GUIDELINES FOR FIRE SAFE DESIGN
COMPARED FIRE SAFETY FEATURES FOR ROAD TUNNELS

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ABSTRACT

This paper contains a discussion of safety features for road tunnels. The paper takes starting point in the result of the work in FIT WG3 "Fire Safe Design, Road Tunnels". The paper includes discussion of prescriptive and performance based guidelines and a comparison and recommendation concerned with selected safety features. Finally a reference is made to the EU tunnel directive proposal.

1. INTRODUCTION

Based on statistics it can be observed that fatality risk in tunnels is generally lower per vehicle km than it is for a comparable open part of the infrastructure. However, some specific events are unique for tunnels or can lead to much more severe consequences in a tunnel than for an open section. So, for tunnels it is of major importance to address these events. Examples of these events are explosions, release toxic gas and other dangerous substances and for tunnels below the water level also flooding. However, first and foremost the discussion of tunnel specific risks is dealing with fire in tunnels, which is the topic of the FIT thematic network.
In recognition of importance of safe traffic in tunnels, most tunnel countries have established guidelines. As part of the FIT network guidelines have been collected and compared in Working Group 3. The draft report reporting on the comparison of guidelines for road tunnels is available from the FIT web site www.etnfit.net and has been one of the most sought items. The present paper takes starting point in the WG3 report.

2. GENERAL

2.1 Safety and safety measures

Safety is achieved, when the risk of specified conditions or events is relatively low and thereby acceptable. Safety is the result of an active approach and can be dived into the links of the so-called safety chain. It is illustrated that safety is achieve measures for preventing incidents and accidents, reducing consequences of the incidents and accidents and giving good conditions for rescue and fire fighting.

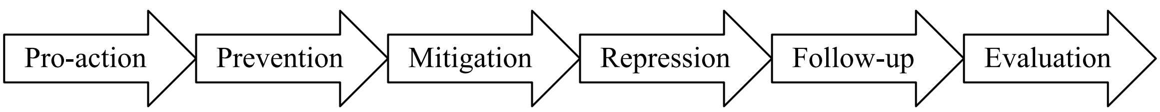

Figure 2.1 Illustration of safety in terms of a safety chain

In order to achieve safety it is in addition important to be proactive and to follow-up and evaluate any incidents and other important occurrences.
For tunnels the safety is related to safety of users, i.e. minimising fatalities and injuries of the car drivers and passengers as well as structural safety, i.e. minimising costly damage or collapse of the structures.
It is important to distinguish these two types of safety because the mitigation measures are different and in some cases even conflicting.
Even though it is very important to design tunnels, which are safe to the users and have high structural safety, it is worth to note that this is not the only criterion for the decision. The traffic flow and construction and operating costs are important factors to take into account as well. In addition could be mentioned the environmental aspect which also play a certain role.
Extreme safety measures could be introduced in order to reduce the risk, e.g. drastic reduction of speed, long distance between vehicles, escorting fire vehicles etc. but these measures may reduce the capacity of the tunnels, cause long delays for the users and result in high costs for the users and society. What is called for is a suitable balance between safety measures, and other important criteria.
In order to integrate risk in the design an evaluation of risk is necessary. Risk evaluation may involve giving safety consequences like fatalities, injuries and environmental damage a weight in terms of costs. A specification of acceptable risks in terms of upper limits can be shown to be equivalent with specifying costs on the consequences. Reference is made in general to the integrated approach in other projects like DARTS and OECD[6].

2.2 Tunnel safety and fire safety

Based on European statistics it is estimated that fire occurs with a frequency of approximately 4 - 5 fires per 100 million vehicle km. Most of the fires are caused by electrical and mechanical problems in vehicles. Less than 1 % of the fires will be characterised as fires with the serious consequences (fires involving injuries, fatalities or large material damage). These fires are often the result of an accident. The Mont Blanc tunnel fire, which was caused by self-ignition of a heavy goods vehicle, is an exception to the rule.
In order to prevent serious fires, measures should be introduced to prevent accidents; these prevention safety measures will have the effect on both accidents with and without fire. As it appears the discussion of fire safety in tunnels is closely related to tunnel safety in general.
In the FIT network particular focus has been given to the safety measures, which can mitigate the consequences of fire, once the fire is a reality.

3. PRESCRIPTIVE VERSUS PERFORMANCE-BASED APPROACH

3.1 General

Traditionally fire safety standards have been prescriptive with minimum requirements, which must be fulfilled. These requirements have been established during years based on experience, tradition, and engineering judgement. Safety is evaluated very crisply: design in accordance with the standard the safety is absolutely acceptable; otherwise it is absolutely unacceptable. Prescriptive standards are uncomplicated to use and ensure minimum levels of equipment etc in the tunnels. On the other hand they may not be able to handle unusual situations and may in some cases not be able to reasonable into account the actual local conditions.

By a performance-based approach the standards give requirements on a higher level, indicating performance (safety) goals to be ensured and giving requirements to design structure, equipment, operation etc. in accordance with these goals.
This aspect has been discussed in other papers in this symposium. However for the purpose of the present paper some few aspects of the discussion is emphasized.

3.2 View point of tunnel safety facilities

The tunnel and its equipment can be regarded from the point of view of the users, the operator or the society. The society may rationally require a specified safety level for tunnels and the tunnel designer/operator will have to find economical solutions within the requirement.
From a user’s point of view, however, it would be optimal if all tunnels had the same equipment, escape facilities, emergency procedures etc. For example the tunnel user would prefer that exits were always, say, on the right side at a distance of 75 m, no matter what type of tunnels and what was the design capacity. However, if the distance between the cross passages should be the same short distance for bored tunnels as it can be for immersed and cut and cover tunnels, the costs would be very high and in disproportion with the risk reducing effect. The safety standard will therefore have to respect the actual conditions.
On the other hand using strictly a cost benefit consideration it might in some cases be shown that exits are very expensive compared to the risk reducing effect. So even if the risk reduction would be the same as for another tunnel it might be decided not to have any exits. Hence, performance based cost benefit considerations must respect some minimum requirements.

4. ROAD TUNNELS

4.1 General

Tunnels are of increasing importance for the road network. The reason for this is the progression of the technology, the growing traffic and the awareness of maintaining urban and natural environment. The tunnels may pass under water, under urban areas and under mountains and hills. From Figure 4.1 it appears that the most long road tunnels are placed in countries with many mountains, like Norway, Italy and Japan. The traffic density in the tunnels varies significantly and considering the "road-tunnel-countries" based on the tunnel traffic volume in tunnels it appears that Italy, France, Switzerland, Germany, Austria and Norway is the top-six.

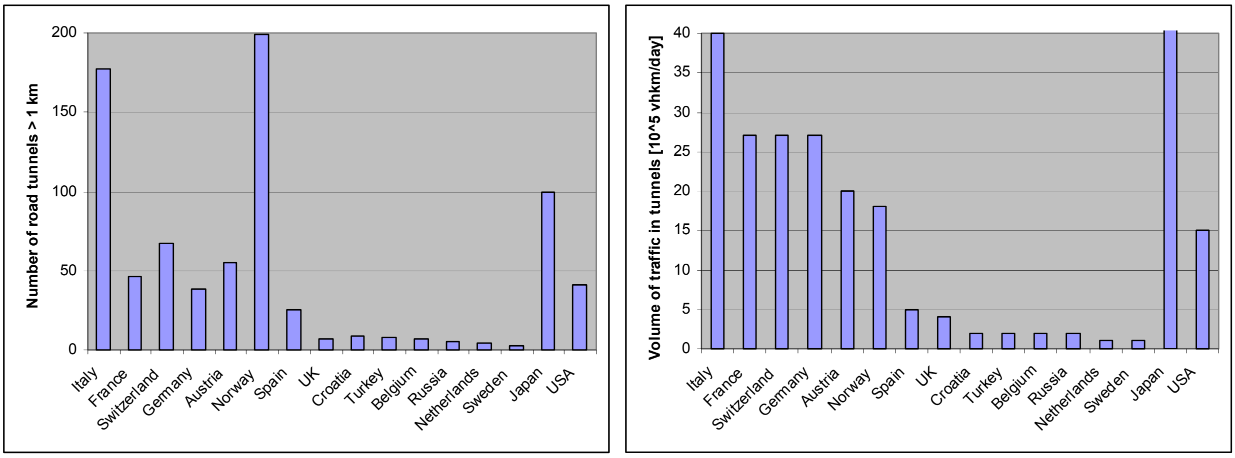

Figure 4.1 Number of road tunnels longer than 1 km and the average daily tunnel traffic for selected countries, ref UNECE[4] and estimated values. The traffic volume in tunnels in Italy and Japan is estimated to be over 40 10^5 vh-km/day respectively 50 10^5 vh-km/day.

A road tunnel consist of 1 bi-directional tunnel tubes or 2 or more unidirectional tubes. The number of tunnel tubes is mainly decided based on the traffic volume. For roads with 4 or more lanes structural reasons will in most cases dictate multiple tubes. With unidirectional traffic the safety is improved due to less traffic accidents (a preventive measure) and improved conditions for emergency ventilation (a mitigation measure).
The ventilation in unidirectional tubes can always operate in the direction of the traffic. In case of a fire, the traffic behind the site of the incident will be in safety. For a single tube tunnel the safety is dependent on ventilation and evacuation. However, it should be noted that constructing two tubes only for the reason of safety might be a very costly safety measure.

4.2 Road Tunnel Safety Measures: Structural measures

Preventive structural measures may include visual design, the cross section, and alignment.
The internal free space (i.e. the width and height of the space for traffic) and the location of lay-bys may have an impact on the frequency of accidents and influence the smoke and fire spread in case of a fire. The possibilities for access by rescue forces and fire brigade are also influenced by the width of the cross section. The alignment and longitudinal profile may also influence the frequency of accidents particularly at the portals.
Mitigating structural measures include the important escape possibilities in form of escape routes and exits to safe places, as well as measures to prevent structural damage in case of incidents.

4.3 Road Tunnel Safety Measures: Equipment

Ventilation is one of the most important safety measures in road tunnels. Tunnel ventilation can be longitudinal, transverse or semi-transverse. The ventilation is operated based on sensors of air quality and air speed.
Lighting is an important preventive safety measure particularly at the portals.

The remaining equipment counts among others signage, communication and alarm systems, traffic regulation and control, and power supply. Finally fire-fighting equipment may normally comprise hand held extinguishers, hose-reels and a water main. Fixed fire suppression mitigation system is not common in road tunnels.

5. COLLECTION AND COMPARISON OF GUIDELINES

As part of the activities of WP3 guidelines concerning fire safety in road tunnels have been collected and compared. The result of this work is reported in the FIT WG3 report[1].
The report includes a list of 36 national guidelines from 10 European Countries and the USA as well as 13 other reference documents. For all national documents an analytical summary has been included and the report includes the list of contents translated into English.
Relevant types of safety measures have been identified and for each safety measure a detailed comparison has been carried out. The detailed comparison includes at present the requirements of the national guidelines of Germany, France, UK, Norway and Austria. These guidelines have been selected based on the ranking they received at the UNECE evaluation of guidelines[4] and importance have been given to countries with a high number of tunnels and high traffic volume in tunnels. It is planned to extend the comparison with the Netherlands and Switzerland as part of the continued work in FIT WP3. The requirements of Italy ought to be included in the detailed comparison, but the relevant material has not been available to FIT WG3. A list of the documents included in the detailed comparison is shown in Table 5.2.
The detailed comparison comprises a description of the role of each safety measure, comparison of the requirements in form of direct quotes from the text of the guideline and a synthesis.
The matrix shown in Table 5.1 gives a comprehensive list of 44 safety measures in three categories: S: Structural measures relevant to safety, E: Safety equipment, and R: Structure & equipment, response to fire. The main categories have been subdivided in 3, 8 and 3 categories respectively. For each of the identified elements the requirement reference is made to the national guidelines of 5 selected countries.

Overview of contents of comparison		Germany	France	UK	Norway	Austria
	Available national guidelines:	3	1	2	2	10
Category	Element					
Structural measures relevant to safety						
S1 Emergency passenger exit for users	S11 Parallel escape tube	A,1	A,1	A,1	A,1	A,1,7
	S12 Emergency cross-passage	A,1	A,1	A,1	A,1	A,2,7
	S13 Shelter	O	A,1	A,1	O	O
	S14 Direct pedestrian emergency exit	A,1	A,1	A,1	O	A,7
S2 Emergency access for rescue staff	S21 Separate emergency vehicle gallery	A,1	A,1	O	O	A,7
	S22 Cross passage vehicle access	A,1	A,1	O	A,1	A,2,7
	S23 Emergency lane	A,1	A,1	A,1	O	A,1,2,7
	S24 Direct pedestrian access	O	O	O	O	O
	S25 Turning areas	A,1	A,1	A,1	A,1	A,2,7
	S27 Firemen station at portals	O	A,1	A,1	O	O
S3 Drainage of flammable liquids	S31 Inclination of tunnel axis	A,1	A,1	A,1	A,1	A,3
	S32 Separate drainage systems	A,1	O	O	A,1	O
	S33 Liquid sump	A,1	A,1	A,1	A,1	A,3
	S34 Non porous surface course	O	A,1	A,1	O	O
Safety equipment						
E1 Smoke control ventilation	E 11 Natural ventilation by shafts	A,1	A,1	A,1	A,1	A,4
	E 12 Longitudinal	A,1	A,1	A,1	A,1	X,4
	E 13 Transversal	A,1	A,1	A,1	A,1	X,4
	E 14 Ventilation control sensors	A,1	A,1	A,1	A,1	A,4
E2 Emergency exit and rescue access ventilation		A,1	A,1	A,1	O	O
E3 Lighting	E31 Emergency tunnel lighting	A,1	A,1	A,1	O	A,6
	E32 Marker light in tunnel	A,1	A,1	A,1	O	A,8
	E33 Emergency exit & rescue access light.	A,1	A,1	A,1	A,1	A,6
E4 Signage (permanent/ variable)	E41 Traffic signals outside the tunnel	A,1	A,1	A,1	A,1	A,7,8
	E42 Traffic signals inside the tunnel	A,1	A,1	A,1	A,1	A,8
	E43 Exit pedestrian signs	A,1	A,1	A,1	A,1	A,8
	E44 Rescue pedestrian signs	O	O	O	O	A,8
E5 Communication and alarm system	E51 Emergency telephone	A,1	A,1	A,1	A,1	A,7,8
	E52 Alarm push button (manual fire alarm)	A,1	A,1	A,1	A,1	A,8
	E53 Automatic alarm on equipments	A,1	A,1	A,1	A,1	A,8
	E54 Automatic incident detection	O	O	O	O	O
	E55 Fire/smoke detection	A,1	A,1	A,1	O	A,8
	E56 Radio rebroadcast	A,1	A,1	A,1	A,1	X,9
	E57 Loudspeakers (in tunnel, in shelters)	A,1	A,1	A,1	O	A,8
E6 Traffic regulation - monitoring equipments	E61 Monitoring of traffic speed and intensity	A,1	O	A,1	A,1	A,8
	E63 Close circuit television	A,1	A,1	A,1	A,1	A,8
	E64 Remote control barriers	A,1	A,1	O	A,1	O
	E66 Thermographic portal detectors (trucks)	O	O	O	O	O
E7 Power supply		A,1	A,1	A,1	A,1	A,8
E8 Fire suppression (fire fighting equipment)	E 81 First aid fire fighting	A,1	A,1	A,1	A,1	A,7,8
	E82 Fire fighting media	A,1	A,1	A,1	A,1	A,7,8
	E84 Fixed fire suppression system	O	O	A,1	O	O
Structure & equipment, response to fire						
R1 Reaction to fire		O	A,1	O	O	O
R2 Structure resistance to fire		A,2,3	A,2,3	A,1	A,1	A,3
R3 Equipment resistance to fire		A,1	A,1,2,3	A,1	A,1	A,6,7,8

Table 5.1 Overview (matrix) giving types of requirements, amount of information and reference to the national guidelines of Germany, France, UK Norway and Austria. For each element a detailed comparison has been made. The letters indicate: O: No requirements, little information, A: Normative information, X: Detailed information or models. The numbers are a reference to the individual national guidelines, see Table 5.2.

Country	No	Ref.	Title
Germany	1	RABT	Road and Transportation Research Association**:** Guidelines for equipment and operation of road tunnels
		ZTV	Road and Transportation Research Association: ZTV Additional Technical Condition.
	2	ZTV1	Part 1 Additional Technical Conditions. Closed Construction of Road Tunnels
	3	ZTV2	Part 2 Additional Technical Conditions. Open Construction of Road Tunnels
France	1	Circ2000-63A2	Inter-ministerial circular n°2000-63 of 25.8.2000 Safety in tunnels of the national road network
	2	Circ2000-82N2	Inter-ministerial circular n°2000-82 of 30.11.2000 Regulation of traffic with dangerous goods in road tunnels of the national network.
	3	Law2002-J2	Law n° 2002-3 of 3 Jan. 2002 relative to safety of infrastructures and transport systems, etc.
UK	1	BD 78/99	Design manual for roads and bridges, Volume 2 Highway structure design Section 2, Part 9, BD 78/99: Design of road tunnels, 1999. The Highways Agency
Norway	1	Road Tunnels	Roads Tunnels Norwegian design guide 21 Directorate of Public Roads, 06.02
Austria		RVS	Transportation and Road Research Association, Guidelines and Regulations for Road Design
	1	RVS9.232	Tunnel cross section
	2	RVS9.233	Structures
	3	RVS9.234	Interior Constructions
	4	RVS9.261	Ventilation, Fundamentals
	5	RVS9.262	Ventilation, Calculation of fresh air demand
	6	RVS9.27	Lighting
	7	RVS9.281	Operation and safety measures, Structure
	8	RVS9.282	Operation and safety measures, Equipment
	9	RVS9.286	Operation and safety measures, Radio equipment
	10	RVS13.74	Maintenance of tunnel equipment

Table 5.2 Guidelines used for the detailed comparison

A detailed presentation of the comparison of all elements is not possible within this paper and reference is given to the WP3 report[1]. However, for illustration two important elements will be discussed in the following chapter: Escape routes and Structural fire resistance.

6. DETAILED COMPARISON

6.1 Escape routes

Guideline	Requirement
Germany RABT	2.5.1.3 Escape routes must be indicated and illuminated. Tunnels ≥ 400 m must have emergency exits at regular distances ≤ 300 m. The emergency exits can connect to the other tunnel tube directly or through a cross passage. Cross passages have doors in both ends.
France Circ2000-63A2	2.2 Arrangements for the evacuation and protection of users and emergency access … shall be provided on a systematic basis and access shall be provided approximately every 200 m; a shorter spacing is to be used in tubes which are frequently congested and which have more than three lanes. In non-urban tunnels these arrangements are to be provided where lengths exceed 500 m and the spacing will be approximately 400 m. 2.2.2 Communication between the (two) tubes represents a satisfactory arrangement … provided that a single door does not provide access from the tube in which the…accident occurred and a traffic lane in the other tube
UK BD78/99	*3.16 Escape Routes:* In twin bore tunnels, passenger escape routes through fire doors positioned in central walls or cross-connecting passages, shall be provided. These shall be positioned at 100m nominal intervals… 5.13 (100m preferred limit, 150m maximum limit). 3.17 *Tunnel Cross Connections*: Tunnel cross connections are generally of three types: i. A single set of fire doors in the partition wall between two traffic bores, ii. A cross passage with fire doors at both ends providing a safe refuge and an escape route from one bore to the other, iii… Normal provision for class AA, to be considered in class A and B.
Norway Road Tunnels	409 Tunnels with two parallel tunnel tubes must be prepared for evacuation by pedestrian cross passages. These are placed for each 250 m. 602.1 Pedestrian cross passages for each 250 m in Class E and F
Austria RVS	RVS 9.233 Dimension and design of cross passages RVS 9.281 Opposite each lay by a cross passage for vehicles is situated (a=1000m) Additionally in tunnels without fire ventilation and in tunnels with a longitudinal gradient >3% a foot passenger cross passage is situated at each emergency call station (a=250m)

Table 6.1 Requirements for emergency cross passages in national guidelines. Comparison table taken from FIT WG3 document "Fire Safety Design, Road Tunnels"[1]

The indicated distances between exits vary from 100m (UK), 200m (France), 250m (Austria and Norway), 300m (Germany), 400m (France) to 1000m (Austria). Some requirements are fixed or approximate target values (UK, Norway and Austria, partly France) other give maximum figures (Germany, UK and partly France).
Some distances are given as requirements: (Germany, France, Austria, Norway, partly UK) other as recommendation to consider (partly UK).
The requirements depend on tunnel length (Germany, France, Norway, UK), traffic volume (Norway, UK), Urban/rural location (France), Risk of congestion (France), Ventilation (Austria) and tunnel gradient (Austria).

- Short tunnels <400m are required to have exits per 200 m only for urban tunnels in France, (less than 200m by risk of frequent congestion).
- Tunnels 500 - 1000m are required to have exits per <300m in Germany, 400m in France (200 m for urban location and less than 200m by risk of frequent congestion), 100m in UK (but only for twin-bore tunnels in Class AA, AADT in the magnitude 40000 - 80000), 250m in Norway (but only for AADT > 10000), 250m in Austria (but for only tunnels without ventilation or longitudinal gradient > 3%).
- Long tunnels >3000m are in UK always in Class AA, i.e. distance of exits shall be 100m, Austrian tunnels > 1000m - 2000m is required to have a cross passage for vehicles per 1000m. In the other countries the requirements are as given above.

Both for short and long tunnels the requirements vary from recommendations to consider exits to requirements of exits per less than 200 m.
With reference to section 3.2 it may be concluded that the tunnel user can expect to experience a large variation of tunnel designs and safety arrangements when travelling in European tunnels.
The tunnel design requirements are dependent partly on factors related to the tunnel safety (traffic volume, length, risk of congestion, ventilation etc.) However, guidelines do no seem to aim for the same safety level. A harmonisation of this aspect may be achieved by use of risk analyses and performance criteria.

6.2 Structural fire resistance

Guideline	Requirement
Germany ZTV 1	10.3 The necessary structural fire protection for an arched or circular tunnel shall be ensured by compliance to structural minimum requirements and by calculated documentation. Normally, with a cover of 6 cm no other fire protection is needed.
Germany ZTV 2	9.31 The necessary structural fire protection for rectangular sections shall be ensured by compliance to structural minimum requirements and by calculated documentation. 9.32 By structural measures it shall be prevented that the load bearing reinforcement is heated to more than 300C. As protection against spalling a galvanised net shall be arranged in the cover… The minimum cover for load bearing reinforcement is 6 cm.
France Circ2000-63A2	4.2.2 - The fire resistance required from structures… is designed to achieve the following main objectives: - protection of users who have entered the evacuation facilities … for the time required for them to reach the exit, which is set at 60 minutes…,- protection of users … in shelters, …for 120 minutes, - no endangering of …the fire service, during…120 minutes… In all circumstances the maximum duration of a fire is fixed at 240 minutes for the standard graph and 120 minutes for the supplemented hydrocarbons fire graph.
UK BD78/99	8.56 The effects of fire on the tunnel structure and associated ducts and shafts shall be carefully assessed… 8.57 Depending on the design fire…, additional fire protection layers to structures may not be required… 5.68 … Measures to reduce concrete spalling from concrete ceilings at 150+ C shall be applied.
Norway Road Tunnels	605.2 Fire load, requirements to structure… Tunnels must be designed for a fire load of 5 MW for AADT < 10000, 20 MW for AADT > 10000. In tunnels with risk of structural collapse the design fire load must be evaluated separately. …
Austria RVS	RVS 9.234 Intermediate ceilings must have a resistance to fire according to fire class F90 (90 minutes resistance)

Table 6.2 Requirements for structural fire resistance in national guidelines. Comparison table taken from FIT WG3 document "Fire Safety Design, Road Tunnels"[1]

The formulation of the guidelines varies from very prescriptive requirements (Germany) and more or less performance based criteria (France, Norway, Austria). The criteria are given in terms of fire duration and specified fire curve (France, Austria) or heat release rate (Norway). The UK guideline only indicates that the topic will have to be carefully assessed.
Calculated documentation is required in all guidelines.
In the non-prescriptive guidelines (France, Norway, UK, Austria) a lot of freedom is left to the designer (reference is partly made to other documents which have not been included in the FIT WG3 work). For the designer of a tunnel there are a lot of steps between the indication of a heat release rate to the practical design of concrete cross section and reinforcement. For the performance based design there steps should be specified.
The prescriptive requirements of the German guideline may not be in accordance with the state-of-the art for fire design of concrete structures: a minimum cover of 6 cm may be very expensive and some tunnels may survive a temperature of 300C in the reinforcement.

In a tunnel fire the temperature will easily reach 150C. Measures to reduce spalling indicated in UK guideline will apply in any tunnel. A galvanised net as specified by the German guideline may not prevent spalling.

In general it is recommended to give a performance-based description of the structural fire resistance requirements and follow the achievements of ongoing research and committee work. Reference is made to DARTS, UPTUN as well as the working group WG6 of ITA (International Tunnelling Association) and task group TG4.3 of fib (international federation for structural concrete).

7. EU TUNNEL DIRECTIVE PROPOSAL

7.1 The European Commission's initiatives for tunnel safety

The fires in road tunnels in 1999 placed the tunnel safety very high on the political agenda, and as part of the European Commission's Transport Policy 2010[5], it was announced that initiatives would be taken to issue a directive concerning harmonisation of minimum safety standards. The directive proposal[2] was launched in December 2002 in addition to other initiatives concerning tunnel safety, among others:

- Research and development in the 5th Framework Programme incl. DARTS, FIT, UPTUN,
- Joint activities with PIARC (The World Road Association) and OECD concerning transport of hazardous goods in tunnels,
- Information material for users, including the leaflet "Safe driving in road tunnels",
- Subsidies granted to safety improvement measures in several road tunnels.

7.2 Comments and development

DARTS-FIT-UPTUN welcomed the initiative of a directive concerning minimum safety standards, which was regarded as a necessary step towards a commonly accepted, supported and harmonised safety approach in tunnels. Comments were given, stating that safety is best regarded from a performance-based approach and recommending that the directive should be formulated in such a way that it does not hamper the development and use of a performance-based safety approach. It should be possible to substantiate safety measures on the basis of a risk analysis, allowing deviations from the measures prescribed. In addition there were some reservations to the classifications proposed.
Since the first proposal for a directive was issued it has undergone some modifications. The new proposal[3] for directive has taken into account to a large degree the reservations and comments expressed by FIT-DARTS-UPTUN.

7.3 Comparison with national guidelines

In order to evaluate the directive proposal a comparison is made of selected minimum requirements in the proposal Annex I Infrastructure measures[3] with the quotes from the national guidelines discussed in section 6, namely escape routes and structural fire resistance.

7.3.1 Escape routes

Directive	Requirement
EU Directive, proposal, new version	2.3.3 Emergency exits allow tunnel users to leave the tunnel without their vehicles and reach a safe place in case of an accident or a fire and also provide an access on foot to the tunnel for emergency services. Examples of such emergency exits are: direct exits from the tunnel to the outside, cross-connections between tunnel tubes, exits to an emergency gallery, shelters with an escape route separate from the tunnel tube. 2.3.4 …Emergency exits shall be provided if an analysis of relevant risks including the smoke extension and spreading velocity under local conditions shows that the ventilation and other safety provisions are insufficient to ensure the safety of road users. In any case…emergency exits shall be provided where the traffic volume is higher than 2 000 vehicles per lane.…Where emergency exits are provided, the distance between two emergency exits shall not exceed 500m. Appropriate means, such as doors, shall prevent the propagation of smoke and heat into the escape routes behind the emergency exit, so that the tunnel users can safely reach the outside and the emergency services can have access to the tunnel. 2.4.1 In twin-tube tunnels where the tubes are at the same level or nearly, cross-connections shall be suitable for the use of emergency services at least every 1500m.

Table 7.1 Minimum requirements for escape routes in the proposal for EU directive[3].

It is stated in the minimum requirements that emergency exits shall be decided based on a risk analysis of the tunnel, the traffic and the provided safety measures. It states that emergency exits shall always be provided if traffic exceeds 2000 vehicles per lane.
The directive also states that the minimum distance between exits, if provided, is 500m.
It appears that the minimum requirements will not affect the specifications of the French and German standard, which require exits per 200 - 400m. The UK and Norwegian standards specifies shorter distances (100m and 250m) for twin bore tunnels in high safety classes. The minimum requirements may influence the design of single bore tunnels and tunnels with modest traffic in UK and Norway, depending on the results of risk analyses. In Austria shorter distances (250m) are specified, but only in tunnels without ventilation or with high longitudinal gradients. The minimum requirements may significantly influence the design of tunnels in Austria, depending on the result of risk analyses.

7.3.2 Structural fire resistance

Directive	Requirement
EU Directive, proposal, new version	2.7 Fire resistance of structures. The main structure of all tunnels where a local collapse of the structure can have catastrophic consequences e.g. immersed tunnels or tunnels, which can cause the collapse of important neighbouring structures, shall ensure a sufficient level of fire resistance.

Table 7.2 Minimum requirements for structural fire safety in the proposal for EU directive[3].

Concerning structural fire safety the minimum safety requirements[3] indicate that "a sufficient level of fire resistance" shall be ensured for certain specified tunnels. This may be regarded as a performance-based requirement, however the formulation does not give any detailed specifications. It is unlikely that any tunnels, where a local structural failure can have catastrophic consequences, have been designed without the aim of ensuring a sufficient level of fire resistance.
The formulation of the minimum requirement does not seem to be in conflict with any of the national guidelines studied in section 6.

8. CONCLUSION

The collection of guidelines for fire safe design in tunnels has illustrated the differences in the formulation of safety requirements as well as the approach to safety documentation. In addition the study of selected guidelines has demonstrated that the both the safety level and the provided safety measures varies significantly from country to country.
The initiative by the European Commission to establish minimum requirements is welcomed, and it is acknowledged that the directive proposal is pointing toward the direction of performance-based requirements and recommends to use risk analysis as basis for a large number of safety related decisions in road tunnels.

9. REFERENCES

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