UNITED
NATIONS

E

Economic and Social Council

Distr.
GENERAL

TRANS/AC.7/2000/3
3 May 2000

Original: ENGLISH

ECONOMIC COMMISSION FOR EUROPE

INLAND TRANSPORT COMMITTEE

Ad hoc Meeting of the Multidisciplinary
Group of Experts on Safety in Tunnels
(First session, 10-11 July 2000,
agenda item 4)

TRANS-EUROPEAN MOTORWAY (TEM) STANDARDS AND RECOMMENDED PRACTICE

Note by the secretariat

TRANS-EUROPEAN NORTH-SOUTH MOTORWAY (TEM)
Meeting of Group of Experts on TEM Standards
27-30 March 2000, Prague, Czech Republic

1. Members of the Group, assisted by invited tunnel specialists from Austria, the Czech Republic, Italy, Slovakia and Turkey examined and re-drafted Chapter 8 of the Standards and Recommended Practice (Tunnels) in order to reflect the present state-of-the-art of tunnel design as well as the lessons learned from the recent accidents in motorway tunnels through the Alps.

2. The final revised text of Chapter 8 of the TEM Standards and Recommended Practice is attached to this document.

* * *

8 TUNNELS

8.1 Scope

Tunnels represent an integral part of the motorway.

The insertion of a tunnel, in particular, especially – but not only – in rough topography, is one of the most difficult tasks right from the initial design stages; as recent experience shows, the costs of such works can vary extremely from case to case, sometimes by as much as ten times, depending on the nature of the terrain involved.

Safety aspects in tunnels must be taken into account in all design phases.

The costs involved – and therefore, the decisions taken at the design stage – may be greatly affected by the rapid strides made recently in tunnel design, construction, technical systems (lighting, ventilation, traffic control equipment, etc.) and in operating procedures.

In conclusion, the decisions as to whether to construct a tunnel and what techniques to adopt have a considerable effect on the economics of the project.

8.1.1 Advantages of Road Alignments with Tunnels

8.1.1.1 In determining the profitability of road alignments involving tunnels, the designer should take into account both the direct and indirect benefits (such as habitat and environmental problems) and the costs (those of construction and operation, of externalities of foreseeable variations in user costs).

8.1.1.2 Among the variants considered in the analysis and comparison of costs and benefits, it may sometimes be preferable to include tunnels, even in non-mountainous terrain.

8.1.1.3 In rough terrain, better flow conditions may be achieved using tunnels.

8.1.2 Geological and Geotechnical Studies

8.1.2.1 Tunnels must be designed and constructed in accordance with the nature and behaviour of the surrounding terrain, the possible presence of water and all other local factors of influence (S).

8.1.2.2 In studying tunnel alternatives, special attention should be given to prior geological and geotechnical studies; these entail surface observations, surveys, borings, assays, laboratory tests, arc sometimes even exploratory tunnels to determine the various types of soil present, their characteristics and their stratigraphic and tectonic relationships (S).

Particular attention should be given to the tunnel portal areas as well as to unstable or landslide zones and other areas affected by seismic action (S).

8.1.3 Decisions Regarding Suitability of Techniques of Tunnel Construction

8.1.3.1 Situations where tunnels might represent valid alternatives to open construction include the following:

(a) solution of specific urban or landscape problems;
(b) improvement of route alignment, with less need to cope with significant differences in elevation and considerable reduction in the length of the route;
(c) crossing of unstable or barely stable hillside zones, with care taken to avoid tunnels with weak coverage in soils showing “flow” phenomena;
(d) protection of a route against natural hazards (avalanches, falling rock, etc.) – recent experiences show that tunnels hold up well in zones hit by earthquakes;
(e) cases where specific environmental protection is required in particularly important areas.

8.1.3.2 On the other hand, there are also difficult situations where heavy water seepage or soil instability, for example, may cause that costs outweigh the benefits of the tunnel alternative.

8.1.3.3 With regard to construction procedures, since the nature and degree of important parameters vary with every tunnel, as do the number and variety of construction techniques which may be adopted, the choice should be made on a case-by-case basis.

8.1.3.4 Finally, every tunnel is a unique structure in itself and must therefore be dealt with in a unique manner, at both the design and construction stages (S).

8.2 Guidelines Related to Technical Characteristics

8.2.1 General

8.2.1.1 Flow conditions occurring in tunnel sections differ from those occurring in open stretches.

8.2.1.2 Where tunnels are located along the route, it will therefore be necessary to ensure that continuity is not disrupted, i.e., that the capacity, service levels and safety conditions remain as similar as possible to those in open stretches (S).

Where this is not possible, the latter need to be adapted to the specific characteristic of underground traffic (S).

In general, the provision of an emergency lane in all motorway tunnels is desirable (RP).

8.2.2 Capacity and Service Levels

8.2.2.1 The methods used in calculating capacity and determining service levels in tunnels generally do not differ from those used in the open motorway, but lateral limitations and different light conditions have to be taken into account (S).

8.2.2.2 Factors to be taken into account include those influencing traffic in the open, specific parameters such as the length of a single tunnel, the possible existence of a series of tunnels in close succession, and the specific visibility conditions (S).

8.2.3 Determination of Tunnel Characteristics

8.2.3.1 Number of Lanes

Once the traffic forecast is known and the service levels established, the number of lanes is determined in the same manner as for adjoining normal layouts, taking into account that it is inadvisable to reduce the number of lanes in tunnels with respect to the motorway approaching the tunnel (S).

8.2.3.2 Cross Section and Lane Width

The tunnel cross section should provide sufficient space for necessary traffic installations and technical equipment. The ventilation and other equipment as well as signs must not reduce the traffic area (S).

Traffic lanes in tunnels should be of the same width as those in the adjacent normal layouts (RP).

The contingent reduction of their width, depending on local conditions (speed limitation, length of the tunnel, composition of the traffic flow) are governed by the national standards.

8.2.3.3 Vertical Alignment

In tunnels, the use of maximum permitted gradients should be avoided as much as possible. The assessment of costs of lower gradient versus savings on ventilation and climbing lanes should be carried out (RP).

8.2.3.4 Lateral Clearance

In between the traffic lane and the curb of the service walkway, the edge line of min. 0.25 m must be safeguarded (S). In special cases (long tunnels, bore tunnels, low traffic volumes, etc.) the shoulder or emergency lane should be avoided in accordance with national standards (RP).

In order to protect pedestrians and equipment located along the wall, it is recommended that service walkways 1 m or at least 0.75 m wide be provided, equipped with reflectors (RP).

In the case of tunnels longer than 1000 m (RP), different solutions should be adopted case by case, depending on the specific factors involved.

In these cases, it will be necessary to provide, in addition to the service walkways, lay-bys for the parking of broken-down vehicles (see paragraph 8.2.3.7) (S).

8.2.3.5 Overhead Clearance

Overhead clearance of minimum 4.50 m should be left in tunnels during their full life cycle (S).

8.2.3.6 Pavement

In tunnels longer than 1000 m, pavement should be cement concrete for fireproof reasons (RP).

8.2.3.7 Lay-Bys

8.2.3.7.1 Lay-bys for parking of broken-down vehicles must have a net length of minimum 40 m and minimum width of 2.50 m, besides the service walkway.

8.2.3.7.2 The spacing of lay-bys should be determined by national regulations.

8.2.3.7.3 It is recommended not to locate lay-bys in horizontal curves, if possible (RP).

8.2.3.8 Turning Bays and Cross-Connection Tunnels

8.2.3.8.1 The cross section must be enlarged at certain points in long two-way tunnels to permit U-turns, at least for passenger cars (RP).

8.2.3.8.2 In twin unidirectional tunnels, turn-arounds should be permitted via cross-connection tunnels between the two tubes, which should also take into account possible constraints related to the ventilation systems employed (RP).

8.2.3.8.3 The distance intervals between the turning bays and/or cross-connection tunnels must be determined according to national regulations.

8.2.3.9 Pedestrian Safety Measures

In tunnels longer than 1000 m, shelters of suitable size and pedestrian escape exits should be provided along the tunnel (RP).

In addition to the contingent cross-connection tunnels for vehicles (see paragraph 8.2.3.8.2), also the cross-connection passages for pedestrians must be provided according to national standards (S).

8.2.3.10 Surface of Tunnel Walls

It is recommended that the colour of tunnel walls be bright and that their surface be non-flammable and easy to clean (RP).

8.3. Traffic Regulation

8.3.1 General

Traffic regulation in tunnels has the following aims:

(a) to maintain as much as possible the service level;
(b) to regulate vehicle movement in emergency situations such as accidents, fires, etc.;
(c) to reduce the risk of accidents;
(d) to regulate the transit of dangerous goods.

8.3.2 Traffic Regulation to Avoid Lowering the Service Level

In general, the following measures could be adopted:

(a) prohibition of overtaking;

(b) installation of illuminated signs and signals (S);
(c) advance signs and direction signs must be repeated in the case of interchanges or service areas located immediately after tunnels – a situation which is in any case highly inadvisable (S);
(d) installation of the management and information system.

8.3.3 Traffic Regulation in Emergency Situations

8.3.3.1 In the event of partial or complete obstruction of the tunnel as a result of accident or fire, traffic access must be limited or barred (S).

8.3.3.2 The reduction of carriageway, change of carriageway, alternation of one-way traffic in the case of two-way tunnels, etc., must always be materialized outside the tunnel.

In case the tunnel is located on the territory of two or more countries, one operation centre only should be set up to deal with emergency situations.

8.3.3.3 Where a tunnel is blocked for a long period of time, traffic must be diverted from the motorway at the preceding interchange (S).

8.3.4 Traffic Regulation Regarding Heavy Vehicles and Transport of Dangerous Goods

8.3.4.1 The transit of dangerous goods must be governed by special regulations issued by the relevant authorities in the individual countries.

8.3.4.2 In general, traffic safety requires that the transit of vehicles carrying dangerous goods be forbidden or obliged to comply with the special regulations set by national legislation (S).

8.3.4.3 Both in the construction stage and in the operation stage, it will be necessary to install special devices designed to limit the damage caused by fire or explosion according to national regulation (S). Examples of these devices are indicated below:

(a) an <u>in-situ</u> channel to collect liquids spilled on the carriageway should be provided along the whole length of the tunnel, with dimensions permitting a flow of 200 l/sec. This channel will be connected by means of siphons to the sump, located at the exit of the tunnel;
(b) this sump should have a capacity of at least 50 m^3 (depending on the length of the tunnel) and be connected to the tunnel cleaning system (RP);
(c) inspection pits with bolted-down covers, situated at least every 65 m (RP);

(d) a fire detection system connected with the operation centre, designed to react at a predetermined temperature or upon sharp rises in temperature;
(e) illuminated signals to close access to the tunnel.

8.3.5 Signing of Tunnel Approaches

On tunnel approaches, the following signs should be installed in accordance with local conditions and national regulations (RP):

(a) informative signs:
- tunnel symbol
- tunnel name and length
- radio station frequency;

(b) regulatory and warning signs:
- traffic signals
- speed limit
- overhead clearance limitation
- prohibition of overtaking
- turn on/off lights.

8.4 Equipment

8.4.1 General

Technological equipment of tunnels is the following:

(a) traffic management system;
(b) lighting;
(c) ventilation;
(d) safety equipment;
(e) communication equipment;
(f) fire extinction equipment;
(g) close-circuit TV;
(h) central operation system;
(i) energy supply;
(j) maintenance equipment;
(k) loudspeakers;
(l) radio broadcasting system.

The choice of equipment depends on the length and type of the tunnel.

8.4.2 To avoid accidents and limit their effects, it is advisable to equip tunnels – depending upon their length, traffic volumes, etc., and also on the costs involved – in order to:

(a) control and regulate traffic;
(b) communicate with users;
(c) provide emergency equipment.

Depending upon the specific case, the following should be supplied:

(a) no-overtaking signs, danger signs, signal lights, etc. (S);
(b) variable message signs to set speed limits and possibly to reverse the flow direction;
(c) traffic counting points;
(d) loading gauges to control the heights of freight vehicles;
(e) television control;
(f) devices for radio transmissions and information;
(g) SOS and fire call posts (S);
(h) equipment to monitor temperature irregularities;
(i) all-purpose portable fire extinguishers (RP);
(j) hydrants directly connected to a pressurized water system;
(k) equipment to measure the level of carbon monoxide, visual opacity, etc., regulating the operation of the ventilation system;
(l) suitable housings for cable passages, conduits, pipes, etc. (S).

All the relevant data must be transmitted to the tunnel operation centre.

8.4.3 To increase traffic safety, it is also advisable to install fog and frost detectors ahead of the tunnel entrance and exit (RP).

8.5 Ventilation

8.5.1 General

8.5.1.1 In general, the feasibility of artificial ventilation should be investigated for two-way tunnels if their length exceeds 300 m (RP) and for unidirectional tunnels with the length exceeding 500 m (RP).

8.5.2 Natural Ventilation

8.5.2.1 Natural ventilation in tunnels depends upon a number of variable factors difficult to evaluate, and is capable of diluting vehicle emissions only to a very limited extent.

8.5.3 Artificial Ventilation

The decision about the type of the ventilation system depends on its economic performance and the safety analysis for normal operation and the operation in case of fire, which should take into account the following (RP):

(a) traffic volume (30^{th} peak hour);
(b) direction of traffic;
(c) points of possible conflict (e.g. merging lanes);
(d) permission and frequency of transports of hazardous goods.

8.5.3.2 Ventilation Systems

The following ventilation systems are distinguished:

(a) longitudinal, where the air draught, generated either naturally or by fans, is longitudinal;
(b) semi-transversal, which injects fresh air along the tunnel length, while the foul air is sucked out through the portals or through shafts;
(c) fully transversal, where fresh air is injected and foul air is sucked out along the whole tunnel length.

8.5.3.3 Design Limit Values

The choice and design of the ventilation system should be based on the following maximum permissible values (S):

(a) CO concentration 150 ppm;
(b) NO_x concentration 25 ppm;
(c) light extinction coefficient related to turbidity/soot 7 x 10^{-3}/m;
(d) maximum longitudinal air velocity 10 m/sec.

Furthermore, the system must be capable of extracting minimum 110 m^3/sec of air from the most unfavourable point of the tunnel (S).

8.5.3.4 Additional Requirements

Jet fans of the longitudinal system should be reversible and distributed over the entire tunnel length to minimize turbulence in case of fire.

With the semi-transversal and transversal systems, fresh air injection outlets should be adjusted so as to give uniform air distribution along the tunnel and their maximum spacing should be 50 m. The maximum spacing of extraction outlets is 100 m (S).

In case of fire it must be possible to switch the ventilation to extraction mode immediately (S).

8.5.4 Pollution in the Area of Tunnel Portals

The contaminated air expelled from the tunnel will diffuse in the atmosphere according to the conditions existing at the tunnel exit. This problem should be examined on a case by case basis and, where necessary, steps should be taken to avoid undesirable pollution.

8.5.5 Recirculation between Portals

In the case of unidirectional tunnels lying adjacent to one another, it is necessary to prevent the contaminated air expelled from one being sucked into the other as fresh air.

8.5.6 Monitoring

The following data related to the tunnel ventilation performance should be monitored (RP):

(a) CO concentration;
(b) turbidity/soot;
(c) air speed and direction of air flow;
(d) air volume and pressure increase (for semi-transversal and transversal ventilation);
(e) fire alarm;
(f) traffic data.

8.6 Lighting

8.6.1 General

8.6.1.1 In daytime conditions drivers experience visibility problems at tunnel entrances due to the sudden drop in luminance after entry.

In order to diminish the luminance springs at the beginning and end of the tunnel, it is preferred not to locate the tunnel in the east-west direction (low sun positions).

It is also preferred to situate portals in shadowy places and to consider the construction of galleries or light-reducing facilities ahead of them (RP).

8.6.1.2 In tunnels longer than 200 m, it is advisable to consider the use of artificial lighting to permit drivers to adapt gradually to the difference in visibility conditions outside and inside the tunnel.

Where there is no lighting installed, it is recommendable to make it possible in the future by providing the respective ducts.

8.6.2 Lighting Sections

From the point of view of lighting, the tunnel is broken down into the following sections/zones (Figure 8a):

(a) approach zone;
(b) entrance section, further subdivided into the accommodation and transition sections;
(c) interior section.

8.6.3 Lengths of Sections

8.6.3.1 The recommended length of the accommodation section is 150 m (RP).

8.6.3.2 The length of the transition section depends on the luminance levels at the end of the accommodation section and on the interior section as well as on the design speed and is governed by national standards.

8.6.4 Daytime Luminance Levels

8.6.4.1 The minimum luminance level on the first half of the accommodation section should be 200 cd/m² (RP).

8.6.4.2 The transition from this luminance level to that one on the interior section can be continuous or in stages. In this case, the maximum allowed level spring should be 1 : 3 (RP).

8.6.4.3 The average luminance level on the interior tunnel section at the highest lighting level should be 2 cd/m² (RP).

At the highest lighting level, the longitudinal L_{min} / L_{max} ratio along the tunnel axis should be higher than 0.55 and the absolute $L_{min} / L_{average}$ ratio should be higher than 0.35 (RP).

8.6.4.4 It is necessary to provide a short zone of 50 - 80 m of additional lighting at the exit only in special cases (view over the sea, frequent snow, etc.) or in the case of unidirectional tunnels which might occasionally be used for two-way traffic (RP).

8.6.5 Nighttime Luminance Levels

To ensure safety at night, it is advisable to provide a low luminance level (e.g., 1 cd/m²) (RP).

8.6.6 Emergency Lighting

The lowest level of the interior section lighting represents at the same time emergency lighting level.

8.6.7 Choice of Lighting System

The lighting system consists of direct-beam devices located above the carriageway or situated at both sides (walls). The continuous translucent panels are not recommended (RP).

8.6.8 Power Supply and Control Devices

It is advisable to provide for installations which, even in cases of a power cut, would provide emergency lighting and power for the safety devices (signals, teletransmission, alarms, etc.).

Economic factors require more than one single operating regime (RP). For example, three regimes should be provided in relation to the luminance present outside the tunnel: night time, cloudy daylight or bright sun.

It is recommended that the maintenance requirements be taken into consideration in designing the system (RP).

8.6.9 Special Cases

8.6.9.1 Interchange Entries and Exits

The tunnel entrance section lighting cannot terminate in the area of slip roads' entries or exits.

In cases of location of entries or exits in the tunnel (which is not desirable generally), the level of interior lighting should be increased at least twice by shortening the light sources' spacing (RP).

Acceleration and deceleration lanes should be equipped by their own row of lights, providing the same (increased) luminance level as on the principal carriageway. Catseyes should be installed on the broken longitudinal line separating this carriageway from the acceleration or deceleration lane and this line should be reflectorised (RP).

8.6.9.2 Escape Routes

Escape routes should be provided with permanent orientation lighting, connected to the emergency energy source. The luminance level on the escape exits should be 1cd/m² with the longitudinal L_{min} / L_{max} ratio higher than 0.33 (RP).

8.6.9.3 Lay-Bys and Cross-Connection Tunnels

The luminance levels on lay-bys and cross-connection tunnels should be higher than these on the interior tunnel section. It is also possible to distinguish optically the lay-bys by choosing the different colour of their lighting (RP).

8.6.9.4 Very Long Tunnels

The luminance level on the interior section could be decreased at the distance of about 1500 m from the entrance portal, but in any case should not be lower than the nighttime level (RP).

To contribute to the drivers' concentration, it is recommendable to create special light zones about 20 m long at every second lay-by. These light zones differentiate from the ordinary interior section by the higher luminance level (about 10 cd/m²) and different colour of lights, which may be switched on and off automatically depending on the traffic volume (RP).