SAFETY DESIGN FOR LONG ROAD TUNNEL

Yoshikazu OTA
OTA Engineering
Tokyo, Japan

ABSTRACT
According to the enhancement of economic conditions and prosperity in each Nations, long road tunnel projects are increasing year by year due to the extension of highway network for transportation business.

Many fatalities were inhaled the hot smoke and toxic gases which generated at vehicle itself and lording goods.

Selection of ventilation system, smoke control strategies with pressure balance control, and operation system with quick response are key issues for tunnel safety.

This paper describe the basic phenomenon of smoke propagation and key points of pressure control by point extraction system for the appropriate smoke control, for the arrangement of universal design concept.

Keywords: Ventilation system, smoke control, point extraction

1. INTRODUCTION: BASIC CONCEPT OF SAFETY DESIGN

In recent years, there are so many tunnel fire occurred in the world.

Fire and life safety design must be made sure for all of tunnel users in combine with all of relevant technology fields with appropriate understandings of tunnel users for fundamentals of tunnel structure.

On the other hand, International road network will be arranged more and more tightly transportation in the world, according to the world wide economic growth and trading net work.

For example, “Silk Road” was built in Asian Continent in more than thousand years ago for the purpose of connection of European continent for the International trade and cultural exchange.

Figure 1-1 presents the typical road network system of “Asian Highway network” in Eurasia continent. This Asian Highway Network should be linking with European Highway Network.

At present, new motorway net work is arranging under the each nation and UN, then these highway network will be integrated as “International Road Network System”

In the future, many of motor way users will take long distance drive to foreign countries for surface transport and tourism through the long road tunnels in some countries.

Especially, long road tunnel is specified structure in comparing with the other ordinary open roads with following characteristics,
Closed space with artificial lighting condition
Different weather condition with open section
Safety system and emergency service must be arranged in the case of incident
High maintenance cost to be necessary with maintenance and operation.

If in the case of serious accident was happened in the long road tunnel within foreign vehicle involved, take communication within concerned personnel, also be difficult with different languages.

Based on these concepts, we must discuss more and more for the “How to arrange the “Appropriate Safety Design for long road tunnel, on the point of view of universal concept with common technologies for mutual understandings with passengers”

Reference
1) UN website : United Nations Economic and Social Commission for Asia and Pacific

2. VENTILATION AND SMOKE CONTROL SYSTEM

2.1. Introduction

In recent years, there are so many tunnel fire occurred in the world.

Due to the fire and life safety, structural design must be assured for life safety in combine with ventilation system.

Tunnel ventilation system with smoke control strategies is one of the key issues for tunnel safety in combine with traffic control system.

Basic planning of Tunnel ventilation system must be planned at initial stage in preliminary design.
In the recent years, required mechanical ventilation volume in normal traffic condition is decreasing year by year, due to the improvement of combustion technologies for vehicle engine.

On the other hand, magnitude of tunnel fire is becoming larger scale, due to the enlargement of fuel tank capacity for the long distance drive and loading materials.

2.2. Basic concepts for ventilation and smoke control systems
The following three points are key issues for tunnel ventilation design

- Traffic direction (uni-direction or bi-direction) must be considered.
- Air pressure must be over pressurized than incident tunnel space for the prevention of smoke inversion to evacuation space for passengers.
- Response time for smoke control must be quicker as possible in combine with appropriate fire detection system.

2.3. Basic behaviour of smoke propagation
If in the case of fire ignited and smoke spread into the tunnel space with natural condition. The heated smoke will be rising up to the ceiling by buoyancy effect, then, flowing to the down stream side with same as wind direction. According to the several experience of full scale fire experiment, the velocity of extreme head of smoke layer on that time will be 2.0 - 2.5m/s generally. Then, smoke will be dropping down to the carriage way by the cooling effects at the tunnel structure itself in the down stream section.

Figure 2-1 presents the basic behaviour of smoke propagation. The hanging length of smoke layer will be 200-250m, which was proved by the full scale test in several countries.\textsuperscript{1,2}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{smoke_propagation.png}
\caption{Basic description of smoke behaviour}
\end{figure}
2.4. Basic character of longitudinal gradient

Figure 2-2 presents the typical phenomenon of smoke propagation and fuel spillage expansion in the grade section.

- Hot smoke and fume from (HGV diesel) vehicle are very effective to the determination of the required mechanical ventilation volume.
- Smoke propagation phenomenon and expansion of spillage should be appeared in the opposite situation in the case of the up and down gradient section.
- In the case of fire occurred in the upgrade section. The smoke will be flowing to the same direction with traffic direction. On the other hand, flammable liquid spillage will be expanding to the backward. This is one of the causes of fire expansion to the following cars. This is big obstacles for evacuation and initial safety management. The design of drainage system with oil separator is very important for this case.
- In the case of fire occurred in down grade section, generated smoke will be propagated to the backward direction by the buoyancy (chimney) effect of heated smoke.
- This buoyancy effect must be taken into account of the computation of capacity of ventilators for the prevention of heated smoke inhalation.

Figure 2-2: Basic concept for the safety design in grade section
2.5. Jet fan system

Generally, jet-fan system can be applied to the relatively short length tunnel. Appropriate Length of Jet fan system should be determined by the following conditions,

- Tunnel length
- Traffic volume and HGV (diesel contents) percentage
- Topographical conditions (Urban or Inter city tunnel).
- Traffic direction (Bi-directional or uni-directional).

Figure 2-3 presents the relationship between location of jet fans and static pressure distribution.

![Figure 2-3: Relation ship between Static pressure distribution and location of Jet fans](image)

If in the case of jet fan system employed for relatively short tunnel. Down stream installation (left side) seems to be better than up stream installation (right side) due to the possibility of creation the wider low pressure zone in longitudinal section.

There are two options,

(Case1) Push the smoke at tunnel entrance zone

(Case2) Pull the smoke at tunnel exit zone

2.6. Basic performance of point extraction system

If in the case of full transverse ventilation system or point extraction system employed for relatively long road tunnel, smoke propagation condition can be significantly improved for safety by the pressure balance control and utilize of Coanda effect (boundary layer attachment). Figure 2-4 presents the basic concept of improvement of smoke propagation.

Expansion of smoke free zone at down stream region can be realized by the application of Coanda effect in combine with ceiling extraction system.

This fact is also contributed to the extension of the spacing of the safety exit.
2.6.1. Single point and multi point extraction system

Figure 2-5 presents the difference of smoke concentration of single port and double-point extraction system. The wind velocity changing point (high smoke density zone: neutral zone) will be extended according to the number of openings and extraction air volume at each exhaust port. In the case of single port opening with maximum extraction air volume, this neutral zone will be fixed at just below of exhaust port.

This high density zone should be varied by the natural wind or atmospheric conditions at both tunnel entrances.

This is one of the serious problems for smoke control strategies and decision making for the evacuation direction for tunnel users.

The single extraction port is preferred rather than multiple extraction port (more than two extraction port) due to the creation of thin smoke layer concentration at extraction port.
2.6.2. Semi and Full Transversal ventilation system

Only fresh air is supplying to the traffic space in ordinary operation of semi-transverse system. Then, if in the case of fire, ventilator and smoke extraction damper should be operated to reverse flow and activate to the smoke control mode after the fire reported. Therefore, response time for smoke control mode takes certain minutes. This is big disadvantage of reverse operation in semi-Transverse ventilation system.

In the case of full transverse ventilation system in combine point extraction system (similar with Plabutsch tunnel in Graz, Austria), it is not necessary the ventilator control to reverse flow at initial stage in comparing with semi-transversal ventilation system. This means so that the response time for smoke control mode could be achieved with short response time for exhaust damper control.

2.6.3. Point extraction system in longitudinal ventilation

Figure 2-6 presents the point extraction system in the type of longitudinal ventilation.

Selection of extraction port will be able to the automatic control by several sensors and detectors, such as, traffic sensor, wind velocity sensor, visibility meter and fire detector.

The fresh air will be coming into the traffic space from both portals, then, polluted air is always extracted into the exhaust air duct through the single extraction port. Therefore, static pressure distribution in carriageway is always lower pressure than atmospheric pressure and other safety space.

This is one of the significant advantages of this system.

In addition, following advantages can be found,

- Not necessary to reverse operation of ventilator
- Fresh air duct is not necessary
- This system can be adapted to both of bi-directional and uni-directional traffic with movable extraction port due to the traffic conditions and atmospheric pressure balance at both sides.
- This system could be adapted to 6-7KM long tunnel according to the traffic condition.
Based on above basic concepts, fully transverse ventilation system with point extraction system and longitudinal ventilation system equipped with point extraction system seems to be preferable for relatively long road tunnel in comparing with the other ventilation systems. The point extraction system is very effective for smoke control (smoke can be extracted at certain points) with depress the air pressure.

**Reference**

3) C, Lin. Y,OTA . Safety Concept for the East Coast Freeway Tunnels in Taiwan

**3. CONCLUSION**

Safety philosophy of long road tunnel is quite complicated system in all kind of highway structures. In addition, safety level can be achieved in collaboration with tunnel users and organization of related public agencies in each country, not only installation of advanced equipments.

On the other hand global motorization in expanding to all countries to Eurasia continent with appropriate automobile universal design concept.

As a fact, due to the universal design concept, many of people who can easy drive the many brand of vehicles with their own taste, which is very important key suggestion for safety design.

Universal design concept must be arranged for all of tunnel systems for the purpose of system assurance to the fire and safety to tunnel passengers.

“The completion of installation of Tunnel structure and hard ware is just addressed on the starting point to the achievement of Real Quality of Road Tunnel.”