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28–30 April 2014, Split, Croatia

## Road and Rail Infrastructure III

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## SAFETY MEASURES IN ROAD TUNNELS

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### Abstract

Road tunnels today, because of their technological and traffic characteristics, belong to the group of highly complex structures. Tunnel safety is primarily a social and then an economic category. It is determined by the relations between road users, vehicles, transportation infrastructure and other factors in its dynamic system. Fire and other major accidents that can occur in road tunnels not only cause direct costs due to the resulting damages and closure, but also threaten human communities and markets related to tunnels. Therefore, it is evident that a high level of safety in tunnels provides a wide range of benefits. This paper will analyse basic safety elements that should be taken into account when designing road tunnels. It will provide an overview of the basic traffic safety elements which are implemented in road tunnels in Croatia.

*Keywords: road tunnels, traffic safety, tunnel design*

### 1 Introduction

Tunnels are underground structures that must, in a safe manner, enable traffic to people and goods between two geographic points on Earth, divided by natural or man-made obstacles. The increase in traffic leads to a growth in risks from accidents in tunnels. Therefore, it is necessary to raise the level of traffic safety to an adequate and socially acceptable level by installing various systems that enable traffic safety. Accidents in tunnels often cause terrible consequences for road users, whereby even a minor incident can result in significant material damage and loss of human lives. Therefore, utmost care should be taken when equipping tunnels with systems such as power supply, lighting supply, ventilation and other safety systems that are fundamental elements for establishing high-level safety required in tunnels. This paper will present measures necessary to prevent accidents and to establish the highest level of safety in road tunnels.

### 2 Minimum safety requirements for tunnels

#### 2.1 Minimum safety requirements for tunnels according to the EU Directive

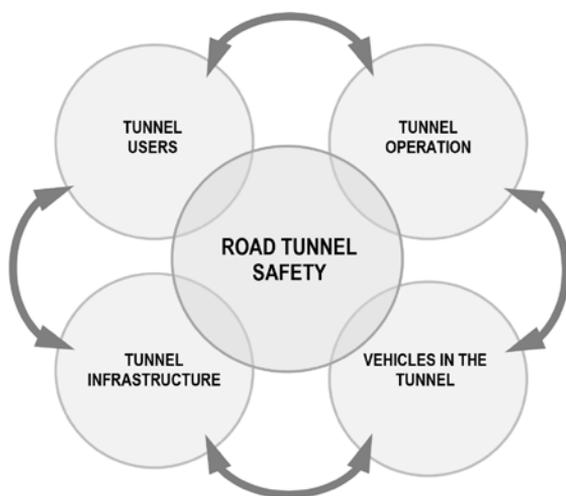
The regulation that defines the minimum safety requirements for tunnels as engineering structures is the “Ordinance on minimum safety requirements for tunnels” [1], being the Croatian national regulation, which actually represents alignment of the Croatian legal system with the EU Directive [2].

The EU Directive [2] was issued at the level of the European Union with the objective of aligning the minimum requirements of the national rules and regulations of the member countries, with the aim of raising and harmonising the level of safety in European road tunnels. Although its provisions are formally only applied to trans-European road tunnels over 500 m

long, they are often applied to tunnels outside this network as a minimum safety criterion. When examining the level of safety in tunnels, we examine factors that can be classified into four main groups, as shown in Figure 1. The stated factors affect safety both individually, as well as in their interaction. Taking into consideration their interplay, it can be concluded that traffic safety as a whole is an extremely complex issue. The Croatian safety system, introduced on the basis of the EU Directive [2], has set forth the following functions/institutions for road tunnels:

- Administrative Authority;
- Tunnel Manager;
- Safety Officer;
- Inspection Entity;
- Emergency Services.

An important element of tunnel safety is the safety documentation, which must contain descriptions of all prevention and safety measures, as well as information essential for safety.



**Figure 1** Safety factors in tunnels

## 2.2 Traffic signs and traffic safety

Factors that affect road traffic safety in general are: road route, technical road elements, condition of roadway, road equipment, lighting, intersections and road maintenance system. In global analyses of road traffic accidents, the following factors are always taken into account: man as road user, vehicle, road, traffic environment and incident factors.

Road traffic encompasses:

- Traffic organisation (traffic regulations and technical means for traffic organisation);
- Traffic management;
- Traffic control (monitoring traffic flow and volume, intervention in emergencies, recording and analysing traffic accident statistics).

Traffic signs are one of the characteristics of roads. The basic role of traffic signs is to promote safety and to successfully manage traffic flow. Traffic signs are used to inform road users on the condition of the road, allowing safe and unhindered traffic flow. Traffic signs must be simple, clear, understandable, visible, unambiguous, universal, continuous, appropriately designed and placed in sufficient quantity (Figure 2).

## 2.3 Weather conditions and traffic safety

Weather conditions in traffic, as well as properly observing and measuring them, exhibit a significant influence on the safety of road users. When analysing weather conditions, the following data are measured: air temperature, roadway temperature, roadway humidity, roadway state, presence of salt and chemicals, intensity and quantity of different types of precipitation, air pressure and humidity, wind speed and direction, snow height, degree of iciness, freezing point, visibility and road illumination.



Figure 2 Example of properly installed traffic signs in a tunnel [3]

Obtaining reliable meteorological data is a complex process which is essential for road traffic safety. Reliable and accurate information is crucial both to end users of roads, as well as to road maintenance services for the purpose of road safety and maintenance.

## 2.4 Procedure in case of emergency in tunnels

An important safety factor refers to the procedure in case of emergency, defined in the instructions on proper steps to be taken in case of emergency in tunnels. Incidents can occur at any moment, while the proper steps to be taken can prevent greater damage and enable safe flow of traffic for other road users. The instructions refer to basic steps in case of the following incidents:

- Traffic hold-up in tunnel;
- Vehicle breakdown in tunnel;
- Traffic accident in tunnel;
- Fire in tunnel.

## 3 Euro Tap project

### 3.1 EuroTAP project methodology

EuroTAP (European Tunnel Assessment Programme) [4] is one of eight research projects on tunnel safety and is directly related to raising the level of traffic road safety. It was established on the basis of European Directive 2004/54/EC [2]. The EuroTAP project includes 11 automobile clubs from 10 European countries. The testing of each tunnel is conducted through the following steps [5]:

- Meeting with tunnel operator and collecting basic information on the tunnel;
- Driving through the tunnel in the presence of the tunnel operator;
- Inspection of characteristic locations;
- Random control of safety equipment;
- Taking photos of the tunnel;
- Inspection of the tunnel control centre.

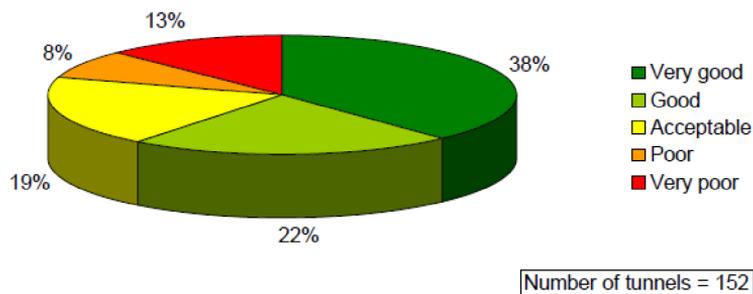


Figure 3 Total result for the years 2005 to 2007 [5]

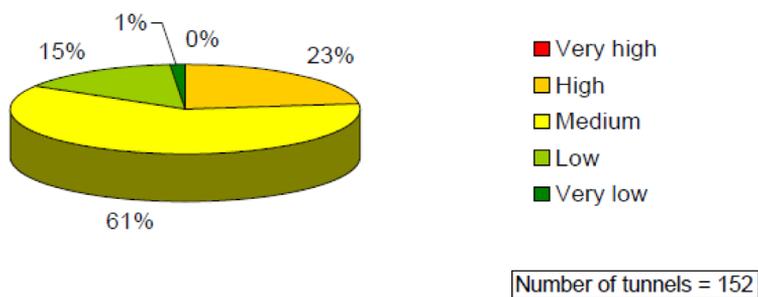


Figure 4 Distribution of the risk potential for the 2005 to 2007 period [5]

### 3.2 EuroTAP project results in the period from 2005 – 2007

In the period from 2005 to 2007, the safety of 152 tunnels was inspected as part of the EuroTAP project. The results show that most of the tested tunnels received a positive grade (Figure 3.). The grade distribution, presented in Figure 3. shows that a surprising 21% of tunnels, that is, every fifth tunnel, received a negative grade (poor and very poor). The main inadequacies in the individual categories, that is, the areas that received the poorest grades are the following:

- Non-existence of loudspeakers;
- Insufficient number of lanes;
- Low level of illumination;
- Non-existence of information signs on portals;
- Non-existence of evacuation lighting and signs in case of emergency;
- Lack of appropriate fire protection equipment for protecting the respiratory tract;
- Lack of equipment for inspecting longitudinal air flow;
- Irregular conducting of safety drills;

By examining the distribution of risk potential for the tunnels tested in the observed time period, it is evident that a surprising 23% of tunnels had a high risk potential, as can be seen in Figure 4.

## 4 Assessment of road tunnel safety

The safety assessment encompasses all safety measures that have to be undertaken and that refer to tunnel structure, technical equipment and tunnel organisation. It is divided into eight categories, as shown in Table 1. The linking of influence factors and safety measures that should be analysed and applied when planning and designing new tunnel systems is provided in Table 2 and Table 3.

**Table 1** Review of safety measures [1, 2, 5]

Category of safety measures	Safety measures
Tunnel system	<ul style="list-style-type: none"> <li>· Number of tubes;</li> <li>· Width and layout of traffic lanes;</li> <li>· Geometry and layout of emergency lanes/lay-bys;</li> <li>· Geometry and layout of emergency walk-ways;</li> <li>· Brightness of tunnel walls;</li> <li>· Additional measures (portal design, road surface, tunnel route).</li> </ul>
Lighting and power supply	<ul style="list-style-type: none"> <li>· Lighting throughout and adaptation zones;</li> <li>· Power supply (utility and internal);</li> <li>· Emergency power supply.</li> </ul>
Traffic and traffic surveillance	<ul style="list-style-type: none"> <li>· Congestion in the tunnel;</li> <li>· Speed limits;</li> <li>· Control centre;</li> <li>· Restrictions for and/or registration of vehicles carrying hazardous goods;</li> <li>· Automatic detection of traffic and congestion;</li> <li>· Video surveillance;</li> <li>· Traffic control (traffic lights, variable traffic signs, signs, etc.);</li> <li>· Measures to close the tunnel (traffic lights, barriers, information displays);</li> <li>· Traffic signs;</li> <li>· Visual guidance equipment;</li> <li>· Additional measures (e.g. for heavy goods traffic, monitoring the distance between vehicles and speed, automatic recognition of hazardous goods traffic, height detectors).</li> </ul>
Communication	<ul style="list-style-type: none"> <li>· Loudspeakers;</li> <li>· Traffic radio;</li> <li>· Emergency phones (distance, signs, functions, insulation against traffic noise);</li> <li>· Tunnel radio.</li> </ul>
Escape and rescue routes	<ul style="list-style-type: none"> <li>· Distance between emergency exits;</li> <li>· Emergency exit signs;</li> <li>· Prevention of smoke from penetrating escape routes, fire rating of doors;</li> <li>· Evacuation lighting and escape route signs in the tunnel;</li> <li>· External access for fire and rescue services;</li> <li>· Access routes for fire and rescue services;</li> <li>· Additional measures (special lighting for emergency exits, signs showing what to do, barrier-free emergency exits).</li> </ul>
Fire protection	<ul style="list-style-type: none"> <li>· Fire protection of the tunnel structure;</li> <li>· Fire resistant cables;</li> <li>· Fire alarm systems (automatic/manual);</li> <li>· Extinguishing systems (arrangement, signs, functions);</li> <li>· Drainage system (system for draining flammable or toxic liquids);</li> <li>· The time it takes for the fire brigade to arrive;</li> <li>· Fire brigade training and equipment.</li> </ul>
Ventilation	<ul style="list-style-type: none"> <li>· Ventilation in normal mode to thin out vehicle emissions;</li> <li>· Special fire programmes;</li> <li>· Control of the longitudinal flow in the tunnel and consideration of this in ventilation control;</li> <li>· Temperature stability of facilities and equipment;</li> <li>· Proof of correct functioning in fire trials and by flow measurements;</li> <li>· Longitudinal ventilation (Air flow rate, Length of ventilation sectors, Air flow in the direction of traffic, Reversible fans);</li> <li>· Transverse/semi-transverse ventilation (Volume flow of extraction, Capacity to control longitudinal flow, Opening/closing of the exhaust air outlets can be controlled).</li> </ul>
Emergency management	<ul style="list-style-type: none"> <li>· Emergency response plans;</li> <li>· Automatic linking of the systems;</li> <li>· Measures in the case of an accident or fire;</li> <li>· Regular emergency drills;</li> <li>· Regular training for tunnel control centre staff;</li> <li>· Maintenance plan.</li> </ul>

**Table 2** Possible evaluation of influence factors [5]

INFLUENCE FACTORS	HAZARD POTENTIAL				
	VERY LOW	LOW	MEDIUM	HIGH	VERY HIGH
Length of tunnel [m]	500 – 1.000	1.000 – 1.500	1.500 – 3.000	3.000 – 5.000	> 5.000
Volume of traffic [vehicles/day/lane]	< 2.000	2.000 – 5.000	5.000 – 10.000	10.000 – 15.000	> 15.000
HGV percentage [HGV mileage/day/tube]	< 500	500 – 2.000	2.000 – 6.000	6.000 – 12.000	> 12.000
Hazardous goods traffic [No. of HGVs/day]	< 10	10 – 50	50 – 300	300 – 1.000	> 1.000
Gradient in the tunnel [%]	< 1	1 – 3	3 – 5	5 – 7	> 7
Speed [km/h]	< 50	50 - 70	70 - 90	90 - 120	> 120
Access time for emergency services [min]	< 5	5 -170	10 - 15	15 - 20	> 120

**Table 3** Linking influence factors and safety measures [5]

SAFETY MEASURES	LENGTH	Volume of traffic	Percentage of HGVs	Traffic routing	Hazardous goods	Speed goods
<b>I.Prevention</b>						
Number of tubes		•		•		
Lane width			•	•		•
Lay-bys	•	•				
Lighting in the tunnel	•	•	•	•		•
Video surveillance	•	•			•	
<b>II.Detection</b>						
Incident detection	•	•			•	
Fire alarm system	•	•				
SOS phones		•				
<b>III.Self-rescue</b>						
Emergency exits	•	•				
Ventilation system	•	•		•		
<b>IV.Incident management</b>						
Barriers/information displays to close the tunnel	•	•				•
Tunnel radio	•	•				
Rescue routes for emergency service vehicles	•			•		

## 5 Characteristics of tunnels on Croatian motorways

Croatia has a total of 42 kilometres of tunnels on motorways, of which 11 are over 1,000 m long. The longest Croatian tunnels are Mala Kapela, Sveti Rok, Učka, Sveti Ilija, Plasina, Tuhobić, which are over 2,000 m long, while Učka is the only tunnel consisting of only one tube without an additional service tube [6]. Concerning safety, Croatian tunnels maintain a high standard, which is supported by the EuroTAP project results [4]. In 2005, Plasina tunnel took third place. In 2006, Grič tunnel was ranked second, whereas in 2007, Brinje tunnel was declared the safest tunnel in Europe. The main positive characteristics of Croatian tunnels on motorways are evident from the following [6]:

- They are built as dual-tube or single-tube with an additional service tube;
- Complete video surveillance;
- Lay-bys and connections to the other tube;
- SOS telephone system installed and fire extinguishers available;
- Larger tunnels are managed from traffic control centres.

## 6 Conclusion

Tunnels, as road structures, represent an important element of traffic infrastructure, in particular of motorway networks. Longer traffic hold-ups due to accidents are not acceptable, let alone human casualties that can be avoided by applying contemporary safety systems and measures. The EuroTAP tunnel test is a key factor for introducing measures defined by EU Directive (2004/54/EC) and national regulations of individual member countries, which should be taken into consideration already in the design phase in order to raise safety levels in tunnels. Analysing the tunnel network in the Republic of Croatia, it can be concluded that the tunnels possess a satisfactory level of safety. They are equipped with state-of-the-art fire protection and fire alarms, dynamic signs and video surveillance systems, as well as other control and management systems that significantly contribute to raising the level of safety in tunnels.

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