PREVENTION MEASURES AGAINST FIRES IN ROAD TUNNELS AND WATER SCREEN FIRE PREVENTION SYSTEM

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ABSTRACT: Disaster prevention measures for fire in underground areas are the important subject of the city reproduction. Kajima researched and developed a new system for fire disaster prevention with water screen. Fire is zoned with water screen in this system. Then sufferers can evacuate from fire and firemen can fight with fire easily and the structures have few damage from fire.

KEYWORDS: water screen, fire prevention system, road tunnel

1. INTRODUCTION

Recently, with the enforcement of the Special Measures Act for the Public Use of Deep Underground Areas as well as with the development of urban renewal, technologies dealing with the prevention of fires occurring in underground spaces and tunnel spaces have become objects of public attention.

The conception of technologies with regard to the prevention of fires in road tunnels is introduced as follows using detailed examples.

2. EMERGENCY FACILITIES

In this section, emergency facilities for road tunnels are introduced based on established standards and guide lines for emergency facilities for road tunnels (issued by the Japan Road Association in October, 2001).

In cases where a fire breaks out in a road tunnel, it is required to quickly inform any occupants in the tunnel of the occurrence of a fire in order to protect them from secondary accidents. At the same time, there must be equipment installed with which any occupants can be guided and evacuated to safety. Furthermore, equipment to prevent the fire from spreading and to minimize the damage caused by it must also be installed.

As for emergency facilities, there are fire detectors, information transfer equipment, fire extinguishing equipment, smoke control devices and guidance systems for evacuation.

2.1 Equipment for Warning and Information Transfer

Information on the occurrence of fires or other accidents in the tunnel is transmitted to persons in charge of the management of roads, fire stations and/or police stations as well as to any occupants in the tunnel through utilizing the equipment for information transfer and warning.

Emergency telephones, push-button information transfer equipment and fire detectors are used for emergency information transfer facilities. Equipment for emergency warning is also employed.

2.2 Fire Extinguishing Equipment

Fire fighting implies initial response fire fighting carried out by occupants in a tunnel and full-scale fire fighting by fire-brigades. Fire extinguishing equipment such as an extinguishers and fire hydrants are installed for initial response fire fighting.

2.3 Guidance Equipment for Evacuation

Occupants who meet with a fire or other accidents in a tunnel are guided to the outside of the tunnel in safety for evacuation through utilizing evacuation guidance equipment such as emergency exit signs, smoke removal equipment and refuge passages. The emergency exit signs indicate the distance through to an exit and the distance and direction to the nearest refuge passages as well as any information with regard to their locations. The smoke removal equipment not only suppresses the spread of smoke in order to improve the environment for evacuation in the case of a fire occurring in a tunnel but also effectively exhausts smoke permeating the whole tunnel to the outside for the purpose of more easily carrying out fire fighting, rescue operations and first aid activities. In general, standard ventilators are used as smoke removal equipment. The occupants in the tunnel can take refuge in safe areas through the refuge passages.

2.4 Other Equipment

Various Other systems complement equipment for information transfer and warning, fire extinguishing equipment and guidance systems for evacuation in order to more easily carry out fire fighting.

With regard to these systems, there are water supply points, auxiliary equipment for radio communication, radio rebroadcast equipment, public-address systems, water spraying equipment and monitors. In particular, the water sprayers cool the vicinity of the origin of a fire and restrain the spread of flames as well as support fire fighting

3. EQUIPMENT FOR EMERGENCY IN ROAD TUNNEL

Detailed example of emergency equipment in road tunnel is shown as follows:

3.1 Road Tunnel (Aqua-line under Tokyo Bay)

In the Aqua-line, emergency equipment is installed at regular intervals of 50m through the entire length of the tunnel. The most conspicuous characteristic of the Auqa-line is that there is another road under the actual drive way to be utilized as a space for evacuation, fire fighting and first-aid activities in the case of emergency.

If fire detectors installed at intervals of 25m discover the outbreak of a fire, water sprayers are activated after a specific time for evacuation to be secured. Drivers and occupants of vehicles can take refuge in the road constructed under the drive way of the tunnel through slopes leading from exits installed at intervals of 300m. Fire engines approach the place of the fire and fire brigades climb the slopes in order to carry out fire fighting.

Fire detection	Fire detector (at intervals of 25m), Push-button information transfer equipment (@50m), Emergency telephone (@150m), ITV (@150m)
Information transfer	Traffic control room, Information transfer signal, Radio rebroadcast,

	Signal, Loud speaker, Radio communication supplement equipment
Fire fighting	Fire extinguisher (@50m), Fire hydrant (@50m), Water supply point, Water sprayer
Smoke control	Ventilator • smoke removal equipment (Longitudinal shaft ventilation system with an electrical dust catcher, Separate system for the road under the drive way)
Evacuation	Refuge passage (Slide type passage at intervals of 300m)

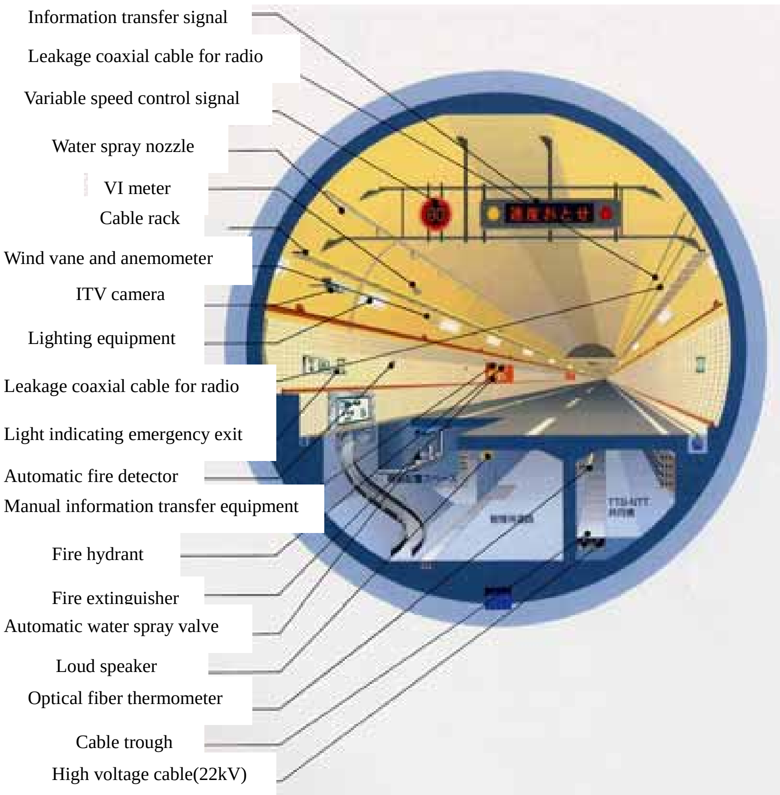

Fig.1 Emergency facilities of the Aqua-line
("The Aqua-line = Prevention of tunnel disasters = Brochures" issued by the Japan Road Corporation)

4. WATER SCREEN FIRE PREVENTION SYSTEM

With the enforcement of the Special Measures Act for Public Use of Deep Underground as well as with ongoing urban renewal, there is a need for fire disaster prevention technology in the case of a fire breaking out in any underground space or in tunnels.

With regard to this, a fire disaster prevention system using water screens was developed. The aim of this system is to secure the occupants' safety from the fire by partitioning the fire zone using water screens (hereafter referred to as WS). This technology creates water screens by spraying water with a droplet diameter of about 200 μm out of nozzles arranged in a line for the partitioning.

In order to understand the partitioning effects of the WS in the case of a fire, fire tests were carried out in a road tunnel. The details and results of the test using gasoline as the origin of a fire are described.

4.1 Fire Test

4.1.1 Aim of Test

This experiment aims at understanding the formation of the WS including their installation angle as well as the characteristics of the WS for isolating the origin of a fire in the case of the wind speed being controlled at 2m/sec by ventilators during a fire in a road tunnel with a vertical ventilation system. The other purpose is to investigate whether or not the partitioned environment can allow the occupants to survive in the case of a fire breaking out.

4.1.2 Experiment Facility and Model

The experiments were carried out at the overall fire test facility (Photo.1). The large area used for the experiments was 26m high, 25m wide and 133m long. Smoke was introduced through 12 ports at a rate of 2000m3/min in total.

The model shown in Photo.2 was scaled down to 1/2 the size of a tunnel with the AA rank in the first class category for road standards. The model, composed of steel frames and fireproof panels, was a box with a height of 2.7m, a breadth of 5.4m and a length of 43.7m. On the sides of the model, fireproof glass windows were installed at 3 locations for the observation of the progress of the fire and the WS in operation.

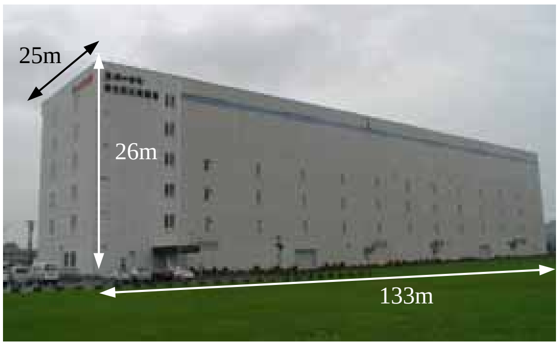

Photo.1 Experiment Facility

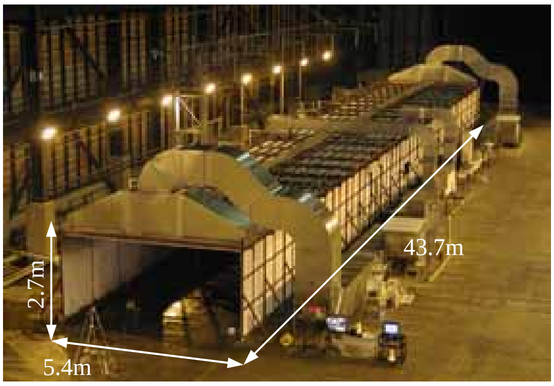

Photo.2 Entire view of model

Nozzles for the WS were arranged in two parallel lines which were about 1.6m apart from each other and formed the partition boundary in the vicinity of both of the end openings of the model. 5 or 6 nozzles were fixed in a zigzag pattern in each line at 1.0m intervals. The total amount of water sprayed from the 11 nozzles installed on each side was 110L/min.

Smoke exhaust ducts and fans were installed at both of the end openings and in the center of the model.

4.1.3 Establishment of Fire Origin

Ordinary passenger cars were assumed as the origin of the fire in two cases, one of a single car and the other of 3 or 4, and the heat release rate for the combustion scale was set at 1.5MW and 5.0Mw respectively with consideration to the reduced scale ratio. A fire plate with a diameter of 1,000mm and a height of 200mm was placed at the center of the floor of the model in order to burn gasoline over a period of 10 minutes. The WS began to work 30 seconds after igniting the gasoline.

4.1.4 Measurement Points and Test Results

① Temperature Distribution on the Inside and Outside of Partitioned Area

The atmospheric temperatures of the inside and outside of the fire zone which are partitioned from the fire using the WS were measured using sheath type thermocouples. The thermocouples were installed at 200mm intervals on the inside and outside of the partitioned area respectively and suspended 50mm below the surface of the ceiling. Fig.2 shows the measurement locations.

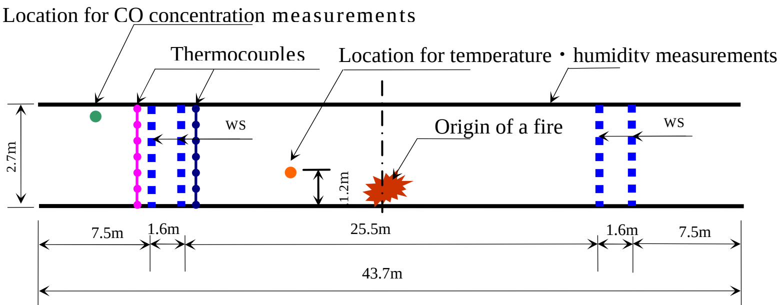

Fig.2 Measurement equipment installation in vertical section of the model

Figs.3~6 illustrate the results of the atmospheric temperature measurements carried out on the inside and outside of the WS in the case of the WS being used. Figs.3 and 5 indicate the measurement results under a dead calm. Figs.4 and 6 indicate the results in the case of the wind speed being 1.4m/s. The wind speed described in this paper is set with consideration to the reduced scale ratio and it corresponds to 2.0m/s in the case of converting it into the actual scale.

As can be seen in Figs.3 and 4, in the case of 1.5MW for the heat release rate, there was smoke in the

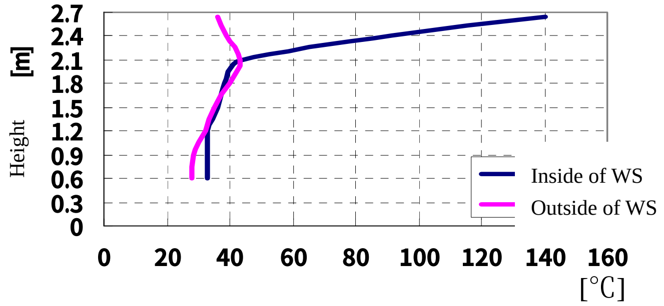

Fig.3 Temperature distribution on the inside and outside of WS (No wind 1.5MW)

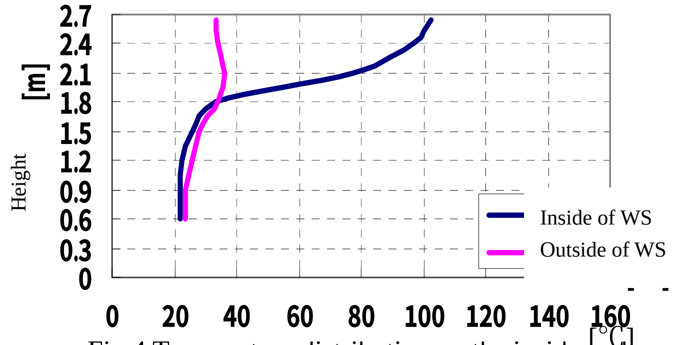

Fig.4 Temperature distribution on the inside and outside of WS(wind speed 1.4m/s, 1.5MW)

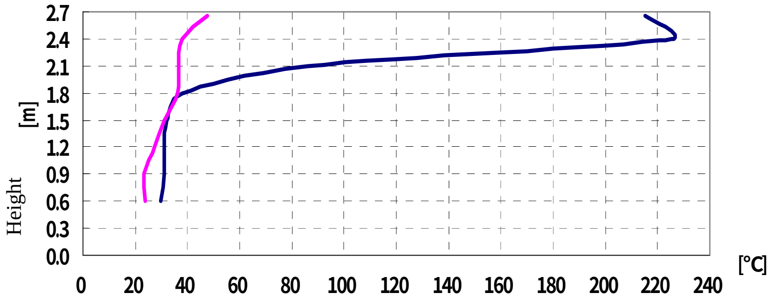

Fig.5 Temperature distribution on the inside and outside of WS (No wind 5.0MW)

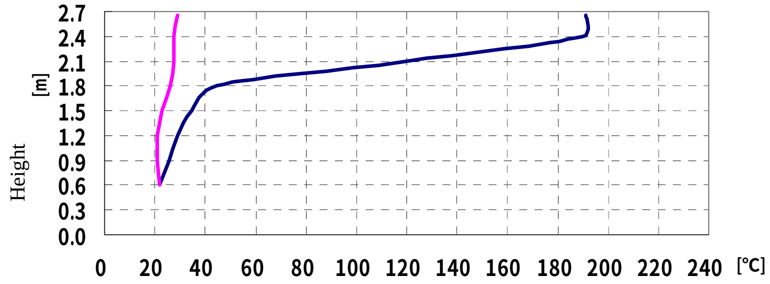

Fig.6 Temperature distribution on the inside and outside of WS(wind speed 1.4m/s, 5.0MW)

proximity of the ceiling surface in the fire zone partitioned by the WS and the temperature in this area climbed up. The temperature in the vicinity of the ceiling on the outside of the WS fell. It can be seen from Fig.3 that under a dead calm the temperature on the outside of the WS dropped by 74% of the temperature in the vicinity of the ceiling surface. Fig.4 illustrates that the temperature under windy conditions dropped by 68% near the ceiling surface.

In the case of 5.0MW, it was discernible that the temperature fell by 79% under a dead calm as shown in Fig.5 and by 85% under windy conditions as shown in Fig.6 respectively.

It was confirmed from the above that the temperature of the air and smoke in the proximity of the ceiling surface was reduced by 70~80% due to the use of the WS regardless of the existence of wind.

② Smoke concentration in the Experiment Facility

Fig.7 shows the locations where smoke concentration gauges were installed.

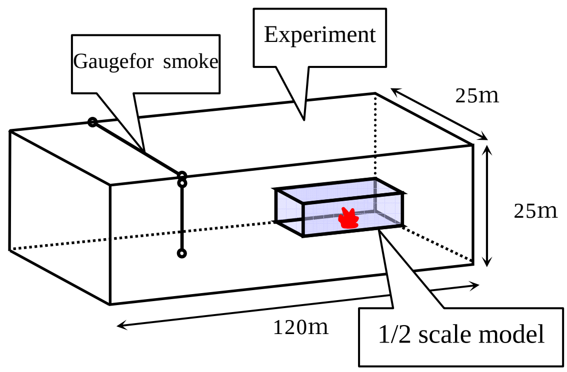

Fig.7 Measurement equipment installation in vertical section of the experiment facility

The concentration of the smoke which filled the experiment area after rising up from the model was measured as the light reduction coefficient in the case of the WS being used and in the case when it was not used. The light reduction coefficient was measured using concentration gauges with photoelectric separating type sensors installed in vertical and horizontal directions (with a height of

9.9m~22.5m) at the end of the experiment areas.

Fig.8 illustrates the time history of the measured values for the smoke concentration obtained in the test facility in the case of 1.5MW. When assuming that the value obtained by integrating the measured value using the time axis corresponds to the total amount of the smoke flowing out of the model into the test facility, the maximum value was reduced by 78% under a dead calm when the WS was used in the case of 1.5MW. When the wind speed was 1.4m/s, the maximum value was reduced by 60% of the value in the case of the WS not being used.

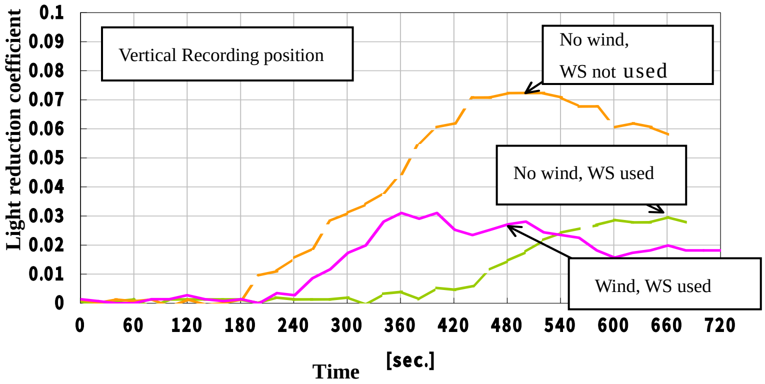

Fig.8 Time history graph of smoke concentration in the experiment facility

It was confirmed from the above that regardless of the existence of wind, 60~80% of the smoke rising from the origin of the fire was isolated by using the WS.

③ CO concentration on the Outside of the Partitioned Area

The difference in the CO concentration of the smoke sampled by smoke exhaust ducts and fans installed at both openings of the model between in the case of the WS being used and in the case when it was not used was measured using CO concentration gauges. The measurement locations are shown in Fig.2.

The maximum value for CO concentration obtained by analyzing the smoke rising from the fire origin, collected at the ceiling of the opening of the model, in both cases of the WS being used and not being used was reduced by about 15% under a dead calm in the case of 1.5MW and was reduced by about 45% when the wind speed was 1.4m/s. It was thought that the fact that the maximum value fell only 15% under a dead calm was caused by CO which is insoluble in water instead of the partitioning of the WS. It can be thought that the great decrease in the CO concentration in the case of 1.4m/s was caused by the incomplete collection of the smoke at the opening of the model due to the effects of the wind. Therefore, the reduction ratio of the CO concentration in the outside of the area partitioned using the WS was set at about 15%.

④ Temperature and Humidity on the Inside of the Partitioned Area

The temperature and humidity with regard to the height of a human body (1.2m from the floor surface) in the case when the partitioned area was formed using the WS were measured using gauges for temperature and humidity installed halfway between the origin of the fire and the WS (6.3m from the center of the model). Fig.2 shows the locations of these gauges.

It was confirmed that the temperature as well as the humidity on the inside of the partitioned area while the WS was used did not reach the condition that is critical for human life. (Human bodies are exposed to the critical condition in 5 minutes when the humidity is 100% and the temperature is 50℃ or more.-----according to field guide to fires) The humidity rose to 100%, but the temperature was 20℃ which was the exterior temperature. The maximum recorded temperature was 35℃.

⑤ **Spray Distribution of the WS**

Several fans for industrial use were installed at one opening of the model in order to create a wind in the tunnel. For the purpose of understanding the formation of the WS caused by the presence of wind speed, the water spray distribution was calculated from the amount of water collecting in each of 25cm square measuring devices which were spread all over the floor in the vicinity of the WS.

With regard to the water spray distribution of the WS under a dead calm, the maximum value for the spraying amount was seen at the center of the WS nozzle. (See Fig.8) In the case of the wind speed being 1.4m/s, the location for the maximum value of the spraying amount shifted to a point of 1.8m on the leeward from the center of the WS nozzle. (See Fig.9) It was confirmed from the above that the spraying angle was 33°. Furthermore, it was discernible from the eye measurement that in the case of 1.4m/s for the wind speed, the water screen was formed extending from the ceiling surface down to the floor surface.

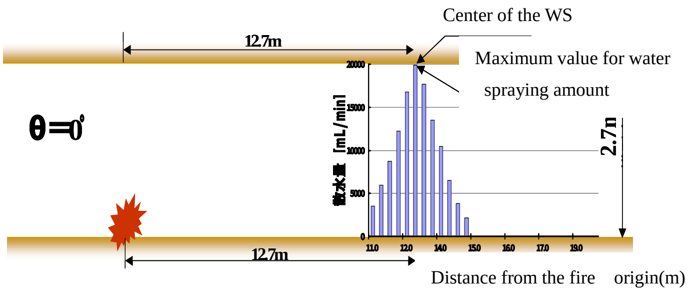

Fig.8 Water spraying graph (no wind)

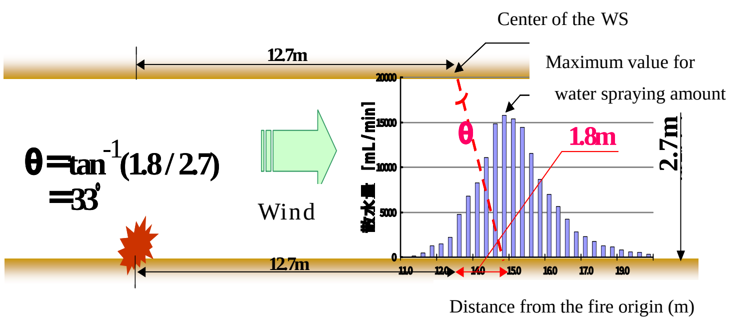

Fig.9 Water spraying graph (wind speed 1.4m/s)

4.1.5 Conclusion

① As for the characteristics of the WS for the partitioning of a fire zone, it was confirmed that the isolation effects for heat, smoke and poisonous gas (CO) were 70~80%, 60~80% and 15% respectively.

② It was discernible that in the case of the wind speed being 1.4m/s (the wind speed converted to that on an actual scale:2.0m/s), the WS was formed at an angle of 33° where the same effects were recognized.

③ It was also confirmed that the occupants could survive in the fire zone partitioned using the WS and that activities for refuge and fire fighting could be effectively carried out.

As a result, the validity of the WS as partitioning technology for a fire was verified.

We would like to express our thanks to the staff concerned of the HOCHIKI Corporation who gave us a great deal of cooperation for the experiments and analyses.

4.2 Applicability to Road Tunnels

An example for the investigation into the applicability of this fire prevention system using a water screen as partitioning technology to road tunnels is shown below.

The deep underground tunnel subjected to this investigation was assumed to be of a vertical ventilating shaft type with a section of $100m^2$ or more, a pitch of 5m for the water spray device and a pitch of 50m for the water screen.

A refuge space was assumed to have been constructed under the road in the same manner as that for the Aqua-line under Tokyo bay as a representative structure for a deep underground

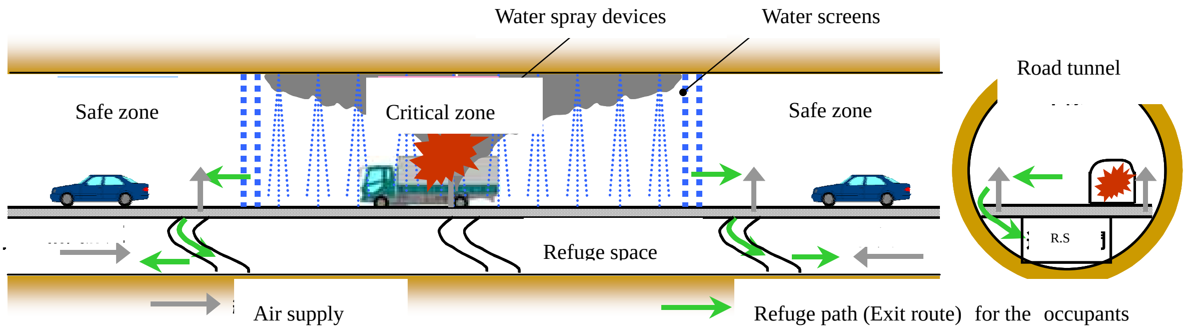

Fig.10 Water screen fire prevention system for road tunnels

tunnel. Positive air pressure is applied to this refuge space in order to prevent the heat and smoke from flowing in from the road. Once the occupants have taken refuge in this shelter, their basic safety can be secured. Therefore, with regard to this, it is important how to safely lead the occupants into the refuge space.

In tunnels, since the air flows in a constant direction due to the effects of ventilation and the movement of vehicles, the heat and smoke are apt to be spread in the same direction as the airflow. In particular, it is important in urban tunnels congested with traffic to prevent vehicles from being ignited by the spreading fire as well as to check the extension of damage caused by the heat and smoke spreading in the same direction as the airflow.

In the aforementioned 4 cases for the investigations, a fire zone was partitioned using water screens under the following steps of procedure in order to secure the occupants' safety movement to a refuge space.

[Operation procedure for the water screen fire prevention system]

① Detect the outbreak of a fire

② Operate water screens surrounding the origin of the fire

③ Prevent the heat and smoke from spreading upward and outward from the critical area (the fire zone)

④ Occupants move to refuge spaces under the road from areas which are not greatly affected by the heat and smoke (safe areas) passing through water screens and escape to the outside of the tunnel.

⑤ Fight the fire and cool the structure by operating water spray devices in the critical area after confirming the occupants have escaped from this area.

⑥ Firefighters go into safe areas in the tunnel from the refuge space in order to carry out fire fighting and rescue activities.

Through these steps, the safety of the occupants can be assured.

Furthermore, the time that the occupants take to escape from the fire zone with safety can be measured as the duration period needed for the water screen to be effective. As a result, a rational design of a fire prevention system including specifications of ventilation devices and arrangement of fire disaster prevention devices can be made.

In the future, further development of this system will be carried out.

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