

**GUIDELINES
FOR
MALAYSIA TOLL EXPRESSWAY SYSTEM
- DESIGN STANDARDS**

**Chapter 7
TUNNELS**



STATUS	DATE	COMPUTER FILE REFERENCE
1st Edition	August 2008	Tunnels_Rev_2013-1[Final Draft 2013].doc

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ABBREVIATIONS

CCTV	Closed Circuit Television
DOE	Department of Environment (Malaysia)
EIA	Environmental Impact Assessment
ITS	Intelligent Transportation Systems
LED	Light Emitting Diode
MHA	Malaysian Highway Authority
PIARC	World Road Association
SCADA	Supervision, Control and Data Acquisition
SSD	Stopping Sight Distance

7 TUNNELS

7.1 Definition of Tunnel

7.1.1 Introduction to tunnel

Tunnels are enclosed roadways with vehicle access that is restricted to portals regardless of type of the structure or method of construction (defined by AASHTO)

7.1.2 Background to tunnelling methods of construction

The principal types and methods of tunnel construction that are in use are:

- Cut-and-cover tunnels
- Bored or mined tunnels
- Rock tunnels
- Soft ground tunnels
- Immersed tunnels
- Jacked box

(sources: AASHTO)

7.2 General Considerations

7.2.1 Safety And Service

Incidents in tunnels can result in fatalities and damage to the tunnel that may take a long time to repair. The economic consequences of the closure of a link in the expressway system will be significant, and toll revenue will cease until the expressway reopens.

It is therefore appropriate to give absolute priority to minimising the risk of incidents occurring, and to minimising the risk of prolonged closure of an expressway tunnel.

In the event of an incident:

- the occupants of the tunnel need to get out
- emergency personnel need to get in
- the asset needs protection

Design Features To Reduce Frequency Of Incidents

- road geometry that provides adequate sight distance for both cars and trucks
- avoiding steep gradients (desirable maximum 2.5%, absolute maximum 5%) to reduce the incidence of breakdowns, vehicle overheating (leading to fire), and crashes (due to high relative speeds of cars and trucks on upgrades¹ and increased truck stopping distance on downgrades)
- provision of a climbing lane on upgrades to ensure tunnel capacity is not restricted and to reduce the risk of rear end collisions
- lighting

¹ Particular care must be taken to ensure SSD in the tunnel is not impaired by horizontal or vertical curvature in tunnels on grades.

- ventilation system to maintain visibility and air quality so that human health and alertness is not impaired
- avoiding interchanges near tunnel portals and within tunnels
- locating any underground interchanges (if unavoidable) on straight alignment and uniform gradient to maximise sight distance to diverges and merges
- aligning tunnel exit portals to avoid glare from the rising or setting sun (or providing shade structures to mitigate glare problems)
- providing a full width shoulder for use by light motorcycles (unless an alternative motorcycle route is available)
- conducting tunnel safety audits as part of the planning and design process to ensure all necessary safety features are included

Management Actions To Reduce Frequency Of Incidents

- enforcing appropriate speed limits with 24 hour speed cameras (all long tunnels)
- providing appropriate security monitoring to deter terrorist attacks
- checking commercial vehicles for overheated engines or brakes and excessive height (and vehicle mass) before entering the tunnel (mountainous areas)
- providing alternative routes for dangerous goods vehicles, pedestrians and bicycles
- educating drivers in road tunnel safety features including use of radio, emergency procedures, and prohibited goods
- conducting tunnel safety audit and hot smoke testing as part of tunnel commissioning
- conducting regular safety audit of tunnel and safety systems

Facilities to Reduce the Consequences of Incidents

- design to deter and resist sabotage and terrorist attack
- providing structural and tunnel services redundancy
- providing appropriate fire ratings for critical structural elements and equipment
- providing fire suppression equipment including deluge systems
- providing cross connections for fire tenders within long tunnels
- providing emergency egress for vehicle occupants (including disabled persons) into an adjacent tunnel and/or to the surface
- providing smoke extraction system
- using non-combustible materials for tunnel construction
- providing emergency services with convenient road access to the tunnel portals
- providing appropriate portal facilities (including emergency median crossovers and helipads)
- providing a control centre and tunnel facilities with:
 - communication systems
 - automatic fire and smoke detection
 - fire suppression equipment

- automated incident detection and CCTV monitoring
- variable message signs, tunnel closure signals, boom gates, variable speed limits, permanent speed cameras
- emergency services in close proximity to the tunnel portals (at both ends of the tunnel)
- a site specific incident management plan
- providing ongoing training to tunnel operational, emergency services and maintenance staff with an emphasis on evacuation of tunnels affected by fire (most fatalities in tunnel fires occur from smoke inhalation)

7.2.2 Geological and Geotechnical Studies

In studying the tunnel alternatives, special attention must be given to the geological and geotechnical studies. This is to be undertaken with the objective to obtain maximum amount of information in the ground. These entail the followings:-

- Regional geology and geologic history study;
- Surface observations and surveys, which include the survey of topography, weather conditions, existing services, utilities or structures, and potential hazards of the influence zone;
- Subsurface exploration associated with relevant field tests. The exploration can be conducted by having sufficient numbers of sub-horizontal or vertical boring, trial pits and sometimes even exploratory tunnels or probing ahead the tunnel face. Geophysical survey can be considered when the rock stratum is anticipated and investigation area is relatively large. These determine the various types of soil or rock present, their characteristic and their stratigraphic and tectonic relationships, and groundwater condition. The present of rock strata may require additional geological mapping for the determination of any unsound areas; and
- Collection of soil, rock and groundwater samples for laboratory testing and assays. These confirm the assumption made through on site observation and provide the characteristic of various soil or rock present in greater details. The chemical content of the ground is also determined.

The interpretation of the ground investigation shall be reviewed by specialist consultants and professional risk managers with demonstrable expertise and experience.

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

Particular attention must be given to the tunnel portal areas as well as to unstable or landslide zones and other areas affected by seismic action. Geotechnical requirements are covered in **Chapter 2 of Reference 7-1**.

Reference 7-1 Road Tunnels - Norwegian Public Roads Administration 2004

http://vegvesen.no/vegnormaler/hb/021/021_e_05_w.pdf

7.2.3 Tunnel Location

Environmental Considerations

Chapter 2 of this document provide information on environmental considerations that need to be addressed in planning and preparation of EIA. **Chapter 3** of **Reference 7-1** also provide guidelines.

Furthermore, prior to any construction works of proposed tunnel, an impact assessment study on the surrounding environment shall be carried out for review and approval. In contrary, prior to any construction works of development immediately above or adjacent to the tunnel, the engineer shall provide the design, construction and monitoring proposal for review and approval.

Rural Areas

Tunnels may be appropriate in rural areas where topographic and/or geotechnical considerations make open cut construction impractical or unstable, especially when crossing over the following areas:-

- Hill side where open cut construction is impractical due to large impact to the existing balanced ecosystem;
- Marine, freshwater and upland swamps where construction of embankments and elevated structures are impractical due to complicated and tedious ground improvement works and/or deep foundation installation; and
- Existing ecological/forest reserves and agricultural lands.

Environmental impacts on sensitive ecosystems may be significantly reduced by tunnel construction.

Urban Areas

In urban areas, tunnels may reduce the environmental constraints to new expressway construction, even if the topography does not require (or facilitate) tunnelling.

If tunnels are provided in urban areas to minimise impacts on existing development, the gradient near the tunnel portals may have to be steep. In such cases, the upgrade section of the tunnel may require an additional lane so that traffic capacity is maintained.

In urban areas, tunnels may follow the alignment of existing roads or other infrastructure to avoid the possibility of structural damage to existing buildings and the need for volumetric title acquisition under private land. (Constructing tunnels under private land may reduce its value if the height of new buildings would be restricted by the tunnel).

Double deck tunnels (**Figure 7-6**) may be advantageous where the available right of way width is limited, particularly if cut and cover construction is proposed, as the width of the excavation is reduced. A narrower excavation may reduce traffic disruption during construction, and alterations to existing services may also be reduced.

The possibility of replacing one long structure by several shorter structures (particularly in the case of cut and cover tunnels) should be considered. The openings allow smoke to escape in the event of fire. A series of short tunnels will limit the number of people at risk during a tunnel fire or toxic gas release. The cost of tunnel services will be significantly reduced by this approach.

7.2.4 Multiple Use Tunnels

Tunnels, particularly in urban areas, may have more than one function including:

- roadway for cars and trucks
- low clearance tunnels (trucks excluded)

- public transport (bus and rail transports)
- public utility services
- flood mitigation
- civil defence (air raid shelter)

7.2.5 Restrictions on Use

Pedestrians and bicycles are prohibited from using tunnels on expressways.

Cut and cover tunnels will suffer structural failure in the event of major explosions such as these following large liquid petroleum gas leaks or TNT accidents. Driven tunnels would also be severely damaged. The transportation of these materials through tunnels is therefore generally prohibited. Radioactive and toxic materials may also be prohibited.

The use of short driven tunnels by dangerous goods vehicles may be acceptable, particularly if the alternate route involves greater risk than the expressway route.

There are also a range of products such as margarine, palm oil, tyres, timber, etc that are not classed as hazardous that can result in powerful fires. These fires must be managed through the coordinated use of deluge systems, smoke extraction system and fire brigade attendance.

Chapter 6 of Reference 7-1 provides information on hazardous goods and the risks of their transport in tunnels.

Hazardous goods include:

- Class 1 – Explosive substances and objects
- Class 2 - Gases: condensed, liquid, or under pressure
- Class 3 – Flammable liquids
- Class 4.1 – Flammable solids
- Class 4.3 – Self-combustible substances
- Class 4.3 – Substances which react with water emitting flammable gases
- Class 5.1 – Oxidizing (fire-intensifying) substances
- Class 5.2 – Flammable organic peroxides
- Class 6.1 – Toxic or harmful substances
- Class 6.2 – Infectious substances
- Class 7 – Radioactive material
- Class 8 – Corrosive substances
- Class 9 – Miscellaneous dangerous substances

7.2.6 Design

Tunnel design is a complex and highly specialised field. Design is to be undertaken by specialist consultants and professional risk managers with demonstrable expertise and experience.

The tunnel design shall made reference to accetable/established international code of practice. The following standards shall be minimum adopted for tunnel design.

1. Building Research Establishment (BRE) Digest 330: 1999 (Building Research Establishment, 1999),
2. Building Research Establishment (BRE) Digest 363: 1996 (Building Research Establishment, 1996),
3. BRE Special Digest 1 (Building Research Establishment, 2003)

4. British Standard BSEN206-1: 2000 (British Standards Institution, 2003)
5. BS 8110 (British Standards Institution, 1997) and BS8007 (British Standards Institution, 1987). BSEN206-1
6. Eurocode 2: Design of Concrete Structures (European Commission, 1992).
7. European standards EN206 Concrete – Performance, Production and Conformity, durability of concrete will rely on prescriptive specification of minimum grade, minimum binder content and maximum water/binder ratio for a series of defined environmental classes.
8. British Standard BS 5930: 1999 (British Standards Institution, 1999), entitled Code of Practice for Site Investigations
9. BD78/99 : Design of Road Tunnel
10. BD 31/01 : Design of Buried Concrete Box And Portal Frame Structure
11. Tunnel Lining Guide ; The British Tunnelling Society and The Institution of Civil Engineers
12. FHWA Road Tunnel Design Guidelines; U.S Department of Transportation Federal Highway Administration

Geotechnical Design Considerations

Tunnels must be designed and constructed in accordance but not limited to the followings:-

- (i) The nature and behavior of the surrounding terrain;
- (ii) The existence of current services, utilities or structures (i.e. foundations and retaining walls), which the tunneling works may cause impact and obstruction to;
- (iii) The vibration, settlement and water drawdown impact by the provisional adjacent or above ground future developments;
- (iv) As appropriate to the current ground conditions, characteristic and stratigraphy;
- (v) Prediction on the unforeseen ground condition;
- (vi) Potential hazards, such as slips and ground movement, due to the change in nature and climate; and
- (vii) All other local factors of influence.

Particular attention must be given to the tunnel portal areas as well as to unstable or landslide zones and other areas affected by seismic action. Further geotechnical requirements are covered in Chapter 2 of Reference 7-1 and Reference 7-2.

Reference 7-1 Road Tunnels – Norwegian Public Roads Administration 2004

http://vegvesen.no/vegnormaler/hb/021/021_e_05_w.pdf

Reference 7-2 Specification for Tunneling Third Edition – British Tunneling Society and The Institution of Civil Engineers

Geotechnical Instrumentation and Monitoring

Tunnels, either during construction or in-service, shall be provided with geotechnical instrumentation and monitoring scheme, where necessary, due to the various subsurface uncertainties. These are especially pointing to the densely populated area and hazardous area, such as area with potential land slip and seismic zone. The monitoring works may include but not restricted to the followings:-

- (i) Tunnel lining profile (displacement and cracks);
- (ii) Existing structures profile;
- (iii) Ground settlement; and
- (iv) Vibration (whenever blasting works are carrying out near the tunnel).

The frequency and duration of monitoring shall refer to the specific requirements and ground hazard index of that particular area.

Seismic Design of Tunnels

In general, buried or underground structures such as culverts and tunnels are relatively undamaged during earthquake events as compared with the surface structures. However, for major earthquakes, damages had also been reported. In the design of tunnel, the seismic effects should be taken into consideration so that the design structures have an appropriate earthquake resistance.

The tunnel design engineer shall carry out an assessment of seismic hazard at the proposed tunnel location and to determine the potential maximum Peak Particle Acceleration (PPA) of the ground. Based on the results of seismic hazard assessment, the design engineer shall evaluate the need to carry out seismic design for the proposed tunnel. In general, there are basically three approaches can be considered to seismic design of underground structures:

- 1) The simplest approach ignores interaction of the underground structure with the surrounding ground
- 2) The pseudo-static approach
- 3) Dynamic analysis approach

7.2.7 Risk Assessment

Every tunnel is an individual structure and the facilities to be provided should be assessed taking into account the site characteristics, tunnel construction method (driven or cut and cover), availability of emergency services, length of tunnel, speed environment, likelihood of traffic congestion, traffic volumes, breakdown facilities, the role of the expressway in the network, need for motorcycle facilities, commercial vehicle numbers, loads carried, and other relevant factors.

Up to date literature and conference proceedings must be reviewed to ensure that world best practice is adopted.

The overall developed tunnel, services, and operational procedures must result in a tolerable level of risk acceptable to the community.

Table 7-1 provides a guide to the selection of features, but each tunnel should be individually assessed at a professional risk management workshop involving MHA, specialist design consultants (including professional risk assessment specialists), and emergency services and security personnel.

Risk Management must be a continuous process and maintained from the start of the Project. Any new or increasing risks must be assessed and pre-emptive and/or contingencies measures be put in place. All foreseen risks are to be monitored throughout the Project.

Table 7-1 Tunnel Facilities

Feature	Requirement	Comment
Right shoulder 1.0m minimum	All tunnels.	Provides emergency pedestrian access to cross passages in twin tunnels, and reduced risk of collisions with tunnel walls.
Left shoulder 3.0m	In all tunnels <500m long.	Speed limit normally the same as approach road.
Left shoulder 3.8m	In all tunnels catering for light motorcycles.	3.8m shoulder provides space for two motorcycles or one stopped truck and one motorcycle (at reduced speed).
Left shoulder 1.2m	In all tunnels without a wide shoulder.	Provides for occasional light motorcycle (rural areas) and reduced risk of collisions with tunnel walls. Requires a lower speed limit than approach road.
Breakdown lay bays	In all tunnels >1000m long without a wide shoulder.	Provide 40m x 4.0m bay. 500m maximum spacing.
Emergency cross over for fire trucks (between tunnels)	In all tunnels >1500m long	Fire rated doors required. 1500m maximum spacing.
Emergency median cross over at tunnel portals	All tunnels.	
ITS and control centre	All tunnels >60m long.	Utilise existing traffic control centre to monitor tunnels – consider local control centre for long tunnels
Lighting (daytime)	All tunnels > 60m long.	Dual electricity supply and UPS (intensity may be reduced when on batteries)
Fire hydrants and emergency cabinets	All tunnels > 60m long.	Locate at portals and at desirable 60m spacing (maximum of 100m spacing) Dual water supply.
Deluge system	In all driven tunnels > 240 long. In all cut and cover tunnels and other tunnels with a support system susceptible to fire damage.	10 litres/m ² /minute in 30m sections with up to three sections operating simultaneously for 4 hours - duplicate water supplies.

Feature	Requirement	Comment
Pedestrian cross connections to adjacent tunnel (also used by emergency services personnel)	Cross connections and air locks at 120m spacing on tunnels >120m length.	Single bore tunnel must have separate egress.
Emergency egress to surface (Shallow tunnels)	All shallow tunnels (<15m cover) shall have connections to surface at 120m maximum spacing unless tunnel is <120m long.	The layout of the egress system must also allow for the movement of emergency services personnel between the two carriageways.
Emergency egress to surface (Deep tunnels)	Consider need for surface egress (in addition to cross connections) at 1200m spacing in tunnels >3000m long.	Where depth is <60m and /or ventilation shafts are required, cost will be reduced. Consider helipad adjacent to egress.
Longitudinal smoke extraction system	Tunnels <240m long does not require smoke extraction system.	Longitudinal smoke extraction may be used in tunnels only where ordinary traffic conditions allow vehicles to drive out of the tunnel in tunnels <3000m long. Longitudinal smoke extraction is lower cost than a fire site extraction system but it can not provide smoke free conditions on both sides of a fire.
Fire site extraction system	Tunnels <240m long does not require smoke extraction system.	Where it may not possible to drive out of the tunnel because of traffic congestion, a fire site smoke extraction system is mandatory. This includes all smoke extraction systems for tunnels in urban areas. Where effective smoke control is required both sides of a fire (such as a fire resulting from rear end collision with stationary traffic) a site extraction system is preferred. For rural tunnels exceed 3000m, injection longitudinal smoke control system with intermediate ventilation shafts or combination with jet fans shall be considered in tunnel sections less than 3000m each. Alternatively, fire site extraction system can be adopted. Risk assessment may indicate fire site extraction appropriate on a tunnel <3000m length.
Ventilation system	Mechanical ventilation system shall not be required in tunnel exceeding 240m in length, where it can be shown by an assessment subject to traffic congestion that the level of air quality and heat rejection provided by a mechanical ventilation can be equalled or exceeded by the use of natural ventilation or other alternative	Longitudinal smoke extraction system can also provide ventilation function.

Feature	Requirement	Comment
	methods, as approved by the authority having jurisdiction.	
Heavy vehicle checking station	Consider for use in mountainous areas	Detection of overheated trucks reduces risk of tunnel fires
Helipad	Long tunnels (>500m) in rural areas.	Also consider for use adjacent to surface emergency egress points (if provided).
Fire station	Ascertain response time from existing fire stations to each portal and provide additional facilities if necessary.	
Motorcycle facility at exit portal	All tunnels where motorcycles are expected	Provides sheltered area for donning wet weather clothing

7.2.8 Feasibility Study

Feasibility are performed to develop and evaluate alternative solutions to major transport improvement needs. The long-range planning process may be used to identify needed studies. The results of feasibility studies may also inform long-range planning, or they may identify specific projects for more detailed evaluation in the capital programming process.

Any study process typically involves four types of activities: designing the scope and issues of what is going to be studied to address a particular problem or opportunity; exploring alternative ways of solving the problem or seizing the opportunity; conducting a detailed analysis of each alternative and finally, making a choice. These choices then are translated into a program of specific road projects over time.

7.3 Portal Facilities

Tunnel portal main practical function is to protect the tunnel entrance from rock fall, landslide and to cut-off surface water runoff. Adequate subsurface drainage shall also be provided where necessary.

7.3.1 Portal Design

Accidents are more likely to occur near the tunnel portals.

Therefore the approaches to tunnel portals and the portal area should be designed to assist drivers in making the transition from the open road into the tunnel and from tunnel back to open road when leaving the tunnel. Excellent sight distance should be obtained by the use of straight (or large radius) horizontal alignment and avoiding crest vertical curves within 500m of the portal (if possible).

Tunnel lighting must be brighter at the portals, as described in **Chapter 14** and **Section 8.5 of Reference 7-2**.

If possible, tunnel portals should be aligned to avoid glare from the rising or setting sun. Shade structures shall be provided if tunnel orientation is unfavourable.

Location of the portal should be such that the tunnel depth provides sufficient cover above the crown. The soil or rock slopes at the portal must be design to a stable slope.

7.3.2 Aesthetics and Landscape

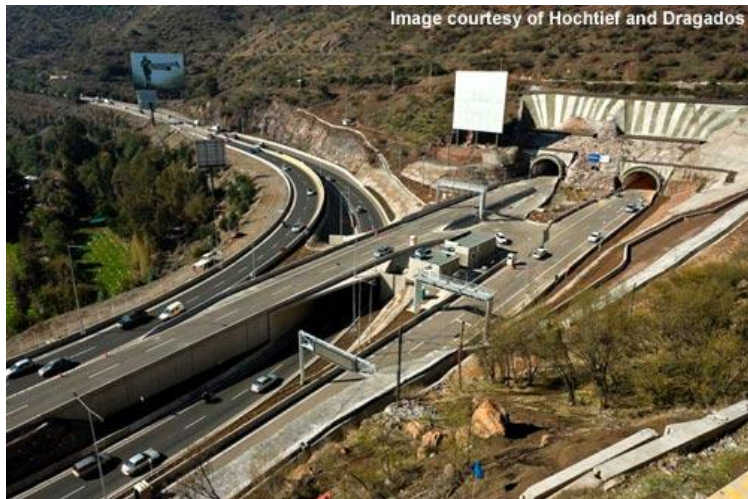
Tunnel portals must be harmonized with the existing landscape to avoid negative visual impact. Well design landscape architecture consideration will provide transition from open landscape to a tunnel with the approach zone making minimal encroachment upon the terrain. Overbridges should be avoided at the approach to tunnels.

Chapter 5 of Reference 7-1 gives guidance on the aesthetic considerations that should be applied when designing the tunnel approaches.



Figure 7-1 Portal Treatment





7.3.3 Signing of Tunnel Approaches

On tunnel approaches, the following signs are to be installed:

- informative signs:
 - tunnel symbol
 - tunnel name and length
 - radio station frequency
 - variables messages system
- regulatory and warning signs:
 - traffic signals / lane signals
 - speed limit (variable)
 - overhead clearance limitation
 - prohibition of overtaking
 - turn on/off lights

If two way operation is required as part of incident management or programmed maintenance, double sided variable message signs and signals will be necessary.

Signs should be placed sufficient distance from the portal. Remote controlled barriers be installed for traffic control during emergencies.

7.3.4 Emergency Median Crossover

An emergency median crossover is required at each end of the tunnel to facilitate traffic management during and after an incident.

Additional median crossovers within the tunnel (fitted with fire rated doors) are required in long tunnels (over 1500m), spaced at $\leq 1500\text{m}$.

7.3.5 Control Centre

The control centre is to be co-located with one of the other portal facilities (such as Heavy Vehicle Checking Station), unless use of an existing control centre is more appropriate.

If a control centre remote from the tunnel is chosen, a local control room is required adjacent to the tunnel for use when emergency personnel have arrived on site. This local control room would also be used for maintenance testing and practice exercises.

7.3.6 Heavy Vehicle Checking Stations

In mountain tunnels with a steep approach road, heavy goods vehicles are likely to arrive overheated.

Heavy Vehicle Checking Stations that check commercial vehicles for excessive mass, height, overheated engines, and overheated brakes before entry to the tunnel are required in mountainous areas. (Many tunnel fires are attributable to overheated vehicles).

Sufficient space is required to conduct inspections and to park and cool down vehicles if necessary.

7.3.7 Emergency Services

Emergency services must be located in close proximity to the tunnel portals at both ends of long tunnels, and would normally be co-located with the heavy vehicle checking station (if provided).

7.3.8 Toll Booths

Tolling facilities (if required) could also be co-located with the Heavy Vehicle Checking Stations. Toll booths must be at the entrance portals only to avoid the possibility of rear end crashes in the tunnel due to queues at toll booths.

7.3.9 Helipad

Helipads are to be provided at each portal of rural long tunnels. Very long tunnels with surface egress between the portals should also have a helipad at each surface egress, especially if there is no alternative ground access.

Helipads may also be appropriate in urban areas to provide speedy treatment for critically injured persons.

7.3.10 Fire Brigade Hardstand and Booster Facilities

A hardstand area with provision for parking fire appliances and booster pumper is required near the portal at each end of long tunnels and one end of shorter tunnels. Six suction and six pressure plugs are normally required. Details are to be agreed with fire brigade.

7.3.11 Motorcycle Facility

A covered motorcycle facility adjacent to tunnel entry and exit portals for donning of wet weather gear is required. This is to avoid an accumulation of stopped motorcycles at portals blocking traffic.



Figure 7-2 Shelter for Motorcyclists

7.4 Roadway Geometry

7.4.1 Speed Limits and Design Speed

Table 7-2 Tunnel Speed Limits & Design Speeds

Type of Tunnel	Normal Speed Limit*	Minimum Design Speed
Short (<500m and where exit portal is visible from entry portal) (3.0m shoulder)	Same as approach road	Speed Limit plus 10km/h
Long(>500m) (3.0m shoulder)	100km/h maximum	
Long (narrow shoulders)	Urban 70 km/h – 80km/h Rural 80km/h	

* A lower limit is to be imposed by the control room when traffic conditions require a lower speed.

To take account of the consequences of incidents, long tunnels are to be operated at lower speeds than the connecting expressways to enhance safety, as detailed in **Table 7-2**.

A uniform approach must be taken to the design of a series of tunnels along a route.

7.4.2 Horizontal Alignment

Horizontal Sight Distance

The horizontal curve geometry is determined by truck stopping sight distance as shown in **Table 7-3**. The values are for a 1.0m shoulder. Lower radii may be used, but will require sight distance widening as shown in **Table 7-3**

While truck SSD is the governing case for the downhill tunnel, for the uphill tunnel car SSD may be the governing case as truck speed and truck stopping distance is reduced by gradient.

Table 7-3 Minimum Horizontal Curve Radii for Use in Tunnels (1.0m shoulder)

Truck Operating Speed	0.5%**	2%	4%	5%****
80	930***	1000	1100	1180
90	1360***	1500	1650	1730
100	2000***	2200	2500	2640

*Truck governs

**0.5% minimum grade desirable (0.3% absolute minimum)

*** If adverse crossfall, use values in **Chapter 3**

**** Through carriageway grades should be limited 2.5% if possible, with a general maximum of 4% (5% absolute maximum)

Tunnel should be as short as practically possible while maintaining as much of the tunnel length on a tangent. A slight curve at the end of the tunnel is desirable to allow driver to adjust to the glare and bright light outside of the tunnel. In long tunnels gentle curves maybe incorporated to prevent monotony.

As widening of tunnel is usually impractical in tunnels the stopping sight distance will determined the sharpest horizontal curve for the given tunnel cross-section geometry.

See **Chapter 3** for a more detailed explanation of horizontal sight distance design standards for cars and trucks.



Figure 7-3 Short Expressway Tunnel (Note widening for horizontal sight distance) Adverse Crossfall

As well as using large radius curves to enhance horizontal sight distance, the use of large radii may allow adverse crossfall to be used. This can reduce the risk of burning fuel flowing adjacent to fire escapes.

7.4.3 Vertical Geometry

The gradient of tunnels should be as flat as possible to:

- enhance upgrade capacity and avoid the need for climbing lanes
- minimise the exhaust gas emissions and reduce ventilation requirements
- minimise truck braking distance

Details are included in **Chapter 3**.

The sag K values are governed by truck sight lines under the roof of the tunnel due to both the increased truck driver eye height and increased stopping distance for trucks. Note that headroom may need to be increased if a sag $K < 60$ is used (see **Reference 7-17 (Clause 4.21)**).

Table 7-4 Sag Curves in Tunnels

Truck Operating Speed	Minimum Sag K Values* for an average grade of				
	0.5%	-2%	-4%	-6%***	-8%***
80	7**	7**	8**	9**	10**
90	10**	11**	12**	13**	15**
100	14**	16**	18**	20**	23**

*Truck governs. Based on 5.4m vertical clearance and 2.4m eye height

**If $K < 60$ used, vertical clearance requires adjustment.

*** Ramps only - do not exceed 5% on through carriageways

7.4.4 Cross Section

Through Carriageway Cross Section

Figure 7-4, Figure 7-5 and Figure 7-5 shows a typical cross section for tunnel.

To enhance access to fire escapes for disabled persons and movement in reduced visibility conditions, kerbs are not used.

Ramp Cross Section

The minimum width of a one lane ramp in a tunnel is 6.0 m.

Lane Numbers

Once the traffic forecast is known and the service levels established, the number of lanes is determined in the same manner as for adjoining surface layouts, taking into account that it is inadvisable to reduce the number of lanes in tunnels with respect to the motorway approaching the tunnel. Upgrades in the tunnel may require the provision of an additional lane to prevent traffic congestion in the tunnel. In particular, *an additional lane on any ascending grade at the exit portal may be beneficial to ensure that the discharge capacity of the tunnel exceeds the entry capacity.* Traffic lanes in tunnels should be of the same width as those in the adjacent normal layouts.

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Figure 7-4 Driven Tunnels

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Figure 7-5 Cut and Cover Tunnels

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Figure 7-6 Double Deck Cut and Cover Tunnels

Crossfall

Where possible, the crossfall of the pavement should slope away from the emergency pedestrian exits, so that burning liquids are less likely to inhibit pedestrian egress.

Twin Tunnels

Twin one way tunnels are normally required to avoid the risk of head on collisions, improve fire safety, and to provide emergency egress for pedestrians. This egress is to be provided by connecting the tunnels by cross passages fitted with fire rated doors at 120m spacing (and as agreed with fire brigade). This provides a fire escape for vehicle occupants via the adjacent non-incident tunnel (which would be closed to traffic). Therefore twin tunnel horizontal alignments are normally parallel, and the vertical geometry of each tunnel is similar so that the emergency cross passages are level or <2% slope.

Where a tunnel is not twinned (such as on a ramp) a separate conduit solely for fire escape shall be provided with fire rated access doors at 120m maximum spacing.

If a two way tunnel is constructed as a first stage, a parallel tunnel for emergency egress must be provided. This would be enlarged for vehicular use as the second stage. During stage 2 construction the emergency egress function must be maintained.

Shallow tunnels shall have fire escapes directly to the surface as this provides greater safety than egress to the adjacent tunnel, which could have a concurrent incident.

Tunnel Equipment

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.

Emergency Walkways - Shoulder

Inner emergency walkways are required with width for wheelchair access. Entry points from the walkways/shoulders to the connecting cross-overs through the central wall are required at 120 m spacing. The walkways are to also function as a shoulder, and are to be 1.0m minimum width. They must be delineated from the through lane with audio-tactile line marking and light emitting diode (LED) pavement markers as shown in **Figure 7-9**. The LED markers shall be operable from the control room, and shall be capable of flashing to guide pedestrians to the most appropriate escape point for each tunnel section.

The inner walkways are essentially designed for safe and clear passage for:

- emergency egress from the tunnel
- access for emergency services personnel to attend to incidents, including running out fire hoses and removal of injured persons
- access for maintenance works
- evasive action and recovery area (shoulder function)

The inner walkway must extend for a limited length past the portals to an area sufficient to marshal people evacuated from the tunnel in an emergency incident.

Connections from the walkways to the portal helipad should be provided so that stretcher bearers can convey seriously injured persons to an air ambulance.

Where possible, the crossfall of the pavement will slope away from the emergency pedestrian exits, so that burning liquids are less likely to inhibit pedestrian egress.

Short Tunnels

Short tunnels (<500m) shall have full width shoulders and operate at the speed limit of the approach roads. The exit from the tunnel will be visible from the entrance portal, as shown in **Figure 7-3**. If the curvature of the tunnel does not provide through visibility, a reduction in the speed limit may be appropriate.

Lay Bys

If a long tunnel (> 1000m) without a motorcycle lane/breakdown lane is to be constructed, breakdown lay byes 40m long 4.0m wide are required at a spacing not exceeding 500m for the parking of broken-down vehicles.

Tunnel Cross Connections for Emergency Vehicles

In long tunnels (>1500m), cross connections allowing vehicles to be diverted to the adjacent tunnel shall be provided within 1500m of the centre of the tunnel. Maximum spacing between median openings (including those at the portals) shall be 1500m. Fire rated doors are required. The design vehicle shall be a fire truck performing a U turn with 1m clearance on both sides between the turning path and the fire door frame/tunnel wall.

Vertical Clearance

Overhead clearance of minimum 5.4m is to be left in tunnels during their full life cycle.

Pavement

In long tunnels consideration should be given to the use of Portland cement concrete pavement for fireproofing reasons and minimisation of maintenance. An asphalt wearing course may be used.

Allowance for a pavement overlay thickness of 200mm should be made. Single slope crash barriers should be used as they can accommodate overlay without modification. (Cross passages may also need additional headroom to allow for possible future adjustment in floor level).

Surface of Tunnel Walls

The colour of tunnel walls is to be bright and that their surface is non-flammable and easy to clean (e.g. white ceramic tiles or equivalent).

In very long tunnels drivers and passengers may experience boredom or anxiety. Use of different colours, variations in lighting levels e.g. brighter illumination of lay byes may assist.

7.4.5 Staging

Single bore two way tunnels shall not normally be used on expressways, even as a stage construction expedient. However, if a long driven tunnel with relatively low traffic volumes is required, then a single two way tunnel may be considered, but only if a parallel tunnel (or frequent surface egress) for fire escape is provided. This could initially be constructed as a pilot tunnel. When traffic demand increases, this tunnel could be enlarged and converted to traffic use. The emergency egress function would need to remain usable during the second stage construction.

Twin tunnels should be in operation when projected two way traffic volumes reach 10,000vpd.

7.4.6 Interchanges

Interchanges near tunnel portals and within tunnels add to the risk of accidents, and should be avoided near or within tunnels. Locating any underground interchanges (if unavoidable) on straight alignment and uniform gradient will maximise sight distance to diverges and merges, and reduce the accident risk. **Chapter 5** of this document provides sight distance requirements to interchanges

7.4.7 Other Considerations

In certain type of construction such as cut and cover, pipe jacked or immersed tube tunnels the carriageway for both directions would most probably be constructed within a single structure. While this provide easy emergency egress by vehicle occupants to the opposite carriageway it is imperative to provide adequate fire rated separation between the two carriageways for a safe cross passageway.

Inundation of tunnels by waves, storms and flood must be avoided. The walls at the tunnel entrances must be designed to prevent such event from happening.

7.5 Tunnel Structural Requirements

A minimum design life of at least 100 years is required for the main tunnel structure. Other replaceable components would have lower design lives.

The loadings to be considered in the design of structures include:

1. soil pressures – on all surfaces of the tunnel
2. hydrostatic pressures – 100 year flood levels
3. buoyancy forces – due to groundwater and flood waters
4. future additional loadings – from buildings, airports, roads etc to be constructed above the tunnel
5. temporary loadings during construction
6. traffic incident impact forces
7. explosions

The design must also accommodate a wide range of services including drainage, lighting, ventilation, ITS facilities, fire suppression and smoke control facilities. All services must be robust throughout the operational life of the tunnel and include easy access for maintenance. Materials of appropriate fire rating capacity would be used throughout the tunnel.

Major structural damage from heat has occurred in tunnel fires through concrete spalling and softening of reinforcing steel. To minimise tunnel damage and an extended closure of the tunnel to undertake repairs, appropriate fire resistant concrete technology, fire protection coating and structural allowances are required to withstand extended heat levels.

In the detailed design stage, modelling of temperatures is to be undertaken in conjunction with ventilation and smoke control modelling.

Particular attention to construction methodology would be required during the detailed design phase. Practical and proven methods are clearly preferred, from which the project can be fully defined in terms of design, construction requirements, environmental impacts, safeguards and mitigation methods. Examples of temporary activities required to build the tunnel are listed as follows:

1. establishing access to and around the site

2. controlling footprint impacts
3. working in conjunction with any adjacent airport height, lighting and operational limitations
4. dewatering
5. sheet piling
6. temporary strutting of walls
7. removal of potential acid sulphate soils
8. management of ground and surface water
9. disposal of excavated material

Tunnel Requirements

- i. Geotechnical characterisation based on soil investigation according to BS 5930:1999 which include ground water monitoring and ground improvement.
- ii. Structure design life
- iii. Durability of the lining;-
 - a) Metal lining shall be protected by the approved protective system and fire resistance normally average of 600-700°C
 - b) Concrete lining shall be address the issue of corrosion, chloride-induced, carbonation-induced, chemical attack, sulphate, acids and ASR
- iv. Fire resistance
- v. Waterproofing
- vi. Design Consideration which cover the following item;
 - a) Ground/support interaction which is strongly influenced by the construction method
 - b) Stand-up time; all ground properties are time-dependent and strain controlled both in the short and long term
 - c) Earth Pressure; the pressure acting on tunnel depend on the excavations and support sequence of the ground condition
 - d) Deformation of the tunnel
 - e) Immediate support system to avoid deformation of the tunnel

7.6 Tunnel Flood Protection and Drainage System

Protection from flooding is required for the 1 in 100 year ocean and river flood level.

Water leakage into tunnels must be minimised, and any leakage is to be intercepted by a lining so that water does not drip onto the pavement.

A tunnel drainage system is required to collect and control run-off from the following sources:

1. rainfall entering the tunnel from the approaches (and dripping from wet vehicles)
2. fire fighting operations
3. tunnel washdown operations
4. seepage flows
5. accidental spills

A drainage collection system of grates, pits and pipes is required, including baffle pits to act as flame traps in the event of flammable liquids spillage. Storage chambers are required prior to pump out. One small pump and additional larger pumps are required to handle low and extreme flows respectively. Pumped out discharge would normally be directed into adjacent water quality treatment basins. Large quantities of pollutants, from spills for example, would not be pumped out into the water quality basins and are to be collected and taken to appropriate off-site disposal depots.

Reference 7-17 (Chapter 7) provides detailed information on drainage design.

Where possible, the crossfall of the pavement is to slope away from the emergency pedestrian exits, so that burning escaped liquids are less likely to inhibit pedestrian egress.

7.7 Fire Life Safety

Due to the fact that tunnels are enclosed spaces, fires that occur in them result in poor visibility and the spread of smoke and toxic gases along the tunnel, the rapid development of high temperatures and a reduction in the level of oxygen in the air. The extent of harm to road users in the event of a fire in a tunnel is therefore far greater than is the case on open roads. In view of this, it is essential to provide adequate facilities for road users to escape or be rescued by emergency crews. This means that there should be enough escape routes and that the smoke extraction system needs to be fast and efficient. These features also reduce the consequences of an accident that does not involve fire, but which results in the release of toxic gases.

Fires in tunnels not only endanger the lives of road users, they can also cause damage to structural components, installations and vehicles, with the result that the tunnel concerned may have to be closed for a considerable length of time with substantial road user cost and toll revenue implications.

Fire life safety is therefore a major issue, and an effective program for fire safety in tunnels is to be provided that incorporates the coordinated interaction of several sub-systems including:

1. detection by sensors
2. alarm
3. use of fire extinguishers and fire hose reels by the public (this is to also trigger alarm)
4. communications
5. smoke extraction activated from control room
6. emergency egress and personnel evacuation
7. activation of deluge system
8. entry of emergency services personnel
9. fire suppression by fire brigade and deluge system

This section are to be read in conjunction with **Section 8 of Reference 7-2**.

7.7.1 Incident Detection

Programmed closed circuit television cameras are to be installed so that a wide range of incidents, including stopped traffic, pedestrians, objects on the road surface and smoke can rapidly and accurately detected. CCTV should face in the direction of travel so that headlight glare does not affect the picture. CCTV cameras (with panning and zooming capability) shall be located near each emergency door at 120m spacing. CCTV cameras shall also be provided in all airlocks.

Roadway loop detectors are an effective means of alerting the operations control centre staff of stopped traffic and potential problems.

Roof mounted linear heat detectors would be installed as a secondary detection system. The loop and linear heat detectors should also be arranged in 30m zones, to assist in determining the incident location. Zone numbers are to be visible in CCTV monitors to ensure central control room staff and local control room firemen operate the correct over ride controls for the smoke extraction and deluge systems should the automatic systems require adjustment.

Opacity meters should also be included in the incident detection system.

The opening of a fire door is to trigger a signal in the control centre that gives the door location to facilitate CCTV monitoring of the area. Likewise, the opening of an emergency cabinet is to register in the control room. This would also deter theft of extinguishers.

7.7.2 Alarm

The alarm system would activate sound alarms within the tunnel, transmit alarms to the operations control centre and automatically activate appropriate ventilation. The alarm system would be capable of activation in a number of ways:

1. manual activation by operations control centre staff
2. linear heat detectors in the tunnel roof
3. smoke alarms located in the switch rooms
4. programmed closed circuit television cameras
5. manual activation of break-glass units provided in emergency egress pathways
6. opening of emergency cabinets

7.7.3 Communications

Effective communications to and from motorists are required including the following:

1. closed circuit television cameras
2. mobile phone coverage
3. emergency telephones
4. variable message signs
5. traffic signals
6. lighting and signage of emergency pathways, doors and other facilities
7. public address system
8. radio re-broadcast systems
9. radio communications system for emergency services

7.7.4 Smoke Control

In the event of a fire, emergency smoke extraction would be activated to minimise the spread of smoke and to maintain safe conditions for evacuation. The design of the ventilation system requires flexibility so that smoke in any area can be contained and removed from the tunnel effectively. Positive pressure must be maintained in the clean tunnel, and high velocity fully reversible longitudinal fans may be required to control smoke movement if longitudinal extraction is adopted.

Computer modelling of ventilation for the control of smoke and heat is to be undertaken during the detailed design phase.

Longitudinal ventilation shall be used only where ordinary traffic conditions allow vehicles (not trapped by the incident) to drive out of the tunnel.

Where it may not be possible to drive out of the tunnel because of congestion, transverse and/or semi-transverse ventilation shall be used, as there could be vehicles on both sides of the fire. See **Table 7-1**.

7.7.5 Emergency Egress and Personnel Evacuation

Tactile Ground Surface Indicators

Tactile ground surface indicators are to be installed in all emergency egress locations including on the tunnel side of cross passage doors in accordance with **Reference 7-3**.

Reference 7-3 Malaysian Standard Code of Practice for Access for Disabled Persons Outside Buildings

Driven Tunnels – Pedestrian Cross Passages

Unidirectional twin tunnels are required for all expressway through carriageways.

If the tunnels are driven tunnels, they will generally be separated by approximately 15m of rock. In the event of an incident requiring personnel to be evacuated, traffic would be stopped in both carriageways, enabling motorists to evacuate from one tunnel into the other via emergency cross passages with fire rated access doors and air locks.

Cross passages are to be fitted with self closing fire rated doors opening inwards (away from the tunnel) and the cross passage acts as an air lock. Doors are to incorporate a glass panel so that any moving traffic in the non incident tunnel can be observed. Doors are to be 1.4m wide and 2.0m high. The opening of a door is to register in the control centre. The minimum width of the passage is to be 1.8m, and vertical clearance 2.2m minimum to the underside of any tunnel services installed in the cross passage. Ventilation is to be automatically adjusted to keep escape areas clear of smoke and other toxic fumes. Ramp gradients are to permit the passage of wheelchairs (1 in 14 maximum slope). The minimum length of the cross passage is to be 5.1m to allow for stretchers. The minimum floor area of an airlock/passage connecting to another tunnel is to be 15m². (This provides storage for persons in case traffic in the non-incident tunnel is still flowing).

CCTV cameras are to be fitted to all air locks so that the tunnel can be rapidly and safely checked for injured or incapacitated persons.

Long Tunnels – Pedestrian Surface Egress

Long tunnels (>3000m) should include supplementary pedestrian escape stairways and elevators (for disabled persons) providing escape to the surface at a spacing of around 1200m, particularly if the overburden is less than 60m and/or if the ventilation system requires surface shafts. (Risk analysis should be undertaken to assess the need for their inclusion). These may be co-located with ventilation shafts. This will increase the robustness of the fire safety system, and reduce the consequences of incidents occurring in both tunnels concurrently. These escape routes must be independently accessible from either carriageway.

Exhaust stacks in hilly or mountainous terrain may be driven laterally (see **Figure 7-7**) if the terrain permits. This would facilitate the provision of pedestrian egress without recourse to stairs and lifts for the disabled.

CCTV cameras are to be fitted to surface egress systems so that the tunnel can be rapidly and safely checked for injured or incapacitated persons.

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Figure 7-7 Driven Tunnels with Lateral Egress and Smoke Extraction

Shallow Tunnels – Pedestrian External Egress

Shallow tunnels (particularly cut and cover tunnels) shall have emergency pedestrian external egress to the surface at 120m intervals. Cut and cover tunnels shall have a fire rated central wall (or floor if double deck tunnel to separate each unidirectional carriageway).

External egresses shall have an air lock of minimum area of 9.2m² to provide space for a stretcher and inwards opening doors. Other dimensions are to be the same as cross passage air locks. If the egress cannot practically be connected to the surface by ramps usable by disabled persons, the air lock is to be increased in width to 3.0m to accommodate a waiting area for disabled persons, resulting in a minimum floor area of 15.3m². An emergency telephone is to be installed adjacent to the waiting area so that trained personnel can be summoned to assist the disabled. The doors to the air lock shall be in line and on one side of the air lock so that waiting persons do not impede others. CCTV cameras are to be fitted inside all air locks so that the tunnel can be rapidly and safely checked for injured or incapacitated persons.

The doors at the surface shall prevent the entry of unauthorised persons. The doors shall open outwards, and be automatically closed. In case the doors are obstructed, the doors shall be double hinged so that they may be opened inwards as well. The push bar is to release the door outwards, and is to also release the door for inwards opening if pulled.

Pedestrian Egress Ventilation

Air locks and emergency egress passages shall be ventilated and pressurised to inhibit the entry of smoke.

Signage and Zone Boundaries

Emergency egress lighting and signage is used to direct personnel to the emergency access doors or tunnel portals and to provide illumination within the air locks and surface ramps or stairs.

Zone numbers on the tunnel walls (and in air locks) visible to both firemen and to the control room CCTV monitors are necessary. There shall be four 30m zones between cross passages. The cross passages will define a zone boundary. The emergency cabinets at 60m spacing will also define zone boundaries. Emergency cabinets are to be located adjacent to cross passages and half way between them. The zone numbering shall be based on the cross passage number and direction of travel. E.g. zone 7E4 will be the fourth zone in eastbound bound tunnel after cross passage 7. The opposite zone in the westbound tunnel would be 8W1. The CCTV cameras would be numbered with the cross passage number and eastbound or westbound e.g. 7E.

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Figure 7-8 Zone Numbering System

Cameras are to face in the direction of traffic to avoid headlight glare. The camera number is to appear in the monitor screen at all times.

Distance and direction to both portals shall be shown on prominent signs adjacent to each emergency cabinet.

The edge of the emergency pedestrian egress is to be delineated by light emitting diode (LED) pavement markers that are to show a ripple light flashing in the direction to the appropriate escape route. The default pattern will be no illumination in the fire zone/s and away from the fire zone/s in adjacent zones. The default pattern in the non-incident

tunnel will be towards the closest portal. The LED Pavement lights are to lead occupants through cross passages (unless the use of a passage is not appropriate) and also indicate the direction to follow in the non-incident tunnel. The LED ripple pattern shall be capable of over ride from the control room. Adjustment of the pattern may be appropriate to direct people to a surface egress or tunnel portal rather than a cross passage. A cross passage near the fire may be required for fire brigade use. It may be preferable to initially order movement away from the fire in the incident tunnel until traffic in the non incident tunnel has cleared the tunnel and entry of additional traffic has stopped. For occupants near the tunnel portal direct egress from the incident tunnel portal may be appropriate if smoke is being effectively controlled.

Air Lock Equipment

Tunnel equipment such as substations, communications equipment etc. should not be located in air locks as this may present opportunities for sabotage.

All airlocks shall be equipped with an emergency phone and fireman's phone and be monitored by CCTV.

Pavement Cross Fall

Pavement crossfall should, if possible, slope away from the fire escapes. The use of adverse crossfall may be required on curves. Minimum curve radii for adverse crossfall are defined in **Chapter 3**. As curves should be of generous radius to provide good horizontal sight distance (see **Table 7-3**), adverse crossfall will usually be achievable. Where pavements must slope towards the fire escapes, interception of kerbside flows is necessary so that burning fuel cannot enter the air lock.

On straights, crossfall is normally to the left, but this will need to be reversed if the fire escapes are located on the left, as may be the case with one carriageway of double deck cut and cover tunnels.

Disabled Persons

Handicapped persons using wheelchairs or other mobility aids must be capable of passing through the cross passages or ramps without help. If possible, one way ramps should be downhill ramps to facilitate the movement of wheelchairs.

Stretchers

All egress facilities shall allow the passage of a stretcher 0.7m wide by 2.3m long. Stretcher bearers must not impede doors being closed to maintain the air lock, so a length of 5.1m is required between closed doors.

Tunnel Pedestrian Facilities

In the event of a fire, occupants of vehicles remaining in the incident tunnel will be directed to use a fire escape. Access to the fire escape from their vehicle is to be via the 1.0m wide shoulder adjacent to the wall with the fire doors. So as not to impede disabled access (and to utilise the space as a shoulder when traffic is moving), no kerbs are to be provided. Pedestrian movement will normally only occur after traffic is stationary.

Tunnel Crash Barriers

The tunnel walls are to be faced with a single slope concrete barrier with working width as detailed in **Figure 7-9**. On the departure side of breaks in the barrier for cross passage doors, the barrier is to be offset 150mm with a 1:15 taper to minimise risk of vehicles (or motorcyclists) snagging on the gap in the barrier.

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Figure 7-9 Detail of Tunnel Interior Wall

Table 7-5 Working Width

Truck Design Speed	Working Width (4.3m above pavement)			
	Pavement Away from Barrier (mm)	2% Crossfall	Drains	Pavement Towards Barrier (mm)
70	500			600
80	550			650
90	650			750
100	750			850

7.7.6 Fire Suppression System

Reference 7- Chapter 8 provides additional guidance.



Figure 7-10 Tunnel Fire Test

Emergency Cabinets

Emergency cabinets are to be provided for dealing with fire incidents are to include:

1. fire hose reel
2. two fire extinguishers
3. fire alarm
4. firemen's phone
5. emergency phone for vehicle occupants including disabled persons
6. fire hydrant
7. placard advising distances to emergency exits and to each tunnel portal
8. placard advising that additional telephones are located behind emergency doors in the air locks (less noisy and safer environment)

These are to be located at 60m desirable intervals (100m maximum) on the same side of the tunnel as the emergency exits in accordance with fire brigade requirements.

The emergency phone system must automatically advise the control room of the cabinet (or air lock) location using the same zone numbering system as the deluge and smoke control zone numbers.

The door to the cabinet shall be hinged at the top, spring assisted opening and with an automatic hold open device. It is not to obstruct the footway when open. The door is to release when the handle is pulled. The opening of the cabinet is to register in the control room identifying the location. The door is to be painted red and is to be flush with the tunnel lining to facilitate automated tunnel lining wash down. The door and electrical fittings are to be water resistant to the deluge system overspray and cleaning operations.

The cabinets are to be located adjacent to the cross passage doors and mid way between them at a 60m module.

The CCTV system is to be capable of monitoring activity at every emergency cabinet and emergency exit, as well as all of the road pavement and shoulders.

Water Deluge System

A water deluge system is mandatory in tunnels longer than 240m, and may be appropriate in shorter tunnels if the structural system for tunnel support is vulnerable to fire damage. Deluge systems have been recognised as an important technique for fighting fires and preventing major damage to the tunnel.

The deluge system (or proven fire mist or other new technology equivalents) is to be automatically activated, but the control room operator is to have a brief opportunity to intervene before the deluge commences in case traffic is still moving. The central control room and local control room are to have over ride control of the deluge system.

Experience in Australia and Japan indicates that the system is of greatest benefit if it is initiated before the fire takes hold.

The deluge system shall capable of delivering 10 litres/m²/minute to three zones each 30m long for four hours.

The fire is controlled in size, if not extinguished, by the deluge discharge. Smoke drawn through deluge systems is cooled and the smoke extract system shall address this dynamic to effectively extract smoke in the occupied zones.

At the detailed design stage, full details of fire suppression systems would be determined in association with emergency services authorities.

7.7.7 Water Supply

The method and quantity will depend upon the fire fighting provisions proposed for the tunnel. Nevertheless, a reliable water supply is vital, such that an incident at any section within the tunnel does not deplete the supply of water. In addition to hydrant supply, allowance for 4 hours of operation of 3 zones of the deluge system is to be provided from each of two independent sources such as a mains supply and a separate storage tank.

Fire brigade booster facilities are required at both portals. This must comprise a hard stand area for fire appliances and booster pumps. Six suction plugs and six pressure plugs are required. Emergency cabinets are the tunnel portals with fire brigade phones should be located near the booster facility, or otherwise additional phones are required.

Consideration should be made for tank storage or mains tapping from both ends of the tunnel, each tapping sufficient to provide the required water quantity. In addition consideration should be made for isolation of parts of the water main for both emergency purposes as well as maintenance purposes. Isolated areas at any one time should be minimised and managed accordingly.

7.7.8 Fire Resistance of Tunnel Systems

The fire resistance of a structure can be defined as the time from which the fire starts to the time when the structure can no longer serve its purpose, due to unacceptable deformation or collapse.

In the event of a fire within the tunnel, the structure and safety equipment should not burn and produce large amounts of toxic gases and smoke. The tunnel structure must not collapse and safety equipment should continue to operate while fire fighting and evacuation is taking place.

The emergency smoke extraction system is to have a fire rating of 250 °C for a minimum of two hours. Other emergency equipment (electrical cabling, fire suppression equipment etc) should have equivalent fire ratings. Further, the design and layout of electrical circuits, communications and sprinkler/deluge systems should limit the risk of localised failure (through extreme temperature or other cause) leading to failure of unaffected parts of the system.

Equipment adjacent to a fire may be destroyed, and calculations and mechanical ventilation facilities and capacity for smoke removal must allow for this.

7.7.9 Redundancy Provisions

The water and power supply and communications systems are to be provided as a grid or network so that loss of a section in the fire area does not lead to system failure.

The emergency services network is to have section length of 120m. Transverse connections are then conveniently located in the emergency exit cross passages.

The control room Supervision, Control and Data Acquisition (SCADA) and associated computers and software are to be self diagnostic, self correcting and fully redundant.

7.8 Electrical & Mechanical Systems

This section are to be read in conjunction with **Section 8 of Reference 7-3**.

7.8.1 Sabotage Resistance

Tunnel services shall be designed and located to reduce their vulnerability to acts of sabotage. **Reference 7-15** provides guidance.

7.8.2 Tunnel Power Supply and Distribution

The electrical power supply system provides power for the operation of the tunnel lighting, pumps, tunnel ventilation system and other tunnel operation systems.

Highly reliable power supply is paramount to the majority of the fire safety systems and other systems required for tunnel operations. Two independent power sources are required from separate and secure parts of the electricity supply grid. Alternatively, the mains supply is to be duplicated using diesel generator/s automatically started in the event of failure of the mains supply. The diesel generator/s would require sufficient capacity to drive essential components of the systems including the smoke extraction system, control room and ITS, emergency lighting, and deluge system and fire hydrants.

Essential power supplies for control, communication and tunnel lighting must be provided by UPS supply to enable them to operate without interruption.

The light output from the tunnel lighting may be reduced to emergency levels while running on the UPS.

High Voltage cables are to provide a dual-redundant (ring-main) electricity supply system. Power is to be distributed through the tunnel via a network of high voltage feeders and substations.

Power supply cable would be located within cable trenches, underground conduits and/or cable ladders. All cables shall be of low smoke zero halogen material type. Emergency services shall use fire rated cables complying to IEC standards.

Control rooms, sub stations, switch rooms and communications rooms, and air locks are to be ventilated and maintaining positive pressure. The ventilation air shall be drawn from outside the tunnel if this is not practicable, from the non-incident tunnel.

An environment suitable for long term operation of the housed equipment must be maintained. Control rooms will require air conditioning to ensure computing equipment operates reliably.

7.8.3 Lighting

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

These problems are exacerbated by sun glare, and it is preferred not to locate the tunnel in the east-west direction.

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

Artificial lighting to permit drivers to adapt gradually to the difference in visibility conditions outside and inside the tunnel is required. Lighting design is covered in **Chapter 14** of this document and **Chapter 6 of Reference 7-17** also provide guidelines

7.8.4 Tunnel Ventilation

The initial requirement of ventilation is to maintain air quality for the comfort, health and safety of motorists during normal operating conditions. **Reference 7-17 (Chapter 5)** provides additional guidance.

The most critical contaminants are carbon monoxide, nitrogen monoxide / nitrogen dioxide, and particulates. The tunnel requires sensors for each of these contaminants, linked to the ventilation system to enable automatic preservation of air quality within permissible limits set by the Department of Environment (DOE).

The second and most demanding requirement of ventilation is to smoke and other toxic fumes extraction in the event of a fire or chemical spillage.

The requirement for independent power sources is stressed to ensure continuing operations in an emergency.

Natural Ventilation

Natural ventilation in tunnels is capable of diluting vehicle emissions only to a very limited extent, and smoke from fires is an issue. It may be adequate for very short tunnels as indicated in **Table 7-1**.

Artificial Ventilation

In rural areas, a longitudinal, jet fan based system, (which assumes all vehicles downstream of a fire incident are able to drive out) may be satisfactory for tunnels less than 3000m long.

This may not be the case in urban areas, where congestion could occur downstream of the incident, preventing the escape of vehicles.

A longitudinal ventilation system with a separate smoke extraction system, or a semi-transverse exhaust system, has the capability of providing localised smoke exhaust over a tunnel section in which the incident has occurred. Such a system incorporates motorised smoke exhaust dampers that can be opened over a section straddling the incident. This is to contain smoke and draw clean air from each side of the incident to prevent back-layering over trapped vehicles upstream and downstream.

In urban areas localised exhaust straddling the fire site is mandatory for tunnel user protection.

Smoke drawn through deluge systems is cooled and the smoke extract system shall address this dynamic to effectively extract smoke in the occupied zones (the cool smoke and water vapour will require higher extraction velocity).

Air velocities in the enclosed tunnel should be greater than or equal to 0.76 m/s and less than or equal to 11.0 m/s.

Fire Intensity

The design fire should be assessed taking into account likely vehicle size and load type. Local factors such as the transport of palm oil, tyres and timber should be considered.

Minimum design fire intensity for typical vehicle table.

Table A.11.5.1 Fire Data for Typical Vehicles

Vehicles	Peak Fire Heat Release Rates (MW)	Time to Peak HRR (min)
Passenger car	5–10	0–30
Multiple passenger cars (2–4 vehicles)	10–20	13–55
Bus	20–30	7–10
Heavy goods truck	70–200*	10–18
Tanker	200–300	—

Air Quality within Tunnel

The design of the ventilation system must be based on the air quality values prescribed by the Department of Environment (Malaysia).

Pollution in the Area of Tunnel Portals

Ventilation systems and tunnel portals shall be designed so that contaminated air will diffuse in the atmosphere to the requirements of Department of Environment (DOE).

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 (see **Reference 7-**) to avoid undesirable pollution.

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.

Exhaust Stacks

In terms of emissions from vehicles and resultant pollutant concentrations, the difference between surface roads and tunnels lies at the point of emission. Emissions from surface roads are released at ground-level where a greater proportion of the population reside. The surface road relies solely on atmospheric dispersion to reduce the pollutant concentrations between the roadway and the sensitive receptor. In contrast, tunnel emissions are generally vented via the tunnel portals and/or a ventilation stack (or stacks).

In urban areas, the ventilation system may be designed to avoid portal emissions during normal operation if sensitive receptors are located close to the portal.

Ventilation is important in order to maintain satisfactory pollutant concentrations within the tunnel, so that the health of motorists using the tunnel is not adversely affected.

With a stack, the point of emission from the tunnel is above ground-level (at stack height) and the reduction of the pollutant concentrations from the stack to the sensitive receptor combines the initial distance of the release point with the dispersive capacity of the atmosphere. An elevated point source is, therefore, more effective than a line source of a surface roadway with the same emission. Dispersion modelling studies demonstrate that, provided the tunnel is sufficiently ventilated, significant air quality benefits can be obtained using tunnels. The most significant air quality benefits occur along surface roads which undergo the reduction in traffic induced by the tunnel. Stacks need to be sited appropriately and where possible not in valleys and not close to high rise buildings.

Sometimes existing structures may be able to incorporate the exhaust stack.

The following criteria need to be considered when identifying potential exhaust stack sites:

- Cost and efficiency of the tunnel ventilation system including operating costs
- Air dispersion characteristics
- Visual impact
- Discharge of tunnel emissions from the stack at each location along the tunnel
- Net change in air quality
- Availability of commercial/industrial land
- Proximity to residential development
- Availability of vacant or government owned land

Exhaust stacks in hilly or mountainous terrain may be driven laterally if the terrain permits. This would facilitate the provision of pedestrian egress without recourse to stairs and lifts for the disabled as shown in **Figure 7-7**.

Monitoring

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

- CO concentration
- Nitrogen monoxide / nitrogen dioxide
- air speed and direction of air flow
- air volume and pressure increase (for semi-transversal and transversal ventilation)
- fire alarm
- traffic data

Fire Safety Testing & Commissioning

The commissioning of a tunnel's safety systems is dictated by the nature of the systems installed in the tunnel. It is usual that all systems would be individually commissioned and then commissioned in a way that would simulate the relevant scenarios and sequence of events that would be expected to take place in an 'incident'. In other words the interfacing of the systems needs to be addressed to demonstrate that they are all working together and talking to each other.

A comprehensive commissioning process needs to be designed so that all likely and some unlikely combinations of events are examined.

Most major disasters can be attributed to a sequence of malfunctions that were not envisaged.

Hot smoke tests or real fire tests must form part of the tunnel commissioning process.

Fire Safety System Maintenance

In terms of the ongoing management of tunnel maintenance of the fire safety systems, an appropriate maintenance schedule and strategy is required.

Fire Brigades must remain involved in the ongoing maintenance and review of procedures for emergency response to tunnel emergencies and liaison with tunnel operators and control rooms.

7.9 Tunnel Traffic Management

This section are to be read in conjunction with **Section 8** of **Reference 7-2**.

7.9.1 Control Centre/s & ITS

The use of intelligent transport systems to manage traffic through tunnels is more important than on the open road, due to the possible consequences of an incident. Resources that must be available to the tunnel control centre include emergency maintenance personnel, tow trucks, fire service, police, and ambulance/air ambulance. Vehicular access to incidents not involving fire will generally be from the tunnel exit portal as access from the entrance portal will usually be blocked by queuing vehicles caught upstream of the incident. Fire fighting access may be from the (closed) adjacent tunnel so that firemen have safer conditions including avoidance of smoke. This may also be necessary in urban areas (or where multiple incidents have occurred), as the area downstream of an incident may not be clear of traffic due to traffic congestion.



Figure 7-11 Typical Control Centre

A control centre with an integrated software package for Supervision, Control and Data Acquisition (SCADA), specifically developed for use in traffic supervision and control is required that includes the following:

1. Automated video detection –detects stationary vehicles, pedestrians, objects on the pavement, smoke, to monitor traffic count and other unusual incidents
2. Variable message signs and changeable message signs (including variable speed limits) – placed before the tunnel to convey brief messages to motorists such as speed reduction, accidents, and lane closures
3. Lane use signals – placed in advance and regularly through the tunnel, to give quick messages to motorists regarding lane availability ahead
4. Closed circuit television cameras – ceiling or wall mounted, located so that full coverage of the tunnel is achieved, to monitor traffic operations and assist in incident management

5. Oversized vehicle safeguards – a range of measures are employed to ensure that over-height vehicles do not enter the tunnel.
6. Advance warnings through variable message signs shall be located at adjacent interchanges to facilitate traffic diversions
7. Monitoring of emergency median crossovers (for incident management)
8. Monitoring of system status for all major installed equipment
9. UPS is required to maintain ITS operations and tunnel lighting in an emergency
10. In addition to the above, provision of automated pre-screening of commercial vehicles to detect fires or overheated components that could lead to fire could

Reference 7-17 Chapter 10 provides further details.

The Supervision, Control and Data Acquisition (SCADA) and associated computers and software are to be self diagnostic, self correcting and fully redundant.

The central and local control rooms must both include CCTV monitors, fire systems monitor panel, provision for smoke extraction /ventilation over ride control, deluge control over ride, telephone systems and communications systems (radio-rebroadcast, public address system, and a full set of plans and manuals.

7.9.2 Emergency Response Plan

Operators at the control centre must monitor all operations, with intervention required when there is an abnormality. Automation of predetermined operational scenarios is to be maximised in the event of emergencies, to simplify and minimise operator decisions. This has proved to be of critical importance in ensuring rapid and effective deployment of warning systems, ventilation and other emergency actions, and in reducing operator error.

Incidents in the tunnel requiring intervention will range from breakdowns, crashes, crashes involving injury, and fires that may follow crashes or result from vehicles or their contents catching fire.

Whenever traffic queues extend into tunnels, there is an increased risk of rear end crashes in the tunnel. Accidents of this type require fire site smoke extraction as longitudinal extraction is predicated on the area downstream of the incident to be clear of traffic. The consequences of this type of accident in a tunnel with a longitudinal smoke extraction system must be mitigated by either closing the tunnel or reducing the speed limit as soon as conditions that will lead to a queue are detected.

The flow of vehicles must be automatically monitored and appropriate management actions taken to minimise the danger of such crashes. Variable message signs, variable speed limits, communication systems, and traffic lights are to be used to warn motorists of the stoppage.

An emergency response plan is to be prepared to formalise and coordinate all systems and emergency procedures. The emergency response plan is to be developed in conjunction with the operations control centre, Fire Brigade, Police, Ambulance and other emergency services.

Roles and responsibilities for the tunnel owner/operator, the operations control centre and all other agencies must be defined in the emergency response plan.

A comprehensive list of credible incidents is to be prepared, and the most effective response to each incident developed.

Primary and secondary approach routes to each portal would be mapped, including with-traffic and against-traffic options. Emergency access from external points to the ends of the tunnel must be considered.

The emergency response plan must also include:

1. the need for full scale integrated emergency response training and exercises to be conducted on a regular basis
2. provisions for periodic review and update

The Incident Management Plan would address matters such as:

1. tunnel closure
 - closure of tunnels to prevent additional vehicles entering by traffic signals (then manually controlled boom gate closure (monitored by CCTV))
 - when a tunnel is expected to be blocked for a long period of time, traffic must be diverted from the expressway at the preceding interchange (see **Reference 7-17, Figure 9.2**)
 - traffic unable to enter the tunnel may be required to perform a U turn at an emergency median opening near the tunnel portal if the tunnel is to remain closed for a period
 - traffic stopped in the tunnel may need to use an emergency median opening to access the adjoining tunnel if the incident causing the tunnel closure results in the need for a protracted closure
 - temporary two way operation of one of the tunnels may be necessary for incident management or maintenance (at reduced speed)
2. queue developing in tunnel (road congestion or incident near exit portal)
3. crash in tunnel
4. crash outside tunnel near exit portal
5. crash outside tunnel near entry portal
6. traffic congestion in tunnel
7. stationary vehicle (broken down or abandoned)
8. adverse weather conditions (unexpected rain, fog at the exit, sun glare at the exit, bush fire smoke at exit)
9. landslide at the exit
10. earthquake
11. animal in tunnel
12. pedestrian in tunnel
13. person in air lock
14. vandalism
15. body on carriageway

16. object on carriageway
17. civil unrest (protests, sabotage, bomb threat, simultaneous terrorist attack on both tunnels)
18. contra-flow vehicle
19. external traffic incident impacting tunnels
20. fire / smoke incident
21. over-height vehicle
22. prohibited vehicle
23. spilled loads
24. equipment failures (lighting, ventilation, pumps, communications)
25. water inundation
26. combinations of incidents including more than one fire
27. concurrent incidents in both tunnels

7.10 Additional References

The following references provide further information on tunnel safety, security, and design. There is considerable variation in accepted practice between various countries, and recommendations may change as the causes of incidents are assessed.

Up to date literature and conference proceedings should be reviewed to ensure that world best practice is adopted.

Reference 7-4 **Good Practice for the Operation and Maintenance of Tunnels PIARC 2005**

Reference 7-5 **Fire and Smoke Control in Road Tunnels PIARC 1999**

Reference 7-6 **Systems and Equipment for Fire and Smoke Control in Road Tunnels PIARC 2006**

Reference 7-7 **Recommendations for Bridge and Tunnel Security - FHWA 2003**

<http://www.mipt.org/pdf/dotbridgetunnelsecurity92003.pdf>

Reference 7-8 **NCHRP 525 Surface Transport Security**

http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_525v1.pdf

Reference 7-9 **Fire Safe Design, Road Tunnels Listing of Guidelines - FIT European Thematic Network 2002**

http://www.etnfit.net/unprotected_documents/WP3_Road_list_guideline.pdf

Reference 7-10 **Recommendations of the Group of Experts on Safety in Road Tunnels - Final Report United Nations Economic and Social Council TRANS/AC.7/9**

<http://www.unece.org/trans/doc/2002/ac7/TRANS-AC7-09e.pdf>

Reference 7-11 **Appendix No. 2 to Inter-Ministry Circular No 2000-63 Technical Instruction Relating to Safety Measures in New Road Tunnels (Design and Operation) – CETU 2000**

http://www.cetu.equipement.gouv.fr/IMG/pdf/Ann2_Circ2000-63_English__BHA_.doc
[20050516111751_cle531f6e.pdf](http://www.cetu.equipement.gouv.fr/IMG/pdf/Ann2_Circ2000-63_English__BHA_.doc)

Reference 7-12 **Fire Safety Guidelines for Road Tunnels - Australasian Fire Authorities Council**

<http://www.afac.com.au/awsv2/publications/documents/FireSafetyGuidelinesforRoadTunnels.pdf>

Reference 7-13 **CURRENT STATE OF ROAD TUNNEL SAFETY IN JAPAN - H. Mashimo Public Works Research Institute, Incorporated Administrative Agency, Tsukuba, Japan T. Mizutani Advanced Construction Technology Centre, Tokyo, Japan**

<http://www.pwri.go.jp/eng/kokusai/reports/mashimo031018.pdf>

Reference 7-14 **Meeting Consumer Expectations for Air Quality in Road Tunnels Alan A. Irwin and Gary J. Hudson Norman Disney & Young, Sydney, Australia, - 11th International Symposium on Aerodynamics & Ventilation of Road Tunnels Luzern 2003**

Reference 7-15 **TCRP Report 86 Volume 12 TRB 2006**

http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_525v12.pdf

Reference 7-16 **Fire and Smoke Control in Road Tunnels - PIARC Committee on Road Tunnels (C5), 1999**

Reference 7-17 **Design Manual for Roads and Bridges BD 78/99 Design of Road Tunnels - The Highways Agency 1999**

<http://www.archive2.official-documents.co.uk/document/deps/ha/ghost/dmrb/vol2/sect2/bd7899a.pdf>

Reference 7-18 **Minimum Safety Requirements for Tunnels in the Trans-European Road Network - COMMON POSITION (EC) No 24/2004**

<http://europa.eu.int/eur-lex/pri/en/oj/dat/2004/ce095/ce09520040420en00310052.pdf>

Reference 7-19 **Safe Driving in Road Tunnels for Professionals (Leaflet) – European Commission for Energy and Transport**

http://europa.eu.int/comm/transport/road/roadsafety/roadinfra/tunnels/documents/leaflet_pro_en.pdf