Planning of Disaster Prevention Measures in Long Urban Tunnel
- Metropolitan Expressway Central Circular Shinjuku Route -

Hisamitsu Hanno\(^1\), Naruhiko Kawada\(^1\), Tomoaki Okada\(^2\), Takashi Okano\(^2\), Tsutomu Hasegawa\(^3\)

\(^1\)Designing Technology Group, Technology Management Office, Metropolitan Expressway Co. Ltd., Japan.
\(^2\)Control Technology Group, Maintenance and Traffic Department, Metropolitan Expressway Co. Ltd., Japan
\(^3\)Tokyo Operational Headquarters, Oriental Consultants Co. Ltd., Japan

ABSTRACT

The Metropolitan Expressway Central Circular Shinjuku Route is an unprecedented large-scale tunnel as an urban highway tunnel. Therefore, the Metropolitan Expressway Co., Ltd. is now planning to establish its own safety measures based on the lessons learnt from major fire accidents in the past. In this paper, it is described that the outline of emergency equipment being installed from our own standard, the traffic systems and management to be implemented effectively using such equipment at an early stage of a tunnel fire disaster.

1. INTRODUCTION

The Metropolitan Expressway Co., Ltd. has many experiences in the construction and management of urban tunnels; however, the tunnel now under construction on the Central Circular Shinjuku Route (its length is 11 kilometer, and most of the route is a tunnel) is an unprecedented long urban tunnel in Japan. Therefore, new studies were required on tunnel disaster prevention measures. Analyses were performed from various viewpoints regarding large-scale fire disasters that have occurred in Japan and abroad in the past. Based on the lessons learnt from these analyses, envisaged disaster scale and the policy of evacuation were targeted, and ideal disaster prevention measures were examined from various angles. In this paper, it is reported that the outline of emergency equipment to be installed on the Metropolitan Expressway Central Circular Shinjuku Route from our own standard was reported. This equipment was installed in addition to the fire prevention equipment to be installed according to the Japanese standard (the Tunnel Grade AA). Furthermore, the traffic management method to be implemented for the early stage of a fire and the examination of the method of providing users with information to support prompt and accurate evacuation are reported in this paper.

Fig.1. Central Circular Route.
2. THE URBAN LONG TUNNEL – METROPOLITAN EXPRESSWAY CENTRAL CIRCULAR SHINJUKU ROUTE

The Metropolitan Expressway Central Circular Route is the circular road located approximately 8 kilometers from central Tokyo. While it is planned to be extended to 47 kilometers in total length, the east and north sections of this road which reach 26 kilometers in length are now in service. The Central Circular Shinjuku Route is a 11-kilometer long route running the west section of the Metropolitan Expressway Central Circular Route, and it is almost entirely a tunnel structure (one-way two-lane twin tunnels) using the underground of major street (Fig. 1).

The features of Central Circular Shinjuku Route are:
(i) complicated alignment due to the junctions inside the tunnel, and due to the longitudinal slope which changes sharply.
(ii) heavy traffic road with its daily average traffic volume estimated from 60,000 to 80,000 cars.
(iii) As there are many junctions in this tunnel, transverse ventilation systems have been adopted, taking account of efficient smoke exhaustion in case of fire.

The rate of traffic accidents on Metropolitan Expressways tends to be higher both at the junctions and at the end of traffic congestion. These two factors can also be applied to the Central Circular Shinjuku Route Tunnel; therefore, consideration to safety is becoming increasingly important.

3. Fundamental Policies of Tunnel Disaster Prevention

3.1 Basic policy of the measures against fire

The basic policies regarding disaster prevention and safety of the long urban tunnel are established as follows:
(i) In the event of a fire, the first priority shall be put on the safety of human life; the emergency evacuation of users.
(ii) Prevention of a secondary accident, comprehensive disaster prevention shall be ensured in cooperation with relevant organization.
(iii) Taking account of traffic congestion, traffic management that can always ensure safe traffic conditions even in normal time (such as reducing congestion as much as possible) shall be implemented. Our traffic management shall be implemented taking into account a fire occurring under heavy traffic conditions. The concrete measures based on the above concepts are shown in Figure-2.

3.2 Basic policy of traffic management in the event of a fire

For the traffic management to prevent disasters in the long urban tunnel, it is important to make efforts to minimize traffic accidents even in normal time by reducing traffic congestion in the tunnel. If an accident occurs in spite of the efforts, traffic management must be performed to avoid a secondary accident effectively, and that can minimize damage from the accident. In Central Circular Shinjuku
Route, individual control in each section between junctions is performed to minimize the number of vehicles running in the tunnel. In our traffic management policies in the event of a fire, access to the tunnel will immediately be prohibited, and drivers will be urged to drive out of the tunnel as many as, and as quickly as possible.

3.3 Basic policy of ventilation management in the event of a fire

3.3.1 Basic concept
The basic policy of ventilation management in the event of a fire must be implemented taking account of traffic congestion. Key points in the policy are as follows:
(i) In the early stage of a fire when the traffic is normal (not heavy), ventilation should be performed so as to lead the smoke downstream of the traffic flow to maintain the evacuation environment at upstream of the fire.
(ii) In addition, when the traffic is heavy, the smoke must be prevented from spreading, and the evacuation environment must be
maintained at both upstream and downstream of the fire. To achieve this goal, a longitudinal wind velocity must be decreased to 0m/s as early as possible, and the section where evacuation is expected must be ventilated further to improve the evacuation environment.

(iii) In the latter stages of the fire, ventilation should be performed to lead the smoke downstream, in consideration of fire fighting upstream of the fire.

3.3.2 Confirmation by numerical simulation
Based on the above policy, numerical simulation of fire smoke was conducted to confirm that the evacuation environment could be maintained for a specific time and section. In the numerical simulation, the fire scale was assumed to be 30MW referring to the fire experiment of EUREKA. The road gradient of both the upper and lower sides of the fire was changed in the range from -3% to +3% which is the same gradient range as that of the Central Circular Shinjuku Route. As a result, it was confirmed that the evacuation environment had been maintained in all assumed cases. In addition, the results of the numerical simulation were evaluated based on the following indexes.

- The evacuation time for evacuees: In 10 minutes after a fire breaks out.
- The evacuation area: Within 350m from the fire, and 1.5m-high from the road surface.
- The smoke density that allows evacuation: 0.4.

4. TRAFFIC MANAGEMENT AND INFORMATION PROVISION IN CASE OF FIRE

4.1 Fire detection, recognition and judgment

4.1.1 Basic concept
Fire detection, recognition and judgment are the first steps to be taken when a fire breaks out. They have a significant impact on early evacuation as well as on subsequent fire fighting activities. For completing the evacuation of users as quickly as possible on the assumption that a fire may lead to a large-scale fire, it is important to ensure sufficient time for evacuation. As a means of early fire detection, fire sensors have long been installed. However, fire sensors can only detect a fire when it has occurred (after the fire breaks out). In view of “ensuring sufficient time for evacuation” as described previously, the Central Circular Shinjuku Route Tunnel introduces a new system designed to automatically detect abnormal traffic conditions before a fire occurs.

4.1.2 Introduction of an abnormal traffic detection system
In the Metropolitan Expressway, it has been implemented a 24-hour monitoring system using emergency facilities (such as fire detectors, emergency telephones, etc.), and traffic control facilities (such as CCTV Images) as usual. On the Central Circular Shinjuku Route, about 380 CCTV cameras will be installed only for this tunnel. However, manual monitoring by traffic controllers using these cameras will be a heavy workload for them. Therefore, it was decided to introduce a CCTV abnormal traffic detection system that can automatically detect abnormal traffic conditions (such as stopping, slowing down and lane changing) by processing the images of such abnormal traffic conditions.

Using only the conventional image processing technology, there have been many false reports in the traffic congestion areas and at the junctions due to the conditions specific to urban highway tunnels (1: frequent traffic congestion, 2: existence of junctions, 3: use of the determined CCTV in terms of its installed height). Therefore, the development of a new system was started in 2002 using an existing
tunnel in service. In this new system, the image determination accuracy was improved by using a new algorithm and improved parameters, and also it was improved that the interface for traffic controllers working for actual traffic controlling. As a result, it has been able to ensure sufficient system accuracy in the quick detection of abnormal traffic conditions (A detection rate of more than 90%).

4.2 Vehicle guidance using information providing equipment

4.2.1 Basic concept

In the event of a fire inside the tunnel, several traffic managements are performed to stop drivers’ access to the tunnel, and to urge drivers to drive out of the tunnel as quickly as possible. For practical vehicle guidance, the best way is to perform physical traffic control such as closing the crossing gates. However, it is difficult for patrol cars to arrive at the entrances and turnoffs of the tunnel to guide vehicles in the tunnel immediately after a fire breaks out. Additionally, there is a traffic safety problem in automatically closing the crossing gates. In the Central Circular Shinjuku Route, therefore, in addition to the conventional means of emergency interruption of a radio broadcast, traffic signals and road information boards are installed at the turnoffs and the U-turn zones in the tunnel, as well as at the JCT turnoffs on other routes to provide information. By taking these measures, it is expected that vehicle guidance is implemented in the early stage of a fire.

4.2.2 Effective messages

Delivering messages on traffic signals and information boards is not a physical traffic control measures: therefore, it is very important for disaster prevention and safety whether drivers who see the messages will evacuate on their own initiative. In the previous fire accidents in the tunnel of the Metropolitan Expressway, information was provided both on the tunnel signals and information boards; however, expected good results have not necessarily been obtained.

Therefore, the information board messages were studied that can effectively urge drivers to take action at their own will. The result obtained by the study showed key points of effective messages as follows: (i) Messages should be displayed conspicuously like a flashing display. (ii) Rather than the previous messages such as “Do Not Enter,” the messages should be more direct indicating the action to be taken by drivers such as “Stop Here” or “Get Out From Here.” (iii) The same message should be repeated at several places to increase the reliability of the message. It is continuously studied to obtain more effective messages based on these study results (Figures 6 and 7).

4.3 Guidance of prompt and secure evacuation from a vehicle

4.3.1 Basic concept

In providing guidance for evacuation from vehicles, the final destination is the outside of the tunnel.
For motorists’ safety, however, it is most important to guide the drivers as promptly as possible to safe areas further than the emergency exits which are provided at 350-meter intervals.

First of all, users confirm information in repeated radio broadcasts in their cars or on the information boards before starting evacuation. After getting out of the car, users listen to the announcements over the loudspeakers, and follow the guide lights to reach the emergency exit. Some equipment are planned to install to emphasize the emergency exit to allow users to see it from a distance.

4.3.2 Introduction of the loudspeaker broadcasting system using time delay technology

Due to the sound field characteristics in a tunnel (long reverberant sound, and low distance decay), a problem in the operation of loudspeaker broadcasting systems is to ensure clarity of the sound when multiple speakers are used in a tunnel. To solve this problem, the loudspeakers have been installed with small output power and small pitch. However, there were many difficulties both economically and technologically to transmit clear sounds to evacuees in the tunnel due to reverberant car noise and ventilation noise. In the Central Circular Shinjuku Route, therefore, the continuous time delay technology that is used in the loudspeaker systems at large stadiums is introduced to ensure clear sound (Fig. 8.).

5. CONCLUSION

The Central Circular Shinjuku Route is scheduled to start partial service from December 2007, and the construction is now in its final stage. The disaster prevention measures, mentioned above, will be improved to take full advantage of the equipment installed in the tunnel. Furthermore, the educational program for drivers, and experimental study and fore drill will be carried out to make full use of such equipment when an accident occurs.