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Water Screen Fire Disaster Prevention System in Underground Space

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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.

1. Introduction

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 to secure the occupants' safety in the case of a fire breaking out in any underground space.

In this respect, a fire disaster prevention system using a water screen was developed for fires in underground spaces. This system aims at securing both the occupants' safety from the fire by partitioning the fire zone using a water screen and the integrity of a structure by reducing damage to it. It corresponds to the performance based design for the provision of areas of refuge for the occupants.

In this paper, results obtained from experiments on the characteristics of the water screen when used as partitioning technology are indicated first. Next, the applicability of this water screen fire disaster prevention system to road tunnels is described.

Furthermore, this paper investigates the

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heat generation speed, which is a basic character of a fire, under the condition that a water screen installed in a model simulating a road tunnel is operated.

2. Water Screen as Partitioning Technology

2.1 Partitioning of Fire Zone

An underground space which is usually closed off must be designed so that people who meet with a fire (hereafter referred to as "the occupants") in the space cannot be caught up in heat and smoke rapidly permeating the whole space when they take refuge. It is also important to prevent the actual structure of an underground space from rupturing in a fire.

Partitioning of a fire zone is a means to solve these problems. It is a method for preventing the spread of heat and smoke generated by a fire to the whole space by confining them to a certain area. This method can separate the occupants from heat, smoke and poisonous gases and prevent damage to a structure in a local area by checking the spread of a fire. Moreover, due to the partitioning of the fire zone, a rational arrangement and design of the specifications of fire-prevention devices can be made.

As for the partitioning technology, steel shutters, fire-prevention sheets and air curtains can be taken into consideration. However, steel shutters as well as fire-prevention sheets become obstacles against the movement to areas of refuge in an underground space such as a road tunnel where a number of vehicles continue to run. It may well be that the space will not be accurately partitioned. With regard to the air curtains, there are problems with the installation of large-scale air ventilation devices and with the methods for controlling them.

Therefore, a water screen was designed as partitioning technology. In this technology, water is sprayed out of nozzles arranged in a line at regular intervals on the ceiling surface. This line is a boundary for the partitioning.

2.2 Characteristics of Water Screen as Partitioning Technology

In order to understand the characteristics of the water screen as partitioning technology, experiments under the assumption of a fire in a road tunnel were carried out. The outline and results of the experiments are indicated as follows:

2.2.1 Experiment Outline

(1) Facility and Model for Experiments

The experiments were carried out at the comprehensive fire test facility. The area used for the experiments was 25m high, 25m wide and 120m long. Smoke was introduced through 12 smoke ports at a rate of 2000m3/min in total.

Photo.1 Entire view of the model

Photo.1 shows the 1/2 scale model 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 5.1m and a length of 18.2m. On the sides of the model, fireproof glass windows were installed at 4 locations in order to observe the progress of the fire and the water screen in operation.

Nozzles for the water screen were arranged in two parallel lines, which were about 1.6m apart from each other along the partition boundary established in the vicinity of the both end openings of the model. 5~6 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. Devices for water drainage and smoke exhaust (221m3/min) were also installed.

(2) Fire Origin

An ordinary passenger car was assumed as the origin of the fire and the heat generation speed was set at 1.5 MW with consideration to the reduced scale ratio. A fire plate with a diameter of 1.0m and a height of 0.2m was placed at the center of the floor of the model in order to burn 23.3L n-heptane mixed with 5% toruene over about 10 minutes.

(3) Measurement Items

① Ceiling Temperature

The temperature of the ceiling was measured using thermocouples. Fig.1 shows the measurement locations. The ther-mocouples were installed at 1.0m intervals at these locations and suspended 50mm below the surface of the ceiling. Measurements were taken at 3 locations around the water screen; the inside of the fire zone (measurement location No.37), the center of the water screen (No.28) and the outside of the fire zone (No.19).

② Smoke Concentration

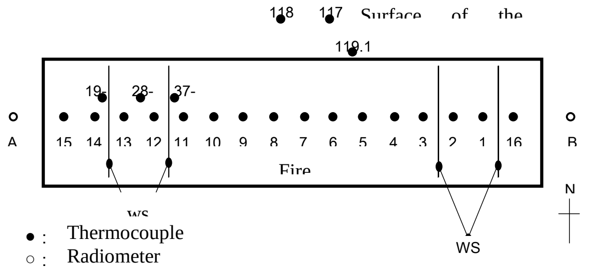


Fig.1 Measurement locations

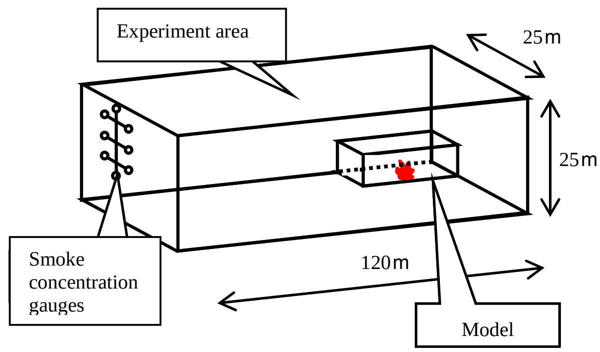


Fig.2 View of smoke concentration gauge locations

Fig.2 indicates the locations where smoke concentration gauges were installed.

The concentration of the smoke which filled the experiment area after rising up from the model was measured in the case of the water screen being used and in the case when it was not used. The light concentration value was also measured using concentration gauges with photoelectric separating type sensors which were installed in vertical and horizontal directions (with a height of 9.9m~22.5m) of the ends of the experiment area.

③ Burning Time

The burning time was measured as an index indicating the burning conditions.

(4) Experiment Cases

Table 1 shows the experiment cases.

Table-1 Experiment cases, conditions and results

case	WS	Temperature in the experiment area (℃)	Burning time (sec)	Maximum temperature(℃)at the ceiling			Smoke concentration in the experiment area (relative concentration)
				Outside of WS	Between WS	Inside of WS	
CASE-1-1	×	6.3	524	219.0	243.4	260.2	1.0
CASE-2-1	×	11.1	550	193.7	209.8	225.5	-
CASE-1-2	○	6.1	635	45.4	76.1	215.4	0.17
CASE-2-2	○	13.0	666	46.7	82.3	203.9	-

- The Smoke concentration in the experimental space is indicated as the relative concentration in the case of 1.0 for the maximum concentration in CASE-1-1.

Experiments were carried out on two different days; one day for CASE-1-1 (without a water screen) and CASE-1-2 (with a water screen) and the other day for CASE-2-1 (without a water screen) and CASE-2-2 (with a water screen). Due to climate change between the experiment days, the temperature in the experiment area varied.

2.2.2 Experiment Results

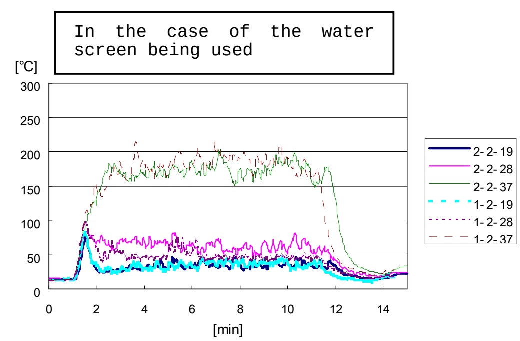
The experiment results are seen as follows:

① Results from the Ceiling Temperature Measurements

The maximum ceiling temperature in the vertical temperature profile was investigated.

Fig.3 illustrates the time history of the ceiling temperature in each experiment case and at each measurement point. The maximum temperature at each measurement point is shown in Table 1. The maximum temperatures at the ceiling in CASE-1-2 and CASE-2-2 shown in the figure indicate the maximum temperature while the water screen was used.

Fig.3 shows that even when the temperature in the experiment area is different due to the climate change on the experiment day, the existence of the water screen does not have a great effect upon the time history of the ceiling temperature. In this respect, a standard pattern of



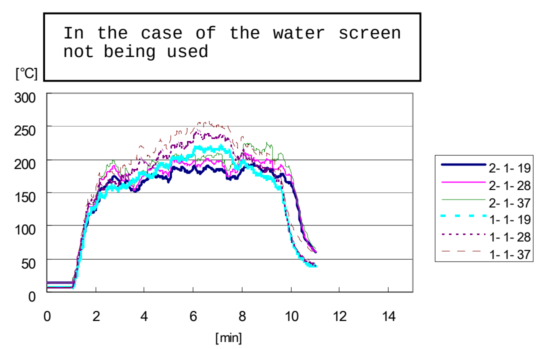


Fig.3 Time history graph for the ceiling temperature of the tunnel model

behavior was confirmed in the experiment results.

Table 1 shows that the ceiling temperature when the water screen was used (CASES 1-2 and 2-2) decreased by about 14% in the fire zone (No. 37), about 35% at the center of the water screen (No.28) and about 78% at the outside of the fire zone (No.19) compared with the temperature when the water screen was not used (CASES 1-1 and 2-1). In CASES 1-2 and 2-2, the temperatures at the center of the water screen (No.28) and at the outside of the fire zone (No. 19) were about 62% and 78% lower respectively than the temperature in the fire zone (No.37). The lowest temperature in the vertical temperature profile at the outside of the fire zone was 37~40℃.

It was confirmed from the above that the heat generated from the origin of a fire decreased by about 80% due to the presence of the water screen.

② Results of Smoke Concentration Measurements

Fig.4 shows the time history of the relative value for the value obtained from the measurement of the smoke concentration in CASE-1-1 and CASE-1-2. The relative value shown in this figure indicates the ratio of the mean value for the value obtained from the measurement of smoke concentration in each case to the concentration value in CASE-1-2 based on the maximum concentration value in CASE-1-1 as the standard (1.0).

The maximum relative value for the smoke concentration measurement value when the water screen was used was 0.17. It was confirmed that about 80% of the smoke generated from the fire was isolated.

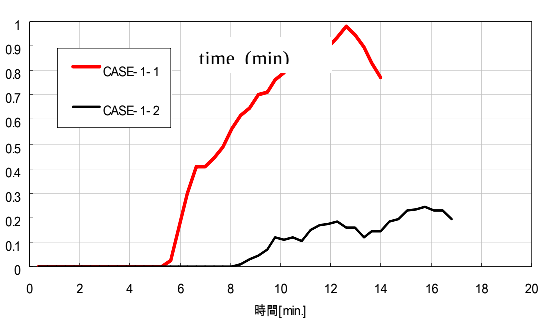


Fig.4 Time history graph for smoke concentration in the experiment area

③ Results of Burning Time Measurements

Table 1 shows that the burning time in CASE-1-2 with the water screen is 1.21 times the burning time in CASE-1-1 without the water screen. The burning time in CASE-2-2 with the water screen was also 1.21 times that in CASE-2-1 without the water screen.

It can be thought that this is so because the intensity of the flames was reduced due to the decrease in the supply of fresh air to the fire zone and cooling effects of water vapour caused by the water screen. Furthermore, this can be confirmed by the results obtained from the direct observation of the burning conditions through the windows at the center of the model and by the fact that the maximum temperature of the ceiling right above the origin of a fire decreased by 180℃ to 833℃ in CASE-1-1 and 655℃ in CASE-1-2.

It was confirmed that the use of the water screen resulted in an overall fall in temperature.

④ Results from other Observations

When observing the conditions of the water screen while it was being used, it was confirmed that the occupants could safely take refuge by passing through the water screen under its normal spraying condition even after the road tunnel was partitioned.

Moreover, the burning conditions inside of the fire zone could be observed from the outside through the water screen.

Furthermore, as a result of the observation of the drainage conditions during the experiments, it was found that the drained water from the water screen contained a large amount of soot. It can be thought that some components creating the burning conditions were probably removed. The effect of the amount of removed components is a subject to be investigated in future.

2.2.3 Characteristics of Water Screen as Partitioning Technology Experiment Results

As a result of the experiments, the characteristics of the water screen are seen as follows:

(1)The partitioning of a fire using the water screen can isolate the heat and smoke by about 80%. Therefore, the effects on the prevention of the spread of a fire can be predicted and a path for the occupants to take refuge can be secured.

(2)Due to the fact that the partitioning of a fire using the water screen can reduce the intensity of the flames, the same cooling effects on a structure as those seen in the case of using sprinklers can be expected.

(3)The occupants can easily take refuge from a fire zone by passing through the water screen.

(4)Since fire conditions can be seen from the outside of a fire zone through the water screen, fire fighting and rescue activities can effectively be carried out.

(5)The water sprayed from the water screen nozzles can be expected to capture and remove any harmful floating particles created by a fire.

2.3 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 100m2 or more, a pitch of 15m 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 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.

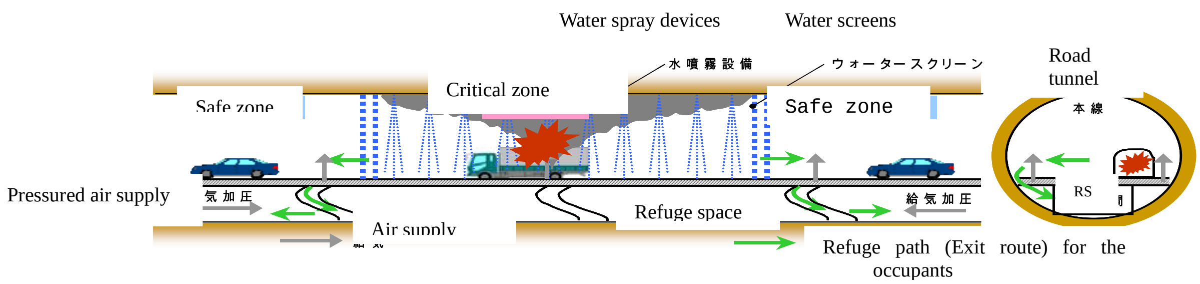


Fig.5 Water screen fire prevention system for road tunnels

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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