Study on the heat insulation performance of fire water curtain applied to the connecting passage

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Abstract: It provide a reference for the design of the heat insulation system of the connecting passage of the urban subway traffic tunnel, carry out 1:3 scale model experimental, discussion on the coupling of artificial ventilation and heat insulation water curtain, thermal radiation and temperature change in two tunnels. The results show that the heat insulation water curtain has good heat insulation effect under the coupling of ventilation and water curtain. However, ventilation will cause turbulence of air flow in the connecting passage, and the hot water curtain is easy to drift. Therefore, it is suggested to reduce the ventilation speed as much as possible without backflow of fire smoke, to reduce its impact on the thermal insulation water curtain.

1. Introduction

In recent years, the state has vigorously built urban underground traffic tunnels. To a large extent, it eased the urban traffic pressure. But the underground space resources are limited. In order to improve the utilization ratio of underground space, Ningbo Metro applies a new type of cross section of subway tunnel - a kind of rectangular tunnel structure cross section. Compared with the mature circular tunnel section, the rectangular tunnel section saves about 35% of the underground space. In the code for design of metro, when the interval length of two completely separated or partitioned metro tunnels is more than 600m, a connecting passage and a class a fire door with two-way escape shall be set in the two tunnels. However, it is impossible to set a class a fire door for two-way escape because of space reasons in a kind of rectangular tunnel[1] [2].

For this new type of tunnel space, it is impossible to set fire doors, so reasonable and effective fire-fighting measures should be taken instead. The flue gas in the tunnel can be controlled by the ventilation and exhaust system in the tunnel. However, the heat insulation problem at the liaison passage shall be solved by corresponding means. At present, there are mainly two fire separation methods, movable open-able type and fixed non movable type. However, in order to meet the requirements of safe evacuation, only the movable open-able fire protection mode can be selected. The movable open-able fire protection mode mainly includes fire door, fire shutter and water curtain, etc. In this experiment, the thermal insulation method of tunnel connecting passage is water curtain. Through heat insulation based on air flow and smoke control, the temperature and thermal radiation changes in the two tunnels are compared when there is water curtain or not. As to explore its heat insulation performance and provide scientific basis and guidance for fire engineering [3] [4].
2. Test method

2.1. Experiment platform setting
This experiment is a 1:3 scale experiment based on a metro tunnel in Ningbo. The experimental tunnel is 75m long, 1.75m wide and 2m high, which is divided into accident and non-accident tunnels. The two connecting channels are located at 37.5m in the middle of the tunnel. The following figure shows the layout of air flow and smoke control in the tunnel:

![Figure 1. Smoke control diagram of experimental platform and air distribution](image1)

2.2. Water curtain system and pipe network design
In the experiment, the height of the connecting passage is 0.7m and the width is 0.3m. The distance between channels is 0.1M, and the spray nozzle is 0.3m above the connecting channel. The distance between two nozzles in each connecting passage is 0.4m, and four nozzles in each side of the tunnel. At the same time, in order to make the water curtain spray evenly and not be disturbed, the spray head is 0.1M away from the wall of the connecting passage. It can well protect the escape of personnel at the liaison passage, as shown in Figure 2.

![Figure 2. Arrangement of water curtain in experimental tunnel](image2)

"Design specifications for automatic sprinkler systems" GB50084-2017 specifies when the nozzle height is less than or equal to 12m. The nozzle strength is 2.0L/(s•m) and the nozzle pressure is 0.1MPa. In this experiment, the sprinkler coefficient is k = 80, the water curtain pressure is 0.1MPa, and the calculation formula of sprinkler flow is as follows [5]:

\[ q = k \sqrt{10P} \]

In style: q is the required nozzle flow, unit L/min; k is the nozzle coefficient, unit L/(min•MPa^{1/2}); P is nozzle pressure, unit MPa;

2.3. Arrangement of pipelines and measuring points
According to the "Code for Design of Automatic Sprinkler System" GB50084-2017, the flow rate in the system should be economical. If necessary, it can be more than 5m/s, but not more than 10m/s. In order to ensure the experimental flow rate, the calculation of resistance loss along the pipeline is particularly important. The following is the calculation formula of resistance loss along the way [5][6]:

\[ i = 0.0000107 \frac{v^2}{d^{1.8}} \]

In style: i is the loss per meter in the system, unit MPa/m; v is the flow rate in the pipe, unit m/s; d
is the pipe inner diameter, unit m;

It can be seen from the formula that there is a certain relationship between the loss along the pipeline and the length of the system pipeline. Therefore, in order to reduce the loss along the route, try to reduce the length of the experimental pipeline, as shown in Figure 3 below [7].

![Figure 3. System piping layout](image)

Thermal radiation and temperature is an important standard to measure the degree of casualties. They can reflect the heat exchange of the fire source to the surrounding environment. The experiment is divided into accident tunnel and non-accident tunnel, both of which are equipped with radiation heat flow meter. Three radiation heat flow meters are set at the place 0.8m high from the fire source to measure the heat release rate of the fire source. Thermocouple is used for temperature measurement at the contact channel, and a temperature string is also set at 1m near the fire source for measurement. The specific temperature and radiant heat flow meter measurement locations are shown in Figure 4 below.

![Figure 4. Thermal radiation and temperature measurement diagram](image)

3. Analysis of experimental results

3.1. Experimental phenomena
The development of fire source without spray and collaborative air supply was observed by camera. The fire reaches its maximum at 50s, and it can be seen that the flame height is suppressed by the system air supply at the evacuation exit. When 800s is gradually reduced and 1000s is achieved, the fire source is completely extinguished. As shown in Figure 5

![Figure 5. Development status of fire source without spray](image)
Through the camera, you can observe that there is spray and coordinated air supply. The fire source reaches its maximum at 50s, and it is relatively fast when it is sprayed at 400s. The fire is greatly reduced, and the fire source is basically extinguished at 600s. As shown in Figure 6.

![Figure 6. Development of fire source with spray status of fire source](image)

### 3.2. Result analysis

It can be seen from the figure that the heat is radiated near the two fire sources. The heat radiation near the fire source tends to be stable at 4.7 kW/m² without spraying. Thermal radiation reaches a maximum at 200s. Then gradually stabilized and slowly declined. When there is a spray, the heat radiation near the fire source reaches 5.9 kW/m². Affected by the ventilation system, the thermal radiation near the fire source rapidly decreases. Then slowly rises and stabilizes slowly after 5.3 kW/m².

![Figure 7. Changes in heat radiation near the fire source](image)

The picture shows the development of heat radiation in non-accident tunnels. The non-accident tunnel heat radiation rises rapidly without spray and is then rapidly reduced by the influence of the ventilation system. Finally, it reaches the maximum value of 6.0 kW/m² at 330s, and starts to decline slowly at 460s. In the case of spray, the thermal radiation of non-accident tunnel rises rapidly. However, the thermal radiation in the front connecting passage is always at a low value due to the influence of ventilation and environment. The change of thermal radiation is relatively large in the rear.

![Figure 8. Change of thermal radiation at non accident tunnel side](image)

It can be seen from the figure that the temperature on one side of the fire source changes. Temperature change without water curtain. The highest temperature is 177 °C at 0.7m from the ground. The maximum temperature is 109 °C at 1.1m from the ground. The maximum temperature at 1.5m from the ground is 75 °C. The maximum temperature at the top is 151 °C. With water curtain, the
maximum temperature at 0.7m from the ground is 408 °C. The maximum temperature at 1.1m from the ground is 331 °C. The maximum temperature at 1.5m from the ground is 218 °C. The maximum temperature at the top is 207 °C.

**Figure 9. Temperature change near the fire source**

It can be seen from the temperature curve of non-accident tunnel without water curtain in collaborative control ventilation. The maximum temperature of the upstream connecting channel port is 50 °C at the upper left after the ventilation system is opened. The maximum temperature of the downstream connecting passage port is 77 °C in the middle after the ventilation system is opened. When there is a water curtain, the maximum temperature of the upstream connecting passage opening the water curtain system in 200s is 34 °C at the upper left. When the water curtain system is opened in 200s, the maximum temperature at the upper left of the upstream connecting channel is 49 °C. After the water curtain system is opened, the temperature at the connecting passage decreases gradually.

**Figure 10. Temperature change at non accident tunnel**

4. Conclusions

1. In the case of coordinated control of ventilation without curtains, Compared with natural ventilation, the radiation and temperature of non-accident tunnel are lower. However, the thermal radiation and temperature at the downstream connecting channel port will be higher than that at the upstream connecting channel port. And the two communication channels are still in extremely dangerous state.
(2) The temperature and thermal radiation of upstream connecting channel are relatively higher than those of upstream connecting channel. Compared with the situation without water curtain, the heat insulation efficiency and heat insulation speed of water curtain are relatively high at the connecting passage. And the water curtain has a certain cooling effect on the fire source.

(3) Collaborative air supply was turned on in both experiments. Cooperative air supply has certain heat insulation effect on connecting passage. But it can be seen from the lens that the thermal insulation water curtain will occasionally deviate. It can be seen from the change of temperature and thermal radiation of non-accident tunnel that the thermal insulation water curtain has obvious effect on the temperature of blocking connecting passage.

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