OPERATION EXPERIENCES AND SAFETY ASPECTS REGARDING LOW TRAFFIC TUNNELS IN NORWAY

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ABSTRACT

Norway is one of the countries in the world that has the greatest length of tunnels on its road network. The total number of tunnels is 990 with a total combined length of 850 km. As the population is small, the traffic density is very modest in most of these tunnels. Norwegian tunnels have much less traffic than road tunnels in the rest of Europe.

Almost all tunnels (about 99%) are owned by the government. The Public Roads Administration is the administrative authority of all tunnels in Norway. The local fire brigades, in accordance with national rules, are the inspection body for fire safety in the tunnels. The Public Roads Administration operates all of the tunnels from five control centres. The centres detect and monitor incidents, traffic flow and pollution. In the case of an accident, they are authorized to stop traffic and initiate a response from the emergency services.

Most of the tunnels are built to a relatively basic standard, and have little safety equipment. In spite of this, statistics show that there are few accidents in Norwegian road tunnels. Self rescue has always been the main philosophy in safety planning in low traffic tunnels. Fortunately, up to now, there has not been a fire with dramatic consequences in any Norwegian tunnel.

Contractors are responsible for the maintenance of the tunnels. During the last decade reinvestments and improvement of installations have made up a very high percentage of the annual costs for maintenance and operation. The need for refurbishment will increase even further in the next 10-15 years with the introduction of new and stricter rules.

Guidelines for the construction and safety improvements are based on experience from operation and maintenance, as well as the results of research.

KEY WORDS

TUNNEL / OPERATION / ACCIDENTS / SAFETY ASPECTS

1. TUNNELS IN NORWAY

Tunnels have played an important role in the Norwegian road system. As of 2003, there are a total of 990 tunnels, with a total length of 850 km on the public road network.

Table 1 – Tunnels in Norway

Length of tunnel	Number of tunnels
< 500m	574
500 – 3000 m	358
> 3000 m	58

Virtually all of the road tunnels have been built in the course of the last thirty years. In spite of this the standard of equipment used in most tunnels is quite basic. The reason for this is the relatively low traffic densities in most of the tunnels.

The traffic volume in tunnels in the rest of Europe is about ten times as high as that in Norway. For some tunnels, for instance the 24.5 km long Lærdalstunnel, the AADT (Average Annual Daily Traffic) is only about 1100 veh./day.

Nearly all of the tunnels are built in rock, and are driven using conventional drill and blast methods.

There are also several sub-sea tunnels that have been built to provide access to small island communities or as fjord crossings. There are a total of 24 sub-sea rock road tunnels, with a total length of 100 km, in use today. The longest tunnel is 7.9 km, and the deepest is 246 m below sea-level. These tunnels typically have very steep inclines, with gradients up to 10%. The AADT for these tunnels normally lies between 500 and 4000 veh/day. Some of these tunnels have three lanes.

In almost all tunnels built in rock, there is water ingress. Because Norway straddles the Arctic Circle, it can be very cold during the winter. Sub-zero temperatures can be expected during six months of the year. This necessitates that the tunnels must be insulated against frost. Different types of insulated arches have been used for this. Many of the arches perform poorly with respect to maintenance and fire safety.

Nearly all Norwegian tunnels use longitudinal ventilation. Ventilation shafts are seldom used. For example the 24.5 km long Lærdalstunnel has only one ventilation shaft.

2. OPERATION AND MAINTENANCE

Almost all tunnels on Norwegian roads (99 %) are owned by the government. Originally the Public Roads Administration was responsible for both the operation and maintenance of these tunnels. However, one year ago this was changed and, during 2003, the responsibility for maintenance has been transferred to private contractors. For this reason the Road Authorities have only limited experience in this new way of organizing and splitting the work. The table below describes the current split of responsibilities:

- Maintenance - By contractor
- Traffic operation (from control centre) - By Public Roads Administration
- Tunnel management and traffic installations - By Public Roads Administration
- Maintenance planning - By Public Roads Administration
- Incident management (help with accidents) - By Public Roads Administration and contractor

The Public Roads Administration are the administrative authority, acting on behalf of the Ministry of Transport, providing rules and guidelines for the construction, operation and maintenance of road tunnels. For each tunnel longer than 500 m, the tunnel owner is obliged to produce a safety and emergency plan involving the fire brigade, police and emergency service. The local fire brigade is responsible for inspection of all safety equipment in the tunnels in accordance with national rules. If there is a difference of opinion, between the tunnel owner and the local fire brigade, this is settled by the national Fire Brigade.

As mentioned above there are about 1000 tunnels in Norway. These tunnels are scattered all over the country, most of them being outside towns and urban areas. Several years ago it was decided to centralise surveillance and road-management systems in a limited number of control centres. The Public Roads Administration is organized into five regions. It was resolved that one control centre would be situated in each of these regions.
So, a control centre is located at one of the district road offices (except in Oslo) in each of the regions. There are no plans for establishing any new control centres.

Figure 1 – 5 control centres for all public roads in Norway

There are often long distances between the tunnels and the control centre, and in some cases they just serve as a call centre. These control centres have round the clock traffic-surveillance. They monitor incidents, traffic flow, pollution etc. The equipment and routines are continually under review and being improved.

All tunnels, longer than 500 metres, usually have more than one of the following alarm systems connected to a control centre:

- Emergency telephones
- Fire extinguishers (with automatic alarm)
- Automatic fire detection cables
- Cameras at the tunnel entrances (very few tunnels have cameras throughout the length of the tunnel)

If there is an accident and an alarm is raised, the traffic will be stopped by signs, traffic lights or barriers activated from the control centre. The centres can also call out the fire and rescue services, as well as the police, if required. When responding to a call the police and fire brigades are only responsible for their own activities (e.g. traffic and rescue management, management of fire extinguishing and juridical aspect of accidents).

In a maintenance context, tunnels are divided in the tunnel structure, the road substructure, the road-surface and mechanical and electrical (M&E) systems.

Maintenance activities are, as far as possible, based on systematic routines carried out at regular intervals. Life cycles are considered as a basis for maintenance of both structures and M&E systems. Optimisation of the maintenance frequency should reduce the probability of undesirable replacement of parts. Systematic maintenance is based upon one of the following methods:

- Maintenance based on the calendar (for instance change of fire extinguishers)
- Maintenance based on operating hours (for instance change of bulbs)
- Maintenance based on technical condition (for instance new rock bolts)

In tunnels there are several M&E systems which have to be periodically replaced in part or in their entirety. Among these are electrical systems, computer control systems, fire extinguishers and pumped drainage systems. In sub-sea tunnels it is particularly important to replace and improve pumps and the drainage facilities. In some tunnels, carrying particularly low traffic flows, doors are provided to give frost protection. These require regular maintenance but are increasingly falling into disuse.

Reinvestment and improvement of installations to fulfil new standards (particularly safety standards) constitutes a very high percentage of the annual maintenance costs. These refurbishment costs will be even higher during the next decade because of new and stricter safety guidelines.

Electricity costs constitute between 25 and 50% of the annual operating costs in most tunnels. This electricity usage is primarily on lighting and ventilation. In long tunnel it is the ventilation power costs which dominate. Some of the other costs incurred include staff for inspection and surveillance, cleaning, training and exercise, telephone and information systems. As a result of the strong increase in electricity prices, operative costs for tunnels will increase proportionally.

3. TRAFFIC AND FIRE SAFETY

In 1997 a large accident investigation program was carried out on Norwegian tunnels. (Amundsen, 1997).

Data on accidents and location were retrieved from the Road Data Bank for the five years 1992 to 1996 inclusive, and grouped into the following four categories:

- Zone 1 - The first 50 m before the tunnel entrance
- Zone 2 - The first 50 m inside the tunnel
- Zone 3 - The next 100 m inside the tunnel
- Zone 4 - The mid-zone, i.e. the remainder of the tunnel (until the other zone 3)

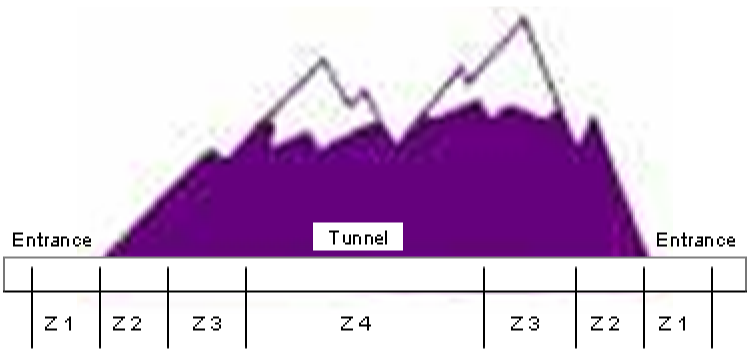

Figure 2 – Location of accident zones

The investigation covered 588 tunnels opened in or before 1992. The average AADT for these tunnels was 3500 vehicles/day. Altogether 499 accidents with personal injuries were registered in the course of the five years in one third of the tunnels. Put in another way – there were no accidents with injuries in two thirds of the tunnels.

Table 2 - Accidents

	Accidents with personal injuries	Accident frequency (Accidents per million veh. km per year)
Zone 1	127	0,30
Zone 2	94	0,23
Zone 3	97	0,16
Zone 4	181	0,10
Within tunnel (zones 2+3+4)	372	0,13
National roads in the open (average for two lanes)		0,25

The investigation found that the accident frequency in zone 1 was three times as high as that in zone 4 (mid-zone). The accident frequency is reduced proportionally with increasing tunnel length and width. When accidents in tunnels are compared with those on the surface, there is a relatively higher occurrence of accidents between vehicles driving in the same direction. In tunnels with two-way traffic there are relatively more head on collisions than on the surface.

A total of 745 persons were injured in the 499 accidents in this study. The grade of seriousness of the injuries in the various tunnels is shown below. (Average for the years 1992-1996.)

Table 3 – Killed or injured

Severity	Zone 1	Zone 2	Zone 3	Zone 4	Total	Within tunnel (zones 2+3+4)	National roads in the open
Killed	6	1	2	17	26	20 (3.6%)	185 (2.8%)
Very seriously injured	1	5	2	5	13	12 (2.1%)	118 (1.8%)
Seriously injured	21	15	20	30	86	65 (11.6%)	655 (9.9%)
Slightly injured	155	121	123	221	620	465 (82.7%)	5 643 (85.5%)
No. killed or injured	**183**	**142**	**147**	**273**	**745**	**562**	**6 601**

The proportion of those severely injured in tunnel accidents is higher than for surface road accidents.

Other investigations show that there is a noticeable increase in the number of accidents in the entrance zones when the road surface is wet, or when there is snow and ice in the entrance zone of the tunnel.

In 2001 an investigation was made into car fires in tunnels over the last 10 years. (Amundsen, 2001). Sixty seven car fires were reported in tunnels in the course of this period. Heavy vehicles stood for more than their fair share of fires representing 30% of the total. Most fires started in the engine or electrical installations of the vehicles. Personal injuries were registered in 6 cases where the collision resulted in a fire.

It is likely that the real number of fires is somewhat higher than determined in the study. If we assume a total of 100 car fires in 10 years, the average will be 10 fires a year. With almost 1000 tunnels in Norway, this is 1 car fire per 100 tunnels per year. Statistically it is about 100 years between car fires in an average Norwegian tunnel. Nevertheless, it is still necessary to be prepared for a car fire tomorrow in every tunnel!

The structure and equipment in all tunnels are designed and constructed to tolerate fires of a specified size. Tunnels with traffic less than 10 000 vehicles/day are designed to resist a 5 MW fire, and tunnels with higher flows a 20 MW fire. Very rarely are full scale fire-tests carried out to verify emergency procedures and smoke control systems.

Vehicles transporting dangerous goods have access to almost all Norwegian tunnels. There are, today, less than 10 tunnels closed to such vehicles. Usually, a risk analysis is performed before any restrictions are placed on the traffic which may pass through a tunnel.

Enquiries have also been made as to the cause of break-downs in tunnels. These stoppages cause much disruption to traffic, and are a cause of at least as many accidents as car-fires. Research has shown that the vast majority of break-downs are caused by engine-failures. The next most common cause is an empty fuel tank. Together these occurrences are the cause of about 75% of break-downs.

A great number of the tunnels are situated some considerable distance away from the nearest fire brigade station and other emergency services. If something happens in tunnels or on the road outside the tunnel, people are accustomed to trying to save themselves. The main philosophy in safety planning in Norwegian tunnels has, for a long time, been that of self rescue. Fortunately, up to now, there has never been a fire with dramatic consequences.

4. TUNNEL GUIDELINES FOR SAFETY EQUIPMENT

New guidelines for the construction, operation and maintenance of Norwegian road tunnels, including recommendations for the improvement of existing tunnels, were published in 2002. The guidelines are based on experience from Norwegian road tunnels in the course of the last few years, as well as research and experience from other countries.

Tunnels are classified in terms of their geometrical design and level of technical installation (see Figure 3 and Table 4 below). The standard levels increase with traffic density and tunnel length.

Traffic density is normally measured in AADT, and is defined as the sum of traffic in both directions. The tunnel classification is based on the traffic volume that is expected 20 years after the tunnel is opened.

Altogether there are 6 tunnel classes, where class F has the most safety equipment.

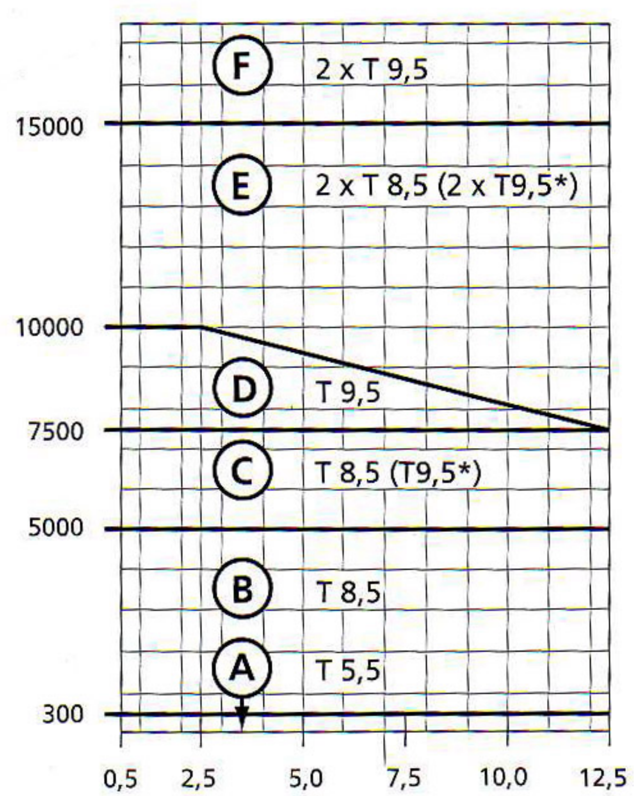

Figure 3 – Tunnel classes (AADT and tunnel length in km)

An example of a typical tunnel cross-section is shown in the figure below.

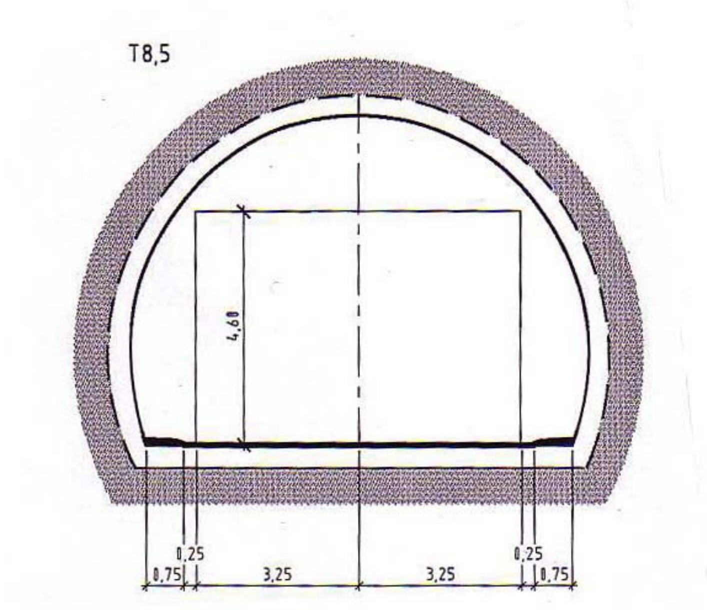

Figure 4 - Typical tunnel cross section for one tube tunnel with bi-directional traffic

Table 4 - Safety equipment in different tunnel classes

EQUIPMENT	TUNNEL CLASSES						COMMENTS
	A	B	C	D	E	F	
Break-down niches		●	●	●	●	●	
Turning niches		●	●	●			
Pedestrian escape possibilities					●	●	Inter-tunnel access every 250 m
"No-break" electricity supply - emergency generators		●	●	●	●	●	Tunnel-lighting during power-cuts
Evacuation lighting			O	●	●	●	Ca 62.5 m spacing
Emergency exit signs					●	●	Must be complied with in other tunnel classes that have alternative exits.
Emergency telephones		●	●	●	●	●	Class B: every 500 m Class C: every 375 m Class D: every 250 m Class E: every 500 m Class F: every 250 m
Fire extinguishers	O	●	●	●	●	●	Class B: every 250 m Class C, D: every 125 m Class E: every 125 m Class F: every 62.5 m
Water for fire-fighting		●	●	●	●	●	
Blinking red stop signal		●	●	●	●	●	
Remote controlled barriers for closing the tunnel		O	O	O	O	●	To be evaluated, based on expected frequency of use.
Remote controlled variable traffic signs		O	O	O	O	O	
Traffic-lane signalling					O	O	
ITV surveillance					O	O	
Communications and broadcasting equipment		●	●	●	●	●	
Cellular telephones		O	O	O	O	O	To be clarified with cellular operator
Height obstruction	●	●	●	●	●	●	

● = obligatory   O = to be evaluated

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