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The international FORUM of fire research directors: A position paper on future actions for improving road tunnel fire safety

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Abstract

Fire safety in tunnels has come in focus owing to numerous catastrophic fires and extensive monitoring in media. Casualties can be counted in hundreds and the economic damages have been enormous not only for tunnel owners but also for users and bordering communities. The recent increase in serious road tunnel fires is closely associated with the increase in the traffic volume as well as in the large number of tunnels being built in recent years. In particular, volumes transported on heavy goods vehicles have increased by 40–80% over a decade in many European countries. Today, about 75% of all goods traffic is by road, and is expected to increase by 40–60% over the next 10 years [Thamm B. The new EU directive on road tunnel safety. In: Proceedings of the international symposium on catastrophic tunnel fires (CTF), SP Swedish National Testing and Research Institute, SP Report 2004:05. p. 19–30].

This FORUM position paper discusses some aspects on how to improve the design of road tunnels in order to obtain a higher level of fire safety. It discusses briefly design principles of tunnels as well as of fire safety of vehicles, use of forced ventilation systems and of active fire suppression.

Keywords: Tunnel fire; Road tunnel; Standard; Sprinkler; Ventilation

1. Performance-based design of road tunnels

Present standards and guidelines for tunnels are to a great extent based on large-scale tests performed in the 1960s and 1970s [1,2] and on vague conceptions on technical aspects developed over the years among various experts in the field. Thus, today's standards contain prescriptive rules whose background often is not known among practicing engineers. New knowledge from large-scale fire tests in the 1990s (EUREKA 499 [3] and Memorial Tunnel [4] test series) has only been partly implemented. It is the opinion of FORUM that it is now time to introduce more fire science in the design of tunnels and move from the current prescriptive type of standards to more performance-based standards.

Design standards should be open for alternative solutions depending on type of tunnel and traffic intensity. This would encourage new suppression technologies to be developed and installed. Unfortunately this is not the case, for example, in the new EU directive [5], which can be regarded as prescriptive. No provisions for installations of suppression systems are given, although such systems in many cases offer cost-effective solutions.

In order to obtain better standards and guidelines for tunnel safety, more rational design approaches correlated to risks and types of tunnels should be developed. Entirely performance-based approaches to all aspects of the tunnel fire safety are probably not desirable but should be endeavoured whenever possible. In some cases, prescriptive approaches are still needed. For example, the number of fire extinguishers to be installed and the distance between them should be specified.

For a performance-based standard and design alternatives to be permissible, a set of physical and numerical tools should be available to allow designers the needed flexibility and the authority having jurisdictions a necessary level of comfort in assessing these alternatives.

The human behaviour should be considered to be integrated in the design and emergency planning. This

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should include the expected behaviour both from the tunnel operator and user in case of incident, allowing proper training for operating personnel and public education. This part of the design may be equally as important to the technical features of the fire safety systems.

2. The ventilation system

Tunnels become longer and more sophisticated, but the design of technical safety systems is still often based on ideas and traditions that were developed for much simpler applications. In this aspect, there are two areas that are of major concern where changes in design concepts are needed.

A tunnel system today may look like a 'Swiss cheese' and the airflow patterns may be very complicated. For example, many twin-tube road tunnels with longitudinal ventilation systems have numerous exits and entrance tunnels coupled to the main tube. Guidance standards on how to solve the ventilation in this type of tunnel systems are therefore highly needed.

Many new urban twin-tube road tunnels often become congested of vehicles due to heavy traffic. If they have longitudinal ventilation systems, the fires can be devastating. The design concept assumes that the traffic is stopped upstream of a fire and that the tunnel ventilation ensures that upstream of the fire the tunnel is free of smoke. Vehicles, downstream the fire, are assumed to continue out of the tunnel. The intention is then that the fire brigade shall be able to attack the fire from the smoke-free upstream side. However, in urban areas, there are very likely queues in the tunnel and thereby the whole concept fails. The fire brigade may not be able to reach the fire and vehicles downstream of the fire trapped in traffic queues, resulting in a large number of people to be put in jeopardy (Fig. 1).

To solve the above problems, ventilation systems should be designed according to the spectrum of potential traffic conditions and realistic accident situations to evacuate the fire gases from the site of the fire instead of spreading it. One way of doing this is to install an exhaust ventilation system with large extraction points located close to the site of the fire, see Fig. 2. Since the fire may develop at any location in the tunnel, extraction must be provided throughout its length. The system must then be strong enough to create longitudinal flows from two directions. In some cases, jet fans in the ceiling or inflow of air at floor level may be needed to balance the longitudinal flow and obtain satisfactory flow conditions. With this type of ventilation system, people stuck in a queue will be much better protected from smoke and the fire brigade will be able to attack the fire from two sides. Design fires should be established to reflect not only the heat release rate but also the growth rate of the fire in association with fire scenarios, its location and influence of the ventilation.

The recent Runehamar tests carried out in 2003 show that the maximum heat release rates and temperatures measured were considerably higher than the design values used today for heavy goods vehicles. Heat release rates in the range of 70–200 MW [6] and gas temperatures in the

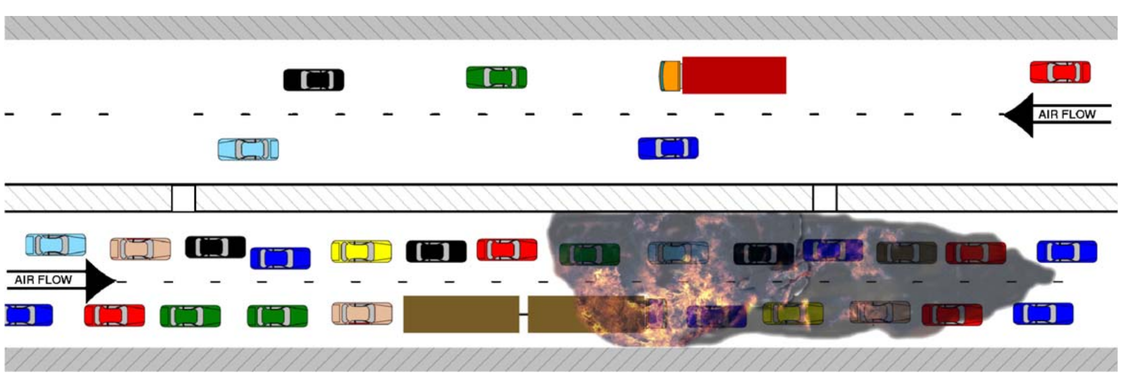

Fig. 1. Congested traffic on both side of a fire can be devastating with longitudinal ventilation only.

Fig. 2. An exhaust ventilation system with large extraction vents that can be opened close to the site of a fire will protect cars and passengers from smoke and fire gases, and will allow the fire brigade to attack the fire from two sides.

range of 1250–1350 °C were measured [7], although the fire load consisted of non-hazardous goods such as wood pallets and furniture. The Runehamar tests also show that we need to take into consideration the fire growth rate. The rate of fire development has in many situations a larger impact on the possibilities of survival than the maximum heat release rates.

3. Time–temperature curves for tunnels

Road tunnel linings are usually designed for standard time–temperature curves according to e.g. ISO 834, EN 1363-1 or ASTM E119, or much more severe curves such as the hydro-carbon (HC) curve, see e.g. EN 1363-2, the German ZTV curve [8] or the Dutch RWS curve [9]. It is the decision of the road authorities to choose a curve and a fire duration that is deemed suitable for a particular project. It is only in some design standards [10] that the tunnel height and type of traffic (e.g. dangerous goods) may be considered. Presently, however, there is no generally accepted engineering approach available that provides clear guidance on which of the design curves to choose for a given application. Consequently, there is no correlation between the time–temperature curves for the design of linings and the fire heat release rates for designing ventilation systems. These systems are therefore chosen independently of size and shape of the cross-section or of thermal properties of lining materials. All these parameters together with the type and amount of fuel (petrol, plastics, woods etc.) will in reality govern the gas temperature in case of a tunnel fire.

In the Runehamar tests [7] very high temperatures (1250–1350 °C) were measured. It is important to determine the tunnel cross-section and ventilation conditions for which the Runehamar test results may be representative. Numerous fundamental research studies that can be used in future work have been performed in mines and ducts [11–14]. The experiences gathered from these tests could probably be used for tunnel fires as well.

4. Focus on the vehicles

At present, we focus very much on the design of the tunnels to obtain fire safety. However, *tunnels do not burn but vehicles do*. More attention should therefore be given to the vehicles, particularly those transporting heavy goods. Tunnels can never be totally fire-safe as long as vehicles carrying large quantities of flammable goods use them. Certainly, various systems for fire-fighting and smoke evacuation can be installed, and escape facilities can be improved, but the protection resources should be allocated on a cost-effectiveness basis. Greater responsibility should be placed on the design of the heavy goods vehicle trailers. They constitute a potential source of catastrophic fires as they may carry large quantities of flammable cargoes. This is by no means confined to goods that are actually classified as hazardous goods. Cargoes deemed as non-hazardous such as furniture can cause very dangerous fires when occurring in tunnels as experienced in the Runehamar tunnel tests. Fires can then spread from vehicle to vehicle with devastating results. The most effective way to minimize the risks of fires from growing and spreading from one vehicle to another would probably be to require that cabs and trailers be made of fire-resistant materials. The practical implementation of this requirement may be hard to establish but on a long-term basis it may be very cost-effective.

Another way of reducing the possibility of vehicles catching fire would be to install fire suppression systems in the engine compartments.

The above-suggested types of measures do already exist, and could be applied within a short period time to vehicles using tunnels. This would probably be more cost-effective than placing the entire burden of fire safety on tunnel structures.

5. Active fire protection [15]

There has traditionally been strong resistance to the use of sprinklers or water mist systems or any other type of suppression system in road tunnels, particularly in Europe. However, the Runehamar tests show that there are good reasons to review many commonly accepted views and attitudes. The surprising test results have renewed the interest in suppression systems in road tunnels. As a matter of fact, not even the most modern road tunnels are designed to withstand such high fire exposures as those monitored in the Runehamar tests. New technology may offer interesting solutions.

Suppression systems in road tunnels may, however, have disadvantages. The water may press the fire gases down to the road level and thereby obstruct the evacuation of people and vehicles. The water can also spread liquid fuel spillages and thereby the fire. On the other hand, the suppression system can prevent fire growth and spread between vehicles and thereby safe lives. The costs of installation, maintenance and freezing risk is of course also an important issue that needs to be considered. However, due to the enormous costs of tunnel fires there is no doubt that sprinkler and water mist protection of road tunnels in urban areas, where private passenger cars are mixed with heavy goods vehicles, should be considered.

6. The FORUM position

Standards and guidelines for fire safety in tunnels, which could be internationally accepted and adopted by appropriate authorities, should be developed. They should be *performance based* rather than prescriptive as is the case today in most countries. The following important aspects should then be considered:

- *Ventilation systems* in tunnels should be designed so that they can evacuate fire gases from both sides of a fire. They should be designed according to the traffic conditions and realistic accident situations.

- Procedures for specifying *time–temperature and heat release curves* for designing tunnels need to be developed and broadly accepted. A set of physical and numerical tools should be made available for practicing engineers.
- *Design fires* should be established to reflect not only the highest heat release rate but also the growth rate of the fire in association with fire scenarios.
- *Heavy goods vehicles* should be made more fire safe, for instance by requiring cabs and trailers to be of fire-resistant materials and with fire suppression systems in engine compartments.
- *Fixed-suppression systems* should be considered in urban tunnels where heavy goods vehicles are mixed with private passenger cars. They will protect the tunnel structure and limit the spread of the fire. However, their benefit from a life safety aspect has been questioned since they may generate more hazardous conditions for people inside the tunnel. Further studies are needed to evaluate this impact.
- *Human behaviour* should be integrated into the tunnel design, the emergency management plan and evacuation strategy. This should include the expected tunnel operator behaviour and tunnel user behaviour in case of a fire incident. There needs to be increased emphasis on training for operating personnel and educating the public.

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