GUIDELINES FOR FIRE SAFE DESIGN: SYNTHESIS AND CURRENT HARMONISATION PROCESSES

Didier Lacroix
Centre d'Études des Tunnels (CETU), France

ABSTRACT

New guidelines dealing with tunnel fire safe design have been developed before and especially further to the catastrophic fires which occurred during the last years in European tunnels. This paper relies on the work performed by the European thematic network FIT (Fires in Tunnels) and shows the background of the guidelines which are examined in more details in the following papers. It recalls the pre-existing regulations and recommendations on safety of road, rail and metro tunnels and outlines the harmonisation processes which take place in various European and international forums. Finally the paper draws significant features and trends of recent and future guidelines. The convergence of the fire safety objectives is greeted. Infrastructure is no longer considered alone, but as part of a system which also comprises operation, vehicles and users, which leads to risk- or performance-based approaches at least as a complement to prescriptions. Finally new procedures to check safety are highlighted.

1. INTRODUCTION

The dramatic fires which occurred in the road tunnels of Mont Blanc (France-Italy; 39 fatalities) and Tauern (Austria; 12 fatalities) in 1999 have caused a radical change of views on tunnel safety. This topic, which was previously reserved for specialists, became a real concern for the European public opinions, so that political leaders became involved. This new view was reinforced two years later by the fire in the Gotthard tunnel (Switzerland; 11 fatalities). Rail tunnels were also affected by fire catastrophes, such as in the Channel tunnel (UK-France; no fatality but very severe damage) in 1996, Kaprun funicular tunnel (Austria; 155 fatalities) in 2000 or Daegu metro (South Korea; 200 fatalities) in 2003.
Of course tunnel fire safety had been studied for a long time before these fires, so that important knowledge was available, as well as a number of recommendations and regulations. However these have been considered insufficient, so that a number of new initiatives have been launched in individual countries and at the European and international levels. They include research works, networking activities and development of new regulations.
One of these initiatives, the European thematic network FIT (Fire in Tunnels), aims at contributing to an European consensus for fire safety in tunnels and enhancing the exchange of up-to-date knowledge gained from current practice and ongoing research. This is obtained through strong information and communication activities, including a website (www.etnfit.net) with consultable databases, and several technical workpackages, one of which is devoted to a compilation of guidelines for fire safe design (WP3).

In a first step, existing guidelines were collected. Three lists were established, separately for road, rail and metro tunnels. They include regulations, guidelines, standards, and to some degree current best practices, from national authorities and recognised European and international organisations. These lists are available on the FIT website, together with an analytical summary and an English translation of the table of contents of each document. In a second step, a comprehensive list of tunnel safety measures was drawn up, covering road, rail and metro tunnels. For each transport mode, the most significant guidelines were compared for each measure in the list, including a description of the role of the measure, a synthesis of the provisions of the guidelines, and a detailed table which shows the requirements of each guideline regarding this measure.
The results of these compilations are described in the following papers at this symposium. The present paper is both an introduction and an extension of these papers. It shortly recalls the recommendations and regulations which existed before the aforementioned catastrophic fires then gives information on the numerous developments which have taken place since. It finally highlights some important features and trends of current and future guidelines.

2. CURRENT HARMONISATION PROCESSES

This section lays more emphasis on road tunnels, because the dramatic fires of 1999 have led to an evolution of the recommendations and regulations which has been more significant and quicker than for rail tunnels. Another reason is that fire safety requirements concerning the infrastructure are much more important for road tunnels: in rail tunnels, safety is first ensured by the rail regulations. For metro tunnels, new guidelines on tunnel fire safe design are scarce.

2.1 Guidelines for road tunnel safety: situation before 1999

Even though public opinions were not really concerned about this question, road tunnel safety had been given consideration in many countries before 1999. In addition to experience gained by consultants, contractors and operators, research works had been conducted to develop basic and technical knowledge, mainly on tunnel fires. However only a limited number of countries had regulations in this field.
Most work aiming at producing international syntheses and recommendations was carried out by the World Road Association (PIARC: www.piarc.org). This non-political and non-profit making association currently has more than 100 member governments and 2 000 other members in 130 different countries. The PIARC Technical Committee on Road Tunnel Operation was created in 1957 and now has 45 members and corresponding members from 28 countries. Its technical scope is geometry, equipment, safety, operation, environment of road tunnels. It does not deal with the constructional aspects, which are dealt with by the International Tunnelling Association (ITA: www.ita-aites.org). Since 1996, both associations have been co-operating on the topic of resistance to fire of tunnel structures.
Recent reports issued by the PIARC Committee deal with: Classification of tunnels (1995); Road safety in tunnels (1995); Road tunnels: emissions, ventilation, environment (1995); Fire and smoke control in road tunnels (1999); Reduction of operational cost of road tunnels (1999); Pollution by nitrogen dioxide in road tunnels (2000); Cross-section geometry in unidirectional road tunnels (2001). As the conclusion of a 6-year joint research project with the Organisation for Economic Co-operation and Development (OECD: www.oecd.org), a common report was published on Transport of dangerous goods through road tunnels (2001).

2.2 Guidelines for road tunnel safety: New developments since 1999

In individual countries
Immediately after the Mont Blanc tunnel fire, besides the judicial enquiry, a technical and administrative investigation was ordered by the French and Italian governments and resulted in two national reports and a joint bi-national report. 41 recommendations were made to improve the safety of this tunnel and similar ones, including information and training of users and stricter regulations concerning the size and flammability of vehicles.
In France, a check of all tunnels longer than 1 km was carried out within 3 months. A new regulation (circular) on road tunnel safety was published a year later, but could only apply to tunnels owned by the State. A law was issued in 2002 in order to apply similar procedures to all tunnels, whoever their owner. In Switzerland a tunnel task force examined the overall safety of road tunnels and made recommendations regarding the users, operation, infrastructure and vehicles. Similar steps were taken in other European countries such as Austria, Norway, etc.

At the European level
In order to harmonise the national initiatives, the Western Europe Road Directors created a working group composed of representatives of the Alpine countries and finally approved common recommendations in September 2000.
This work was resumed and enlarged by the Economic Commission for Europe of the United Nations Organisation (UN ECE: www.unece.org). Located in Geneva, this body covers 55 countries and manages a number of European agreements, e.g. in the field of road signing and road traffic, transport of dangerous goods, etc. UN ECE established a multidisciplinary group of experts on road tunnel safety. Their final report was published in December 2001 and includes recommendations on all aspects of road tunnel safety: road users, operation, infrastructure, vehicles. This report was approved by all member countries and will lead to amendments to the European agreements managed by UN ECE.
The European Union also became involved, further to a request by the Heads of States. In a first step, tunnel safety was included in the 5th framework programme for research and development. Significant research projects and thematic networks were funded, such as DARTS (www.dartsproject.net), FIT (www.etnfit.net), UPTUN (www.uptun.net), SIRTAKI (www.sirtakiproject.com), SAFE TUNNEL (www.crfproject-eu.org), Safe-T, etc.
In a second step, the European Commission decided to prepare a directive on minimum safety requirements for tunnels in the Trans-European Road Network. This would be a legislative document, which would become compulsory in all member countries once approved and transposed into national legislation. The proposed directive was presented in the first days of 2003 and is currently under discussion at the European Parliament and Council. Numerous amendments have been adopted, so that the current draft seems to be acceptable by both institutions. However, it is not certain that the directive will be issued before the next European elections of June 2004. If not, this text will probably be seriously delayed.

At the international level
Further to the 1999 fires, the PIARC Technical Committee on Road Tunnel Operation decided to lay still more emphasis on safety. Its working groups have produced the following new outputs (the reports will be printed in 2004):

- WG1 (Operation): Report on 'Examples of good practices for the operation and maintenance of road tunnels';
- WG2 (Pollution, ventilation, environment): Report on 'Vehicle emissions and air demand for road tunnels';

- WG3 (Human factors of safety): Leaflets on 'Safe driving in road tunnels', produced with the European Commission;
- WG4 (Communication systems and geometry): Reports on 'Traffic incident management systems used in road tunnels' and 'Cross-section design for bi-directional road tunnels';
- WG5 (Dangerous goods): Finalisation of the Quantitative Risk Assessment and Decision Support models jointly developed with the OECD;
- WG6 (Fire and smoke control): Report on 'Systems and equipment for fire and smoke control in road tunnels'.

In the framework of the aforementioned co-operation with PIARC, ITA is finalising a report entitled 'Guidelines for structural fire resistance for road tunnels'.

2.3 Guidelines for rail and metro tunnel safety

Current situation

A limited number of requirements specific to the safety of rail tunnels can be found in national regulations. As a matter of fact, safety is globally much higher in railway systems than on roads, and tunnels are not a specially dangerous part of the railway systems. Safety regulations which apply to the whole railway also improve safety in tunnels. More specifications on tunnels have been issued by the network owners.

The same still more applies to metro tunnels, and few national regulations specifically deal with their safety. The situation is opposite for stations, which are generally submitted to the regulations concerning buildings open to the public. Indeed the probability for a train to stop in a tunnel and not in a station is very low, and even in such a case, the stations will normally provide the evacuation routes. A number of standards are available for the rolling stock and networks use some or others. As the characteristics of the rolling stock have a large influence on safety, especially fire safety, there are specific safety concepts for each network, if not each new line.

UIC harmonisation

The Paris-based International Union of Railways (Union Internationale des Chemins de fer – UIC: www.uic.asso.fr) is the umbrella organisation of railways worldwide. It issues leaflets, which have no regulatory status but are considered the state of the art. In 2001-2002, a working party of 14 railway infrastructure managers and operators produced a new leaflet on safety in railway tunnels, which was published in August 2003 as UIC-Codex 779-9 R. It covers new and existing tunnels over 1 km in length with mixed passenger/freight traffic of normal importance, but not very long tunnels over 15 km. It is a compendium of more than 50 measures in the fields of infrastructure, rolling stock and operations. Each measure is described in detail, considered in terms of its cost-effectiveness and gives rise to recommendations, which distinguish between new and existing tunnels.

UN ECE group of experts

After the finalisation of the report on road tunnel safety mentioned in § 2.2 above, UN ECE launched another multidisciplinary group of governmental experts to deal with rail tunnel safety. This group limited its work to heavy rail main lines, as likely to be found on international and interoperable routes. Their recommendations were finalised in December 2003 and will be submitted to the Inland Transport Committee in February 2004. They apply to all railway tunnels, but they can be reduced for tunnels shorter than 1 km and should be adapted or enhanced for very long tunnels over 15 km.

For new tunnels, the report provides an overview of best practice, similar to the UIC leaflet; in addition it proposes that 19 of these measures could become minimum safety standards in the 55 member states. For existing tunnels, recommendations are given and mainly aim at minimizing the risk of accidents.

Technical Specifications for Interoperability
The European Association for Railway Interoperability (Association Européenne pour l'Interopérabilité Ferroviaire – AEIF: www.aeif.org) has started to draft a Technical Specification for Interoperability (TSI) on Safety in Railway Tunnels. AEIF is the joint representative body mandated by the European Commission to lay down the TSIs. It brings together representatives of infrastructure managers, railway companies and industry. It has been co-founded by UIC, UNIFE (Union of the European Railway Industries: www.unife.org) and UITP (International Union of Public Transport: www.uitp.com) and is supported by the European Commission. By 2005, the relevant working group has to propose the measures to become mandatory in new and upgraded tunnels on interoperable railway lines all over Europe.

3. SIGNIFICANT FEATURES AND TRENDS

We will not try to draw a synthesis of the various provisions for fire safe design which appear in the numerous guidelines we have mentioned. This is done in the following papers at this symposium. The aim of this section is to show that these provisions fit in an integrated safety approach, which takes into account the whole tunnel system: infrastructure measures are only a part of fire safety; fire safety is only a part of the global safety; safety is an aspect of the whole system. This section attempts to derive common trends of the new and future guidelines.

3.1 Convergent safety objectives

A basic point is to define the objectives for tunnel safety, including fire safety. A real convergence has appeared thanks to the international work of PIARC (report 'Fire and smoke control in road tunnels' of 1999) for road tunnels, UIC (leaflet 779-9 of 2003) for rail tunnels, and the UN ECE groups of experts for both road and rail tunnels. Some differences nevertheless exist between road and rail, due to their different characteristics and operation.
The general consensus is to give priority to the prevention of accidents and any critical events which may endanger human life, the environment and tunnel installations. This is important in all transport modes, but more efficient for rail and metro, which can achieve accident rates much lower than road. To limit accidents will also limit major fires. In road tunnels, most fires are initiated by the self-ignition of a vehicle (without any accident); however all known fires which entailed fatalities were the result of an accident, with the very important exception of the Mont Blanc tunnel fire.
As a second priority, the consensus is of course to limit the consequences of an accident if it has nonetheless occurred. At this stage, road tunnels should create the prerequisite for:

- people involved in the incident to rescue themselves;
- road users to intervene immediately to prevent greater consequences;
- ensuring efficient action by the emergency services;
- protecting the environment;
- limiting material damage.

Rail tunnels have the following order of priority:

- mitigate the impact of accidents;
- facilitate escape;
- facilitate rescue.

Clearly the final objective is the same: to save the people involved. In road tunnels, operating staff or rescue teams are not available on the spot in the first minutes, so that the priority is self-rescue and intervention by the users; this requires a number of measures such as detection, smoke control, emergency exits, etc. In rail tunnels, train drivers and crew are trained and available immediately; on the other hand, evacuation from the train requires time. Priority measures are first to drive the train out of the tunnel as far as possible, limit the importance of the fire (including through rolling stock measures), limit the spread of smoke, and only after these, to facilitate escape and rescue in the tunnel.

3.2 Provisions aiming at infrastructure, operations, users and vehicles

Traditionally, guidelines dealing with road tunnel safety were mostly, if not uniquely, dealing with the infrastructure and its equipment. Indeed this is an important topic, and the next papers will focus on infrastructure design. However concern about operation has started for many years. Historically, the first studies and recommendations were devoted to operation in normal conditions, and operation in case of an emergency, including emergency response plans, came later. These topics gave rise to national and international (PIARC) recommendations and were finally included in some national regulations.

The Mont Blanc and Tauern tunnel fires showed how important the response from the operator and emergency teams was in a dramatic situation, and that such response had to be properly prepared by careful planning and regular exercises. This led countries like France to include detailed provisions on operational means, including appropriate levels of tunnel surveillance, instructions to operators, emergency response planning, exercises, compulsory collection and evaluation of incidents and accidents, in their national regulations.

The Swiss road tunnel task force stressed the importance of users' behaviour and education, as well as the problems raised by the vehicles, whose flammability played a disastrous role in the Mont Blanc and Tauern fires. The UN ECE group of experts on road tunnel safety worked on the basis of these analyses and its recommendations were made in the following order, which gives an idea of the relative cost-effectiveness of the measures:

1. Road users
2. Operation
3. Infrastructure
4. Vehicles

The proposed European directive for tunnels on the Trans-European Road Network does not reflect the same priorities and mainly deals with infrastructure and operation, although it does contain provisions related to the users, including information campaigns. The reasons given by the European Commission is that other legislation will deal with users behaviour and vehicles.

The important role for safety of the rolling stock and operations had been recognized long before for train and even more metro tunnels. The recommendations of the UN ECE group of experts on rail tunnel safety include infrastructure, rolling stock and operational measures. Human behaviour is not specifically mentioned, but a number of measures deal with the preparedness of the train crews, operational railway staff and emergency services, including training, emergency planning and exercises. Recommendations are also given on emergency information for passengers.

3.3 A holistic approach

The previous paragraph shows that the most recent guidelines on tunnel safety include provisions regarding users, operation, infrastructure and vehicles. This means that all these aspects are important for safety and interact. As a consequence, measures concerning each aspect should not be decided independently from those concerning the other ones. It is necessary to take into account the whole tunnel system, if not the whole transport system which includes the tunnel: this is what we will call a 'holistic' approach.
Such an approach is not new for metro tunnels, whose safety is very dependent upon the rolling stock, neighbouring stations, operation, etc. It is probably a little newer for tunnels on main rail lines. The UN ECE group of experts dealing with them has highlighted the need for what they call a 'system view' and stated that 'cost-effective safety in rail tunnels is the result of the optimum combination of infrastructure, rolling stock and operational measures'.
A holistic approach is still newer for road tunnels and only appears in some recent guidelines. A demonstrative example is given by the current draft of the proposed European directive. The beginning of its annex devoted the safety measures states that 'safety measures to be implemented in a tunnel shall be based on a systematic consideration of all aspects of the system composed of the infrastructure, operation, users and vehicles'. A list of parameters which shall at least be taken into account follows.

3.4 Prescriptive versus performance-based approach

A holistic approach is hardly compatible with fully prescriptive guidelines, which do not make it possible to take into account all the characteristics of the tunnel system.
The most developed guidelines for tunnel safety are those for road tunnels. These guidelines are traditionally prescriptive, which means that safety provisions directly result from some characteristics of the tunnel, such as length, number of tubes, traffic, percentage of heavy goods vehicles, etc. Such guidelines are based on a tunnel classification, which is more or less complex and can be presented as such, for instance in a table or a graph, or not. The main advantage of prescriptive guidelines is probably the simplicity of their use. They also ensure uniformity in tunnels, which is favourable to obtain an appropriate behaviour of road users, because they more easily know which safety facilities are available in a tunnel, from their experience of other ones. A serious drawback is that prescriptive guidelines do not lead to optimal choices with regard to cost-effectiveness. But the major risk is that owners, designers and operators may forget to really think about the safety of the tunnel: they implement the required measures and may not examine how the system works as a whole.
On the other hand, purely performance-based approaches are not used for road tunnel design, although there are some examples for rail and metro systems, e.g. in the UK. A purely performance-based approach means a fully free design, with the only constraint that given safety criteria are met and demonstrated through a risk analysis. Several reasons limit the use of such approaches, including the difficulty to set detailed quantitative safety objectives and the unwillingness of a number of countries to publicise such criteria as e.g. accepted number of fatalities. But the basic problem is the lack of reliable quantitative risk analysis tools to demonstrate that the objectives are met: such tools are extremely difficult to develop and comparison tests between existing models show large discrepancies in the results; in any case, uncertainties will remain large. Another difficulty is that leaving complete freedom in the design may lead to very different safety facilities in different tunnels, which would be detrimental to appropriate user behaviour. This is especially important in road tunnels, where self-rescue is the main objective and requires that users easily find the safety facilities.

Although design is very rarely performance-based only, a number of new standards include some part of performance-based or at least risk-based analysis, as a complement to prescriptive provisions:

- A risk analysis can be required to choose between alternative solutions, e.g. where the prescriptive approach is not able to give the best solution because a number of factors are not taken into account in the underlying classification but have a significant role.
- Risk analysis may also be required to check the general consistency of the design and operation. As the design is generally made facility per facility when using prescriptive guidelines, the functioning of the whole system has to be checked through a 'transversal' examination. For this purpose, the draft European directive on safety in tunnels on the Trans-European Road Network requires 'specific hazard studies' in which all possible accident scenarios are examined.
- A further step appears in some guidelines, which define reference safety facilities with prescriptive provisions, then allow deviations from some or all prescriptions provided that a risk analysis shows that the proposed design is at least as safe. This is envisaged in certain cases in the aforementioned draft European directive on road tunnels, and also in the UN ECE recommendations for rail tunnel safety.

3.5 Provisions to check the safety of tunnels

A seemingly new question was raised by the investigation into the Mont Blanc fire: which procedures were implemented to make sure that the tunnel was safe. This fire occurred some 34 years after the tunnel was opened. Although the structure and equipment were globally well maintained, the tunnel did not have the same safety features as recent ones. While a number of countries had some kind of verification of new structures, it appeared that very few, if any, had compulsory procedures to ensure an independent check of the safety of in-service tunnels.

France has consequently implemented a regulatory system to fill this gap. Elaborating on this basis, the draft European directive defines for each road tunnel the respective responsibilities of an administrative authority, a tunnel manager, a safety officer and an inspection entity. Among other provisions, the following procedures would apply to all tunnels longer than 500 m on the Trans-European Road Network:

New tunnels:

- Construction works cannot begin before the tunnel manager has submitted a safety documentation to the administrative authority.
- The initial opening to traffic is subject to an authorisation by the administrative authority (commissioning).
- Every six years, the inspection entity must carry out an inspection; the administrative authority may request measures to improve safety on the basis of their report.
- Any substantial modification of the infrastructure or operation requires a new authorisation to operate from the administrative authority.

Existing tunnels:

- The compliance of all existing tunnels with the directive must be assessed by the administrative authority within 30 months and remedial measures implemented if necessary. After this, existing tunnels are submitted to the same procedures as new ones.

For all these steps, the tunnel manager must establish and keep up-to-date a complete safety documentation, which includes the opinion of an independent expert.

4. CONCLUSION

Although concern about safety in tunnels did not start with the dramatic fires of the last years, these catastrophes have led to a profusion of initiatives due to the involvement of public opinions and political leaders.
The first and most important actions concerned road tunnels. In addition to previous international work by PIARC, ITA, OECD, new reflections have been carried out in many countries and research projects and thematic networks launched by the European Union. In order to avoid inconsistencies between countries, harmonisation of regulations and recommendations has been looked for and at least partly obtained, firstly thanks to the group of experts on road tunnel safety created by UN ECE. A new European directive is currently being discussed by the European Parliament and Council and should lead to harmonised road tunnel safety regulations throughout the European Union.
Similar developments have taken place for rail tunnels, even though fewer provisions are devoted to their safety. In the first place, the railways jointly worked at common recommendations which have been published as an UIC leaflet. Their work was used as a basis by the group of experts on rail tunnel safety created by UN ECE, which has just finalised its recommendations and proposed part of them to become minimum standards for new tunnels. A new step is ongoing in a working group of AEIF, which is due to propose compulsory provisions for new and upgraded tunnels on interoperable lines.
Recent and future guidelines converge on common safety objectives and take into account not only the infrastructure, but the whole system composed of the users, operation, infrastructure and vehicles. This holistic approach is accompanied by a move of the safety guidelines from purely prescriptive provisions to incorporating more performance/risk-based approaches, at least as a complement. In many cases, tools and minds are not yet prepared for fully performance-based design.
An important new feature, which appears in the draft European directive on minimum requirements for tunnels on the Trans-European Road Network, is the implementation of compulsory procedures aimed at ensuring that a tunnel is safe when opened to traffic, and remains so later, with regular inspections of the structure and operation. Existing tunnels will also have to be checked and meet minimum standards.

5. LITERATURE

No literature list is given, because the reader can refer to the websites mentioned in the paper.
Three lists of guidelines on fire safe design for road, rail and metro tunnels are available on the FIT website: www.etnfit.net. Interested readers can freely register on the website as corresponding members and will then be able to download these lists, which include an analytical summary and a translation in English of the table of contents.