SMALL EMERGENCY TUNNELS INSIDE ROAD TUNNELS

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ABSTRACT

When fire provokes in a road tunnel, it is most important to let the drivers escape from the tunnel as rapidly as possible. In order to do this, an emergency tunnel is supposed to be one of the best ways. The week point of emergency tunnels that have been built separately from the main road tunnel is its high cost. To solve this problem, the idea of small emergency tunnel inside a road tunnel has occurred.

On the other hand, the idea to cover up the pedestrian pass inside a road tunnel for the sake of walkers’ comfort has come into reality in Japan. So it is considered good to take advantage of this inside pedestrian tunnel to make inside emergency tunnels.

As emergency tunnels have different requirements from those of pedestrian tunnels, research has been started to examine the requirements of both small tunnels. The main requirements of emergency tunnels include heatproof capability and design to prevent smoke. The main requirements of sidewalk tunnels includes level of atmospheric cleanliness and lighting.

Key words: emergency tunnels, pedestrian tunnels, sidewalk tunnels requirements, safety

1. BACKGROUND

Japan has 8889 road tunnels, as shown in Table 1, and the safety is a large subject for a road administrator. When an accident, such as a fire, occurs in a tunnel, in order to minimize the damage, there are facilities for emergencies, for example, a fire extinguisher, a fire detector, and an emergency tunnel. The emergency facilities for a road tunnel are installed according to traffic volume and tunnel length in Japan. For example, road tunnels the traffic of which is 20,000 vehicle/day and the length of which is 3000 m are classified as AA class tunnel. AA tunnels have to install an emergency tunnel or smoke-eliminating equipment. The emergency tunnels have so far been built by different line from the main tunnel like Figure 1. For this

<table>
<thead>
<tr>
<th>Tunnel length</th>
<th>Number of tunnels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Above3000m</td>
<td>67</td>
</tr>
<tr>
<td>above2000m</td>
<td>118</td>
</tr>
<tr>
<td>below3000m</td>
<td></td>
</tr>
<tr>
<td>above1000m</td>
<td>540</td>
</tr>
<tr>
<td>below1000m</td>
<td>8164</td>
</tr>
<tr>
<td>total</td>
<td>8889</td>
</tr>
</tbody>
</table>

Note) data of April 1st 2002

Fig. 1 Emergency passage the former and new idea
reason, although the emergency tunnel is effective especially for refuge, it has a difficulty that the cost is high. To solve this problem, the idea of small emergency tunnel inside a road tunnel shown in Figure 1 has occurred. On the other hand, the idea to cover up the pedestrian pass inside a road tunnel for the sake of walkers’ comfort has come into reality in Japan. So it is considered good to take advantage of this inside pedestrian tunnel to make inside emergency tunnels.

As emergency tunnels have different requirements from those of pedestrian tunnels, research has been started to examine the requirements of both tunnels. The main requirements of emergency tunnels include heatproof capability and design to prevent smoke. The main requirements of sidewalk tunnels includes level of atmospheric cleanness and lighting.

2. EXAMPLE OF A SMALL SIDEWALK TUNNEL INSIDE A ROAD TUNNEL

2.1. Outlines

The first small sidewalk tunnel was built in Utatsu road tunnel on national highway No. 159 (Fig. 2, Fig. 3) (Murata 2003). That was bypass construction aiming at relief of the chronic traffic congestion of the Kanazawa city zone. In order that this tunnel might connect the area where a residential section, a high school, and a university are located, many bicycles and pedestrian traffic were assumed. The sidewalk is 3m wide and passage by walk takes 20 to 30 minutes because the tunnel is 1,220m of length. The images of the walk in a tunnel were something like -- "exhaust gas is a smell", "noise being noisy", "dark", and "since it is danger". Considering the creation of comfortable space for bicycle and pedestrian, the idea of the wall between sidewalk and driveway occurred to the road administration, and it lead to a small sidewalk tunnel in a road tunnel.

Concerning the design of the small sidewalk tunnel, the partition wall desirably should be transparent and it also should be strong, durable in tunnel, reasonable in price and semi-non-flammable. It results in using the polycarbonate board (t=5mm) as the panel of sidewalk-tunnel wall and H shaped steel beam as the support of the panels. Moreover, the door is installed in the wall at the place where disaster prevention equipment like an extinguisher is set in the wall of main tunnel and passing to a sidewalk from a driveway is enabled in an emergency. For the purpose of security, cameras for sidewalk and monitors are to be installed in respect of crime prevention, and four images of the sidewalk can be simultaneously shown by the six monitors in a sidewalk tunnel so that passing situation can be checked by the public.

![Fig. 2 Section of Utatsu Tunnel](image1)

![Fig. 3 View from the carriage way](image2)
2.2. The environmental improvement by the sidewalk tunnel

As a result of installing a partition wall, the noise by large-size car is 80dB or more on the driveway and has changed to be 67-72dB in the sidewalk tunnel, which means that 13.2-13.7dB reductions is achieved. As for the atmosphere, suspended particulate matter on the driveway is 0.570mg/m³ and that in the sidewalk tunnel is 0.180 mg/m³, which is about one third of driveway value. Nitrogen dioxide concentration also became 0.025 ppm of sidewalk parts to 0.085 ppm of driveway parts, and this also became the value of the around 1/3 of a driveway part. This is a value equivalent to the measured value of 0.012-0.036 ppm of a neighbouring open sidewalk.

3. PERFORMANCE OF EMERGENCY TUNNEL AND SIDEWALK TUNNEL

3.1. Preface

The research of performance has just started in 2003 and the standard concept and numerical value which are shown in this paper is based on the results in this time of the research and can be changed by future research.

3.2. Performance of Small Tunnel Only for Emergency

3.2.1 Performance of Geometry and Structure

a) Width and clearance

The width and clearance in the case of installing the small tunnel only for emergency escape in a road tunnel is to secure the width in which safe escape is possible. In Japan, there are the following regulations for a refuge passage width and clearance.

According to the law on barrier-free, "passage should be effectively more than the width: 1.4m". According to the installation standard for road tunnel emergency facilities (administrative document), escape passage should be 1.5m wide or more and 2.1m high or more. Therefore, width of 1.4 or 1.5m and height of 2.1m has been considered as width and clearance value for emergency tunnel.

b) Heat resistance

As for the heat resistance, the resistance which can secure the escape time to take people in the tunnel to the place where the people are not involved in smoke or gas anymore is necessary. However, the above-mentioned time differs by fire scale. An assumption fire scale is the item, which must be examined in the future. Anyway in Japan, there are the following regulations for building heat resistance.

<table>
<thead>
<tr>
<th>Name</th>
<th>Max temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard of ISO</td>
<td>(1,029°C)</td>
</tr>
<tr>
<td>- temperature curve</td>
<td></td>
</tr>
<tr>
<td>JIS A 1304-1975, Japanese Standard</td>
<td>(1,010°C)</td>
</tr>
<tr>
<td>- temperature curve of a building fire</td>
<td></td>
</tr>
<tr>
<td>HC: hydro carbon fire</td>
<td>(1,080°C)</td>
</tr>
<tr>
<td>Supposing only fire or a HC fire</td>
<td></td>
</tr>
<tr>
<td>RABT: a guideline on facilities and management of road tunnels in Germany, ZTV Tunnel Curve</td>
<td>(1,200°C)</td>
</tr>
<tr>
<td>HCM: modified curve of HC fire</td>
<td>(1,300°C)</td>
</tr>
<tr>
<td>RWS: a curve of the ministry a public works and transport, flood control head office in Holland</td>
<td>(1,350°C)</td>
</tr>
</tbody>
</table>

Fig. 4 Various temperature curves including Japanese Standard Curve?
According to the Building Standard Law of Japan, the performance of the fire prevention equipment of a building is prescribed by the temperature curve. Fire prevention facilities are classified into the following two groups on the basis of the JIS curve that is almost the same as ISO curve (Fig. 4).

? One is the specific fire prevention facilities used for the door or a window installed in an indoor wall of fire prevention division (JIS curve 60 minute 945 degree C)

? The other is the fire prevention facilities used for the door or window of an outer wall of a fireproof building (JIS curve 20 minute 781 degree C)

As the point which should be taken into consideration:

a) Considering that it might be rational to keep the risks of each field in accordance in one country, the door or the window of emergency tunnel should have fireproof ability of 20 minutes on JIS curve because those facilities are supposed on the outer wall of the emergency tunnel.

b) Considering the tunnel fire, heat-resistant time for a certain heat-resistant temperature are needed to secure the escape time. 600m of escape distance will be secured if the heat resistance is 20 minutes and the start of escape is assumed to be 10 minutes after the outbreak of a fire, and walk speed is assumed to be 1 m/s.

c) The temperature in the past tunnel fires amounts to 600-1,150 degrees C. However, according to the results of the real-scale-bus-fire experiments (Mizutani 1982), the temperature distribution in a tunnel section near the fire of the tunnel shows that the temperature of upper part of the tunnel is very high and the temperature of the side wall is low (Fig. 5). Taking this into consideration, the design with more economical performance might be achieved in the future.

Future research is supposed to focus on above-mentioned a) and also taking b) and c) into account.

Temperature distribution

![Temperature distribution and bus fire experiment in tunnel](image)

Temperature distribution
elaped time 16min
at the section 5m away from the fire

Fig. 5 Temperature distribution and bus fire experiment in tunnel
d) Protection from smoke

The requirements about protection from smoke should come from the performance that escape walking does not become difficult by smoke for people to escape to the place where they are not involved in smoke anymore. Experiments have revealed that smoke is usually distributed near a ceiling in layers till about 10 minutes after the outbreak of a fire in a tunnel but after that smoke becomes cooled and descending. As for the numerical value of the smoke concentration to which walking does not become difficult, extinction coefficient \( C_s \) of 0.4 (m\(^{-1}\)) at 1.5m in height from the road surface is usually used (Takekuni 2002).

Although the door closing automatically is to be installed on the wall of an emergency tunnel, if people in the main tunnel escape continuously through the door, there is a risk of smoke advancing into an emergency tunnel. In order to intercept the smoke that comes into the passage in the small tunnel, one solution is to install an interception wall and a door in an emergency tunnel. However, attention must be paid to the point that the width of that portion of the small tunnel might become narrower.

3.2.2 Performance on environment

a) Atmosphere

Since people do not pass along a refuge passage at the time of usual, it considers that air environment of the small tunnel should be the same grade as a driveway. According to the road tunnel technical standard (ventilation section) (documents on administration), it has been prescribed as follows from the demand on driving operation on the environment of a driveway. In consideration of the comfort and the safety on a run, 50% or more of light transmissivity over 100m should be secured by design speed 80 km/h, and 40% or more by 60 km/h. Carbon monoxide concentration should be 100 ppm or less in consideration of 30 minutes maintenance work in a tunnel.

b) Illumination

The performance of illumination in the case of installing a small emergency tunnel in a road tunnel should come from the requirements that safe refuge can be performed. According to the standard for tunnel emergency facilities (documents on administration), illumination required as an escape passage is specified as from 10 to 20 lx of average illumination from a viewpoint of the safety of refuge. So the numerical value can be 10-20 lx for average level illumination.

c) Crime prevention

Since the pedestrians do not usually use emergency passage, there is no necessity of crime prevention performance for small tunnels only for emergency. However, it is necessary to examine necessity of the surveillance and correspondence system in case of a fire.

3.3. Performance of Small Tunnel Only for Sidewalks (Pedestrians)

3.3.1 Performance of Geometry and Structure

a) Width and clearance

According to the Road Structure Ordinance, sidewalks must be 2.0m wide or more and 2.5m high or more.

b) Heat resistance

Heat resistance is not a performance required as a sidewalk. However, if the safety in case of a fire is taken into consideration, it is desirable to use non-flammable material or semi-non-flammable material for sidewalk-tunnel material. The problem is that non-flammable material is not necessarily heat-resistant material. It should be judged from
cost and a social request how far the small tunnel only for sidewalks is asked for heat resistance.
One direction of future examination is to pursue heat resistance so far as the cost does not increase greatly. The other direction is to give up the heat resistance for a sidewalk tunnel and make it easy to combine an emergency tunnel and a sidewalk tunnel.

c) Protection from smoke
Protection from smoke is not a performance required as a sidewalk.

3.3.2 Performance on environment

a) Atmosphere

In Japan, there are following regulations for atmospheric environment.

According to the road tunnel technical standard (document of administration), in the tunnel in which a sidewalk is installed the design concentration for carbon monoxide shall be set up by taking exposure time into consideration, and the design concentration of the smoke or SPM (suspended particulate matter) shall be set up by taking comfort of pedestrians into account. Furthermore, wind velocity should be less than 7 m s$^{-1}$ from a viewpoint of pedestrian's safety and comfort. It also shows that as the relation between smoke transmissivity and unpleasantness, the condition of 60% transmissivity of light over 100m can be described as fairly good state.

On the other hand, according to the environmental quality standard, as for CO, the one day average value of 1-hour values shall be 10 ppm or less and the 8-hour average value of 1-hour values shall be 20 ppm or less. Moreover, as for SPM the one day average value of 1-hour values shall be 0.1 mg m$^{-3}$ or less and the 8-hour average value of 1-hour values shall be 0.2 mg m$^{-3}$ or less, and as reference it shows that the petition of residents' displeasure will increase by three or more beyond 0.6 mg m$^{-3}$.

On the other hand, according to the labour sanitary standard, the limit of carbon monoxide concentration for the exposure of 8-hour labour per day and 40-hour labour per week shall be 50 ppm and the limit of carbon monoxide concentration for the exposure of several hours shall be 100 ppm.

A numerical value for the performance on environment can be considered as the following.

- Smoke

On the basis of the road tunnel technical standard, 60% of transmissivity over 100m which is the same as $K_{VI_{at}}=0.51 \times 10^{-2}$ (m$^{-1}$) by natural logarithm concentration expression is supposed to be the value for smoke.

On the basis of the environmental quality standard, SPM is supposed to be less 2.0-6.0 mg m$^{-3}$ from the comfort to the body.

However, since it is unknown whether the above values show the same smoke level, examination is still required.

- Carbon monoxide : 100 ppm
- Wind velocity 7 m s$^{-1}$ or less

b) Illumination

The performance of illumination in the case of installing a small sidewalk tunnel in a road tunnel should come from the requirements that pedestrians do not become unsafe or unpleasant within a pedestrian's walk time through the tunnel.

According to the pedestrian-underground-crossing technical standard (administration document), 50 or more lx of illumination should be set up at the stairs and the passage of an underground pedestrian crossing. Therefore, a numerical value is supposed to be 50 or more lx of average level illumination.
c) Crime prevention
When sidewalk in a road tunnel is covered up from the driveway, drivers can not see what happens on the sidewalk. This condition is considered to be likely to generate crimes resulting in the mental pressure to pedestrians. In a survey of pedestrian’s feeling by questionnaire, the proposal of no transparent boards on the wall of small sidewalk tunnel has been refused, and all large majorities has supported the proposal using transparent boards.
Then, as the required performance from a viewpoint of preventing a crime, attention to prevent the crime resulting from the closed space must be paid in the design of small sidewalk tunnel.
For this, while using a transparent boards for the side wall of a sidewalk tunnel, it is possible to install emergency warning equipment or the television for surveillance, if necessary. However we have demerits in implementing such measures. The transparent board becomes the hindrance of the heat-resistant characteristic so that it becomes difficult to make a double purpose small tunnel for both sidewalk and emergency service. Moreover, the television for surveillance needs some staffs to keep the management, which raises the cost of maintenance. In the previous Utatsu tunnel, the monitors of camera and television have been set up at the portals and in the sidewalk tunnel itself, which gives the presence-of-situation inside sidewalk tunnel to the majority of pedestrians walking at that time. Such method could make better performance by using the Internet and giving the presence-of-situation inside sidewalk tunnel not only to the majority of pedestrians but also to the people in public.

4. CONCLUSION
The required performance of small sidewalk or emergency tunnels in road tunnels has been examined and the main results are as follows.
As for the heat resistance of the small tunnel only for emergency, heat resistance for JIS curvilinear 20 minutes seems most in accordance with current building fire regulations. As a future research subjects, there are possibilities of the necessity for 60-minute heat resistance. In order to make cost down, it is necessary to take the difference of temperature in a fire section into account and also to examine the appropriate fire scale to assume.
As for the environment requirements of the small tunnel only for sidewalks, SPM of less 2.0-6.0 mg m\(^{-3}\) has been proposed from the comfort to the body and the natural logarithm smoke concentration below \(K_{VI}=0.51\times10^{-2} \text{ (m}^{-1})\) also has been proposed from how to be visible.

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