  
Figure 5: Modern emergency exits are more noticeable!

In some countries the local regulations demand that the doors in the emergency exit have to be fitted with crash furniture and open in the direction of escape, just as when escaping from a building. In those countries this means that each emergency exit door has to be two doors, one opening in each direction. This configuration introduces another potential hazard of people fleeing through the emergency exit and “running” into the opposite tube into the path of vehicles still moving in there. The obvious solution to this hazard is to put a barrier on the kerb in front of the exits to “deflect” people. Unfortunately this mitigation measure introduces another hazard – drivers veering away from the barriers on the kerb as they pass them potentially resulting in an accident.

In most countries the “fleeing into moving traffic” hazard is not an issue because the doors from the tunnel only open into the cross connection and they are not fitted with crash furniture, just a normal handle. This means that those escaping from one tunnel reach a place of relative safety – the cross connection – through a door opening in the escaping direction but to go on to the opposite tube they have to pull the door towards them. This simple measure effectively mitigates the hazard especially when it is combined with a very visible notice on the inside of the door warning of possible moving traffic.

3.2. Internal finish/décor and lighting

Over a decade ago the potential impact on safety of the interior design of a tunnel on the drivers’ perception, orientation, boredom and distraction was identified and some recommendations were made (Carmody, J. 1995). Questions concerning the internal décor of tunnels also formed part of the Austrian studies (Eberl G. 2002) but apart from these two papers there has been little attempt to really understand the effect of internal décor on safety.

Notwithstanding the lack of published information the potential hazard of the internal décor is recognised and some novel approaches have been adopted to prevent drivers becoming bored in long tunnels such as the lighting effects used in the Laerdal Tunnel in Norway and the Zhongnan and Xuefeng Mountain Tunnels in China (Figure 6).
Figure 6: Internal décor in Zhongnan (left) and Xuefeng Mountain Tunnels

It will be interesting to learn if these radical approaches have the desired effect or will they actually be a hazard and result in drivers being distracted and accidents occurring.

The Södra Länken Tunnels in Stockholm also have a novel way of informing drivers of the tunnel alignment and approaching junctions with white panelling suspended from the roof of the tunnel. Again, will this innovation reduce incidents or will it be a hazard?

3.3. Structural Fire Protection

The impact of a large fire on a tunnel’s structure and fittings can be devastating as seen in the Channel Tunnel. In many tunnels the only hazard is physical damage to the tunnel resulting in parts of it falling be it a bare rock tunnel or one lined with concrete that spalls. The fire does not destroy the tunnel and it can relatively quickly be repaired. However structural damage to tunnels such as submerged tube tunnels could result in the complete loss of the facility.

Several manufacturers are promoting the use of materials to protect the structure of the tunnel from the effects of the fire using one of two fundamentally different concepts – modifying the reaction of the concrete to the effects of the heat from the fire or protecting the concrete by stopping the heat reaching it. The first incorporates polypropylene fibres in the concrete lining which has been shown to significantly reduce or eliminate spalling. The second approach is to protect the structure by applying materials to stop heat passing to the structure.

So what are the hazards associated with these two approaches? Adding polypropylene fibres to the concrete has very little impact on the conditions in the tunnel. They do not reduce the amount of heat passing into the tunnel structure and the temperatures in the tunnel falls quite rapidly with distance from the fire purely because of the heat losses to the walls. However, preventing heat from entering the structure means that it stays within the tunnel and the temperatures there will be significantly higher for greater distances from the fire. The higher temperatures will increase the extent of damage to fixtures and fittings within the tunnel and may pose an increased risk to anybody in the tunnel because of the higher temperatures there. In a very large fire there may even be sufficient heat retained within the air/smoke in the tunnel to enable the fire to “jump” considerable distances along the tunnel even if vehicles are separated by tens or hundreds on metres. Heat protection for small sensitive parts of the tunnel’s structure is totally understandable but the consequential hazards of applying it to the whole structure must be carefully considered before such an approach is adopted.

Polypropylene fibres will pose no additional hazard to tunnel users during normal tunnel operations because the fibres are an integral part of the concrete structure. Measures to protect the tunnel structure from heat could potentially become detached from the tunnel surface or its support structure which would be hazard to motorists as it could result in accidents and, possibly, casualties.
4. DISCUSSION

Although the number of fatalities in road tunnel fires is relatively low there is still the drive to improve it still further. Manufacturers are developing more sophisticated systems each with the aim of reducing the consequences of fire incidents in particular; it appears that very little is being developed or research work being carried out to reduce the likelihood of incidents occurring.

So why are all these new safety-related facilities and systems being installed by tunnel owners? Is it because those responsible fear being accused of not doing everything they possibly can for the safety of the tunnel users irrespective of the cost effectiveness?

When the decision is taken to include these facilities and systems, how many of those responsible actually consider what hazards they are introducing into the tunnel? How many risk analyses have actually been done on safety related equipment and facilities? Or is it just assumed that because it is a safety-related system it must be safe?

The question of the cost effectiveness of all these measures has to be asked especially when considering the relative small amounts of money which need to be spent to save a life on open stretches of road. Would the massive investments currently being made for each and every tunnel actually be better spent trying to reduce the likelihood of incidents occurring?

Measures such as better driver education and training, stronger enforcement of traffic regulations, etc have been shown to be effective and, most importantly, they are effective for every tunnel.

5. CONCLUSIONS

1. Systems and facilities introduced into tunnels to reduce the consequences of fire incidents do introduce real additional hazards into the tunnel

2. The risks associated with these additional hazards cannot be ignored; they need to be addressed.

6. REFERENCES


Day J.R. (2003); Are we doing the correct things to make road tunnels safer?; Proceedings of the 5th International Conference on Safety in Road and Rail Tunnels, Marseilles, France, 6-9 October 2003, Organised and sponsored by the University of Dundee and Tunnel Management International, ISBN 1 901808 22 X
