Experimental Study on Influence of Natural Ventilation on Near Wall Fire in Cable Tunnel

Zhenpeng Bai, Yueyang Yu, Kefeng Lv, Hengjie Qin, Haowei Yao, Cunxiang Yang

***Abstract*—In this paper, a series of fire experiments were conducted in a small-scale cable tunnel to study the effect of ventilation on fire characteristics near walls. The distance between the oil pool and the bottom cable tray is 0.15 m. Five main influencing factors were considered, namely, the number of cables per layer, the amount of fuel, the type of oil pool, ventilation conditions and the type of cable. In the cable compartment of a utility tunnel, the dimensionless maximum temperature rise and the dimensionless longitudinal temperature distribution at a distance of 0.5 m from the fire source near the wall were studied. The results showed that under natural ventilation, the combustion of cables is relatively sufficient in some cases, and the total mass loss rate of cables is different in each case. This indicates that different factors have a significant impact on cable combustion under natural ventilation. The influence of natural ventilation on the longitudinal distribution of dimensionless temperature was analyzed. The contribution of this paper is to prevent fires in the cable compartments of the utility tunnels and reduce social and economic losses.**

***Index Terms*—Experimental study, Fire characteristics, Cable tunnel, Near-wall fire**

I. INTRODUCTION

This is very dangerous when a fire breaks out in a tunnel [1]. When a fire accident occurs in a cable tunnel, it is difficult for smoke to spread vertically upward, and it can only be discharged through the vents at both ends [2]. Therefore, smoke tends to spread along the longitudinal direction of the cable tunnel. Generally, a small fire in a cable tunnel can cause a huge disaster [3]. In the case of fire, the temperature changes with the ventilation velocity and heat release rate (HRR) varies, and the temperature distribution changes over time [4].

All previous studies have used numerical simulation and experimental testing methods to study the fire characteristics in tunnels [5]. Kim et al. [6] conducted an experimental study on the fire smoke flow and temperature distribution in the cable compartment of a utility tunnel. Ye K et al. [7-8] studied the longitudinal maximum temperature of smoke at the top of the urban utility tunnel plumes, and proposed a temperature attenuation prediction model. Liang Z et al. [9] studied the combustion characteristics of fire sources and the distribution of fire temperature field in the utility tunnel caused by the side wall constraint effect. Zhang X et al. [10] revealed the smoke temperature distribution below the ceiling in different directions caused by linear plume induced ceiling jets. In summary, previous studies have conducted a large number of studies on utility tunnel fires [11-19]. However, there are few studies have been conducted on fires near cable tunnel walls with natural ventilation.

Within the range of the closed end, the heat flow deflects and returns, resulting in a thickening of the thermal layer in the closed area, which is significantly different from the opening at the end of the tunnel. In previous studies, the fire characteristics of ventilation tunnels have been studied. The designed fire source is usually located at the center line of the utility tunnel. However, one of the main characteristics of cable tunnel fires is that the combustion environment is a confined space. The initial stage of a confined space is usually controlled combustion of fuel. As the fire reaches its peak stage, it will become a ventilated controlled combustion. At this point, ventilation conditions typically affect the maximum fire source heat release rate. Therefore, it is necessary to study the development characteristics of cable solid wall fires and liquid oil pool fires during natural ventilation cable material fires.

In this paper, a series of fire tests were conducted in a small cable tunnel to study the effect of natural ventilation on fire characteristics near walls. The distance between the oil pool and the bottom cable tunnel is 0.15 m. Five main influencing factors were considered, namely, the number of cables per layer, the amount of fuel, the type of oil pool, ventilation conditions, and cable type. The dimensionless maximum temperature rise and the dimensionless longitudinal temperature distribution near the cable tunnel wall at a distance of 0.5 m from the fire source were studied. It has certain guiding significance for the fire safety of actual cable tunnel structures.

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II. Method

A. Physical Model and Fire Scenario

The small model size of the cable tunnel is 6.0 m × 0.4 m × 0.5 m (Length× Width × High). As shown in Figure 1, a physical model of the cable tunnel is shown. The similarity between the model experiment and the actual scene is that it can truly reflect the burning situation of cables in a fire. The difference between the model experiment and the actual scene is that the model experiment uses small-scale cables and cable tunnels. However, this does not affect the accuracy of the model experimental results.

Figure 1. Physical model of cable tunnel in utility tunnel

As shown in Table 1, there are experimental cases of cable tunnel fires. In this paper, there are 23 fire tests were conducted in cable tunnels. The effects of five important factors, fuel volume, pool type, cable type and number of cables per layer, on cable tunnel temperature and heat release rate (HRR) were considered.

TABLE 1 EXPERIMENTAL CASES OF VENTILATION ON FIRE IN CABLE TUNNEL

Case	Fuel quantity (ml)	Oil pool (cm)	Cable type	Number of cables per layer
1	20	4×21	RVVR	2
2	20	13×13	ZRYJV	2
3	20	13×13	ZRYJV	4
4	10	9.2×9.2	RVVR	1
5	20	9.2×9.2	RVVR	2
6	40	9.2×9.2	RVVR	4
7	10	13×13	RVVR	2
8	40	13×13	RVVR	1
9	10	18.3×18.3	RVVR	4
10	20	18.3×18.3	RVVR	1
11	40	18.3×18.3	RVVR	4
12	10	4×21	ZRYJV	2
13	10	9.2×9.2	ZRYJV	2
14	10	13×13	ZRYJV	2
15	20	2×42	ZRYJV	2
16	20	4×42	ZRYJV	2
17	20	18.3×18.3	ZRYJV	2
18	20	4×21	RVVR	2
19	20	9.2×9.2	RVVR	2
20	20	2×42	RVVR	2
21	20	13×13	RVVR	2
22	20	4×42	RVVR	2
23	20	18.3×18.3	RVVR	2

The oil pool is located below the cable tray, near the wall in the cable tunnel, is a source of ignition. Considering the the most adverse effects of fire in cable tunnels, the oil pool should be placed at the bottom of the cable tray. There are no oil pools in the cable tunnels of underground utility tunnels. Different types of oil pools represent different sources of ignition for HRR. The cables is not flammable. The temperature of the cable reaches the ignition point, causing combustion under the ignition of different oil pool fires. Both vents are 0.2 m × 0.2 m. The distance between the oil pool and the bottom cable tray is 0.15 m. This can lead to a fire near the cable tunnel wall. The ambient temperature is 15 °C. On one hand, two layers of cables are arranged at the bottom of the cable bracket. On the other hand, four layers of cables are arranged at the bottom of the cable bracket. The cable length is 0.15 m. Longitudinal ventilation is used in case 1, and natural ventilation is used in other cases. In case 1, the ventilation velocity is 1.1 m/s. In the experiment, the ventilation velocity was considered to accurately simulate the actual environment of the cable tunnel. The fire source is 3.0 m away from the cable tunnel shaft. The fuel is n-heptane. The cable types are fire-retardant cross-linked polyethylene sheathed PVC insulated cable ZRYJV and RVVR. Fire-retardant cable ZRYJV, 2 cores with an area of 10 mm^2. Fire-retardant cable RVVR has 1 core with an area of 10 mm^2. Some thermocouples are arranged in the cable tunnel.

III. Results And Discussions

A. Influence of the number of cables in each layer

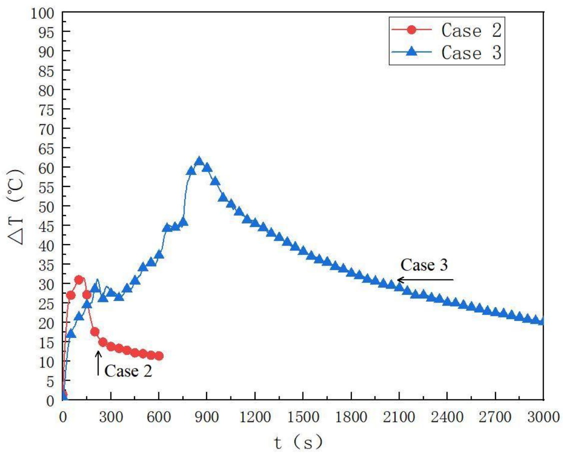

Figure 2. Temperature rise 0.5m below the ceiling in cable tunnel are affected by the number of cables in each layer

As shown in Figures 2 and 3, a comparison between case 2 and case 3 shows that the temperature rise and HRR below the ceiling and HRR increase over time, reaching a maximum value at a distance of 0.5 m from the fire source. Then, as the fire extinguishes, the HRR decreases, and the temperature rise below the ceiling gradually decreases. In case 2, the number of cables per layer is 2. At a distance of 0.5 m from the fire source, the temperature rise below the ceiling reached a maximum of 31.6 °C after 130 s, while the HRR reached a maximum of 10.90 kW after 100 s. In case 3, the maximum temperature rise below the ceiling reached 61.7 °C after 215 s, while the maximum HRR reached 13.32 kW after 785 s. The results show that the more cables per layer, the higher the temperature below the ceiling, the higher the HRR, and the longer the time required to reach the maximum value. This is due to the increase in the number of cables. When combustible materials are ignited, they release more heat. .

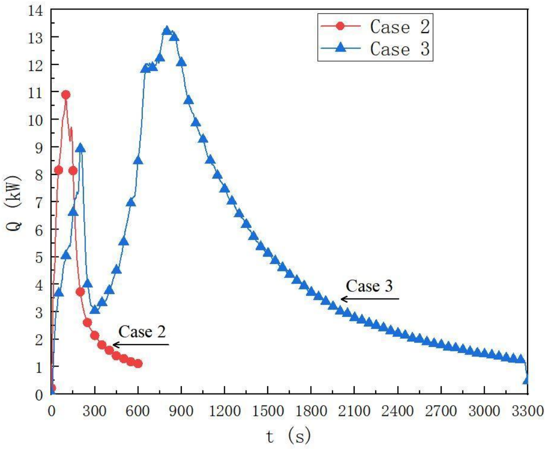

Figure 3. HRR with the near-wall fire characteristics of cable tunnel are affected by the number of cables in each layer

B. Effect of fuel quantity

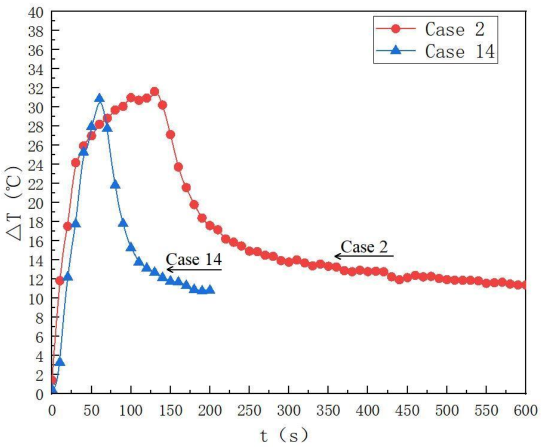

Figure 4. Temperature rise 0.5m below the ceiling with the influence of fuel quantity on near-wall fire characteristics of cable tunnel

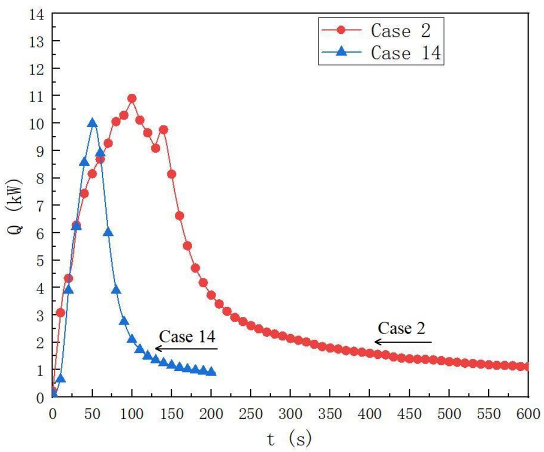

Figure 5. HRR with the influence of fuel quantity on near-wall fire characteristics of cable tunnel

As shown in Figure 4 and Figure 5, the comparison between case 2 and case 14 shows that the temperature rise below the ceiling 0.5m from the fire source reaches a maximum value of 31.6 ℃ after 130 s, and the HRR reaches a maximum value of 10.90 kW after 100 s for case 2 with a fuel volume is 20 ml. In case 14, the fuel volume is 10 ml, and the temperature rise below the ceiling 0.5 m from the fire source reaches a maximum value 30.9 ℃ after 60 s. After 55 s, the HRR reaches a maximum value of 9.96 kW . The results showed that the larger the fuel volume, the higher the maximum temperature below the ceiling, the larger the maximum HRR, and the longer the time required to reach the maximum HRR. This is due to an increase in the amount of fuel, and the amount of heat released by combustion.

C. Influence of oil pool type

As shown in Figure 6, in cases 18 ~ 23, the temperature below the ceiling rises at a distance of 0.5 m from the fire source. According to the square pool fires in case 19, case 21 and case 23, the temperature rise below the ceiling reached the maximum values of 25.6 ℃, 31.7 ℃ and 70.0 ℃, after 220 s, 115 s and 45 s respectively from the fire source, respectively. After 100 s, the HRR reached a maximum value of 10.90 kW. According to the linear pool fires in case 18, case 20 and case 22, the temperature rise below the ceiling at a distance of 0.5 m from the fire source reached the maximum values of 20.9 ℃, 34.2 ℃ and 42.5 ℃ after 515 s, 115 s and 250 s, respectively. For square pools, the higher the temperature rise below the ceiling, the shorter the time to reach the maximum. The larger the opening area of the oil pool, the higher the temperature rise below the ceiling, and the shorter the rise time to reach the maximum value.

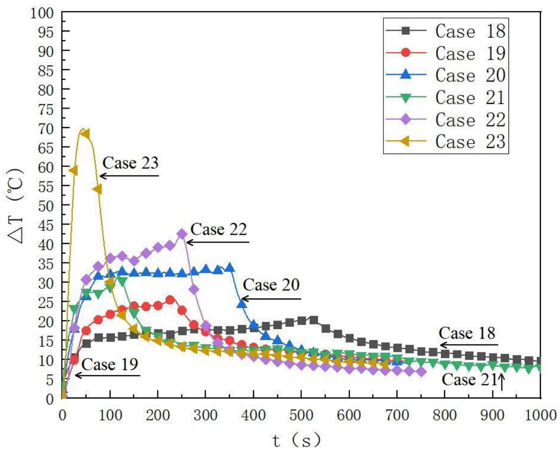

Figure 6. Temperature rise 0.5m below the ceiling with the near-wall fire characteristics of cable tunnel are affected by the type of oil pool.

As shown in Figure 7, the HRR in cases 18 ~ 23 in a cable tunnel. According to the square pool fires in case 19, case 21 and case 23, the maximum HRR after 225 s, 115 s and 35 s was 7.84 kW, 14.27 kW and 16.28 kW, respectively. According to the linear pool fires in cases 18, 20 and 22, the maximum HRR after 85 s, 360 s and 200 s was 2.18 kW, 3.06 kW and 4.67 kW, respectively. The pool size is 18.3 cm × 18.3 cm, the higher the HRR, the shorter the time to reach the maximum HRR.

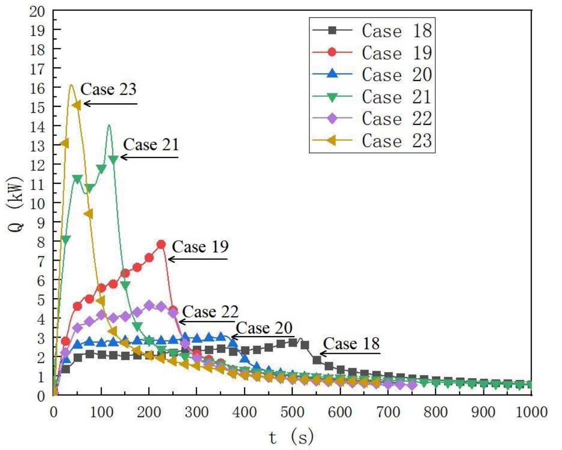

Figure 7. HRR with the near-wall fire characteristics of cable tunnel are affected by the type of oil pool

D. Influence of ventilation condition

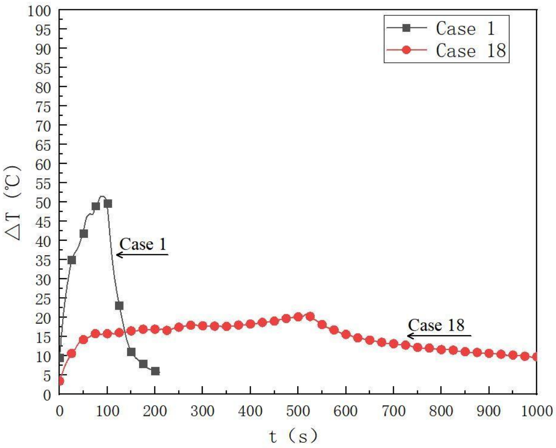

Figure 8. Temperature rise 0.5m below the ceiling with effect of ventilation on fire characteristics near-wall of cable tunnel

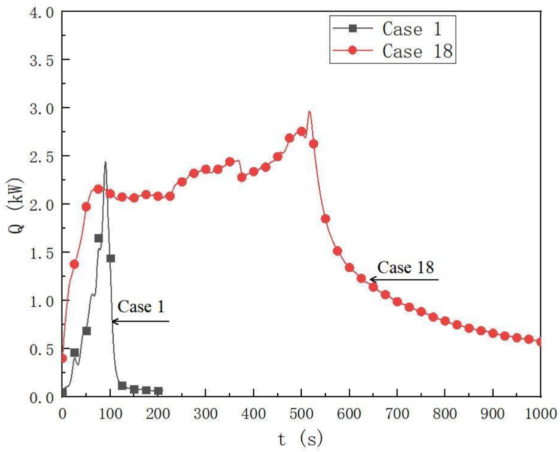

Figure 9. HRR with effect of ventilation on fire characteristics near-wall of cable tunnel

As shown in Figures 8 and 9, in case 1 and case 18, the temperature rise below the ceiling rises at a distance of 0.5 m from the cable tunnel fire source. The ventilation velocity is 1.1 m/s in case 1. The maximum temperature rise below the ceiling at a distance of 0.5 m from the fire source reaches 51.8 ℃, and the maximum HRR after 90 s reaches 2.73 kW. When it is not ventilation in case 18, the maximum temperature rise below the ceiling at a distance of 0.5 m from the fire source is 20.9 ℃ after 250 s, and the maximum HRR after 515 s is 3.03 kW. The results show that ventilation is beneficial to the combustion of RVVR cable, when the distance from the fire source is 0.5 m, the ceiling temperature increases and the time required for the ceiling temperature to rise to the maximum value is significantly shortened. Ventilation reduces the time required to reach maximum HRR.

E. Influence of cable type

As shown in Figures 10 and 11, in cases 4 ~ 11, the temperature rise below the ceiling rises at a distance of 0.5 m from the cable tunnel fire source. The maximum temperature rises reached 17.9 ℃, 33.7 ℃, 35.1 ℃, 32.4 ℃, 57.6 ℃, 39.8 ℃, 75.7 ℃ and 94.9 ℃, after 110 s, 225 s, 340 s, 70 s, 135 s, 35 s, 105 s and 50 s, respectively. The results show that the more fuel, the more cables per layer, and the higher the maximum temperature rise. This is because the more cables per layer, the more heat released by combustibles, which are part of the fuel-controlled combustion. Compared to a linear pool fire, the temperature below the ceiling rises and the time to reach the maximum temperature decreases. Due to the large open area of the square oil pool, it is exposed to more air and releases more heat in a shorter time.

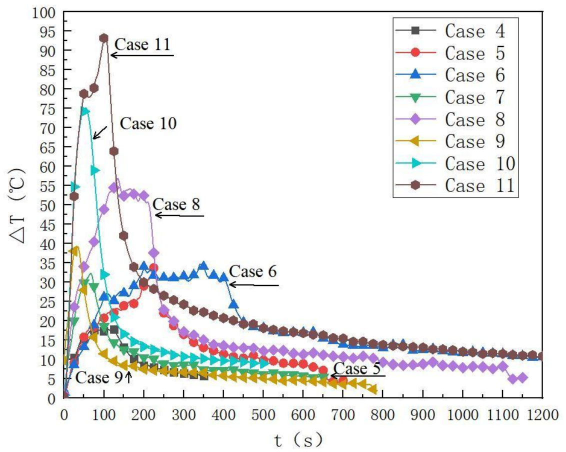

Figure 10. Temperature rise affected by number of cable layers in cases 4 ~ 11

As shown in Figures 12 and 13, the HRR in cable tunnels in cases 4 ~ 11 and cases 12 ~ 17. In cases 4 ~ 11, when the time is 115 s, 210 s, 165 s, 45 s, 200 s, 25 s, 45 s and 105 s, the maximum HRR is 4.74 kW, 10.38 kW, 15.42 kW, 8.96 kW, 20.50 kW, 6.33 kW, 15.26 kW and 25.98 kW, respectively. The results show that the higher the fuel consumption, the higher the maximum HRR, and the longer it takes for the HRR to reach its maximum value. This is because more fuel releases more heat. The more cables per layer, the higher the maximum HRR. This is due to the increase in the number of cables. When combustible materials are ignited, more combustible materials release more heat. The more cables per layer, the higher the maximum HRR, and the longer it takes to reach the maximum value. HRR is strongly influenced by the number of cables per layer and the amount of fuel. This is because the number of cables per layer and the amount of fuel used as a combustible factor have a significant impact on HRR. The higher the HRR of a linear reservoir, the lower the HRR, and the longer it takes for the HRR to reach its maximum value. This is because the ZRYJV cable is placed in a naturally ventilated cable tunnel, and the HRR is strongly influenced by the type of oil pool and the amount of fuel.

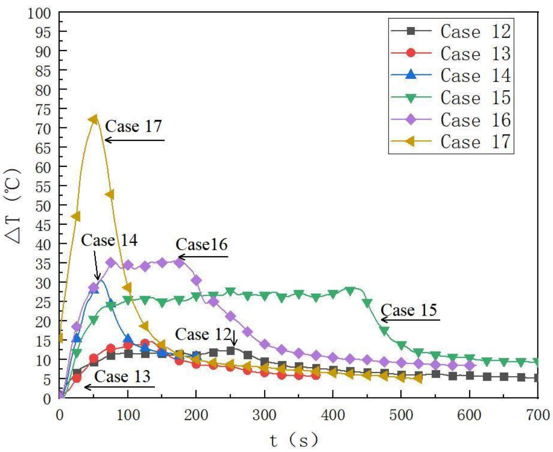

Figure 11. Temperature rise affected by number of cable layers in cable tunnel in cases 12 ~ 17

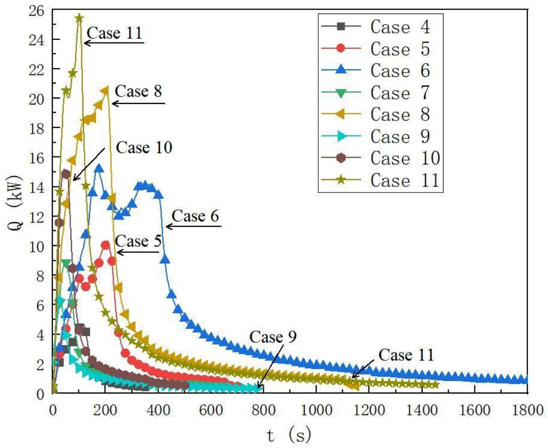

Figure 12. HRR with the fire characteristics of cable tunnel near the wall of utility tunnel are affected by the number of cable layers in cases 4 ~ 11

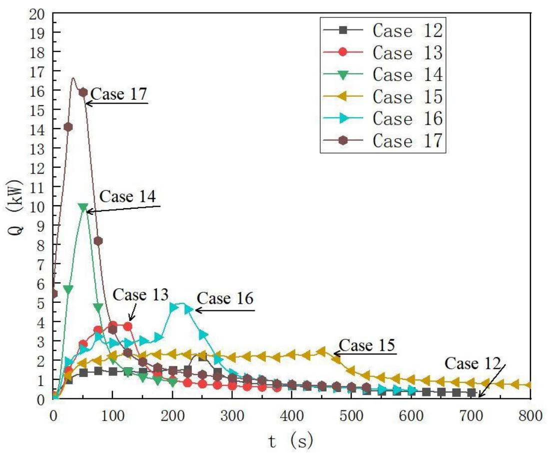

Figure 13. HRR with the fire characteristics of cable tunnel near the wall of utility tunnel are affected by the number of cable layers in cases 12 ~ 17

IV. Conclusions

In this paper, a series of fire tests were conducted in a small cable tunnel to study the effect of natural ventilation on fire characteristics near walls. Five factors were considered, namely, the number of cables per layer, the amount of fuel, the type of oil pool, ventilation conditions and cable type. The main conclusions are as follows:

(1) Single factor analysis of fire characteristics near cable tunnel walls under natural ventilation conditions. The more cables per layer, the more fuel, the higher the maximum temperature below the ceiling, the higher the HRR, and the longer the time to reach the maximum temperature.

(2) Analysis of the impact of HRR and ventilation velocity on fires near cable tunnel walls under natural ventilation conditions. The results show that the number of cables in each layer and the amount of fuel have a significant effect on the temperature rise and HRR below the ceiling of the cable tunnel.

(3) Under natural ventilation conditions, the larger the opening area of the oil pool, the higher the ceiling temperature rise, the shorter the time for the maximum temperature rise to reach the maximum value, the larger the maximum HRR value, and the shorter the time for the HRR to reach the maximum value.

(4) Under natural ventilation conditions, the higher the number of cable layers, the lower the temperature below the ceiling, the longer the ceiling temperature reaches its maximum value, and the lower the HRR. Ventilation is conductive to the combustion of RVVR cables, increasing the temperature rise below the ceiling, and reducing the time required to reach the maximum value. Ventilation reduces the time required to reach the maximum HRR. RVVR cables have shorter ignition time, higher combustion temperature, and lower HRR than ZRYJV cables. This paper provides some basic fire safety guidelines for cable tunnels.

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