Experimental Study on the Influence of Sealing and Ventilation on the Fire Characteristics Near the Wall of Utility Tunnel

Zhenpeng Bai, Yueyang Yu, Yang Zhang, Zihe Gao, Haowei Yao, Jin Zhang

Abstract—**In this paper, the temperature rise in the longitudinal direction, the heat release rate (HRR), the endless area temperature under the ceiling of the utility tunnel, and the root of HRR (oil and fuel type), cable type, number of cable layers and and cables per layer. The effects of airtightness, natural ventilation, and longitudinal ventilation on the fire characteristics of cable compartments were compared. The results showed that the effects of enclosed cable tunnels and natural ventilation on fire behavior near walls in cable tunnels were compared. Compared with the natural ventilation state, when placing RVVR type cables, the fire duration of the enclosed cable compartment was shorter, the ceiling temperature rise was greater. And the time that was necessary to increase the ceiling temperature to its maximum value was shorter. The HRR inside the enclosed cable compartment was very high and could almost reach its peak quickly. The contribution of this article is to reduce the social and economic costs of utility tunnels by preventing tunnel fires.**

Index Terms—**Sealing, Fire characteristics, Utility tunnel, Ventilation**

I. INTRODUCTION

The risk of fire in tunnels is high [1][2]. The longitudinal direction of cable tunnels is where smoke is easily dissipated. Usually, small fires in cable tunnels could lead to catastrophic events [3]. When a fire occurs, the temperature also changes with changes in ventilation, HRR, and time [4]. A fire broke out in a cable compartment of utility tunnel . The method of sealing fire was used to isolate external air, thereby isolation of oxygen to extinguish the fire. After the cables inside some utility tunnels, the fire extinguishing effect of sealing measures was studied. Therefore, this article provides relevant research on cable fire in a utility tunnel.

Some researchers have studied cable compartment fires through experimental tests [5-7]. Tunnel fires are mainly studied in the field of transportation tunnel fires, where scenarios such as blocked tunnel fires are similar to those of utility tunnels [8]. Wang et al. [9] suggested that when installing gas detection devices on the ceiling every 15 meters, the last device and exhaust outlet should be as close to the firewall as possible. Zheng et al. [10] independently invented a hot smoke test smoke generation system based on optical flow technology and a method for measuring the two-dimensional velocity field of fire smoke in public engineering tunnels.

The author has conducted some research on the fire and ventilation [11-15]. Tang et al. [16] studied the effects of cable trestle spacing, ignition location, and tunnel ventilation rate on fire characteristics. Huang et al. [17] conducted a fire experiment using three cable bridges located in different cables, studying the burning behavior of cable bridges on the walls of an enclosed room. Kim et al. [18] selected South Korea's representative nuclear power plant cables, and used the cable real fire response to study the failure temperature of the cable function under the fire. Pretrel et al. [19] studied the effects of side walls and cable layout on the fire behavior involving horizontal cable bridges.

In recent years, with the continuous promotion of domestic and foreign researchers, in-depth research has been conducted on the basic dynamics of automatic fire extinguishing systems, ventilation and smoke exhaust, detection and alarm, gas explosions, and fires. The current and future research directions include the dynamics of cable fires in enclosed environments, extreme fire behavior after boundary conditions such as ventilation intervention. For a traditional closed-circuit rectangular trestle, the location of the ignition source affects the temperature distribution at the fire site, the degree of fire development, and the time required for the fire to spread to unburned cables. Cable fires caused by terminal ignition sources have higher local temperatures, while bottom ignition produces a higher overall temperature

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distribution. The speed and range of fire propagation are relatively large. However, studies concerning temperature and HRR distribution or related characteristics near the firewalls of enclosed and rectangular cable bays are rare.

This article conducted 15 sets of fire tests using small-scale cable compartment tests. It combined the HRR (oil and fuel) of each layer, cable type, cable layer, and cable root, which used ceiling temperature rise and HRR. A comparative analysis was conducted on the effects of airtightness, natural ventilation, and vertical ventilation on the fire characteristics near the wall of utility tunnels.

II. Method

A. Physical Model

The size of the experimental platform model is 6.0m × 0.4m × 0.5m (Long × Wide × High). This is the physical model as shown in Fig. 1.

Fig. 1. Physical model of cable compartment in utility tunnel

Table 1 Test cases of cable compartment fire blocking strategy

Case	Mode	Fuel quantity （ml）	Oil pool	Cable type	Cable length (m)
j1-1	Ventilation	20	9.2×9.2	ZRYJV	0.15
j1-2	Ventilation	40	13×13	ZRYJV	0.15
j1-3	Ventilation	40	18.3×18.3	ZRYJV	0.2
j1-4	Seal	20	4×21	ZRYJV	0.15
j1-5	Seal	40	13×13	ZRYJV	0.15
j1-6	Seal	40	18.3×18.3	ZRYJV	0.2
j1-7	M1	60	9.2×9.2	ZRYJV	0.15
j1-8	M2	40	9.2×9.2	ZRYJV	0.15
j1-9	M3	40	9.2×9.2	ZRYJV	0.15
j2-1	Ventilation	40	9.2×9.2	RVVR	0.15
j2-2	Seal	40	9.2×9.2	RVVR	0.15
j2-3	Ventilation	40	13×13	RVVR	0.2
j2-4	Seal	40	13×13	RVVR	0.2
j2-5	Ventilation	40	18.3×18.3	RVVR	0.3
j2-6	Seal	40	18.3×18.3	RVVR	0.3

This paper conducted 15 sets of physical fire experiments on a small j series cable compartment. The cable compartment was enclosed, naturally ventilated, and longitudinally ventilated, and maintained under these conditions from the beginning to the end of the experiment. This paper measured the combustion state of cables and the temperature distribution inside cable compartments. As shown in Table 1, it is a test case of fire prevention and sealing strategies for cable compartments.

In series j, the cable was placed directly on the oil pool instead of the bracket on the side of cable compartment A, which reduced the distance between the oil pool and the cable. This paper investigated the combustion state of cables and the temperature distribution inside cable compartments. In some cases, the height of the ignition source was 0m. The number of cable layers was 1. In the case of j1-1, there were 2 cables per layer. In other cases, there were 4 cables per layer. ZRYJV and RVVR type flame retardant cables with PVC insulation in cross-linked polyethylene jacket.

B. Theoretical Analysis

For the test conditions near the sidewall, the Zukoski [20] mirror model was used to modify the HRR of cable fire sources:

$$\dot{Q}=[\frac{\Delta T_{dp}}{4.73\times\vartheta\times T_{\infty}}(c_p\rho T\sqrt{g})^{2/3}H_{ef}^{5/3}(0.6+\frac{r}{H})^{4/3}]^{3/2} \tag{1}$$

where, ϑ=1.59.

III. Results And Discussions

A. Burning time of sealing cable compartment

The burn durations for cases j1-1 ~ j1-9 were 285 s, 361 s, 226 s, 389 s, 678 s, 167 s, 357 s, 512 s and 726 s, respectively. The square oil pool was 9.2 cm × 9.2 cm, which had the longest burn duration. Although 60 ml of fuel was used in case j1-7, the combustion duration was not as long as in operating condition j1-9, due to it had high ventilation rate. Compared to natural ventilation and enclosed utility tunnels, the duration of cable burning is longer when using enclosed utility tunnels. The use of ZRYJV cables in the paper increased the duration of cable compartment fires. The burn durations in cases j2-1 ~ j2-6 were 990 s, 750 s, 398 s, 360 s, 161 s, and 132 s, respectively. The combustion time of natural ventilation was longer than that of enclosed cable compartment fires.

B. Temperature difference of the ceiling of the closed cable tunnel

It conducted a comparison of the effects of ZRYJV type cable enclosed utility tunnel and natural ventilation on the longitudinal temperature of the cable compartment. At 90 s and 550 s, in the case of j1-2 was natural ventilation, in the case j1-5 enclosed cable compartment located 0.5 m near the fire source. The maximum temperature rise was 60.8 ℃ and 50.4 ℃ , respectively. It indicated that the closed cable compartment reduced the ceiling temperature rise. The maximum temperature rise was reduced for the closed roof compared to natural ventilation.

As shown in Fig. 2, the maximum temperature rise of natural ventilation near the fire source was 94.2 ℃ and 107.5 ℃ in cases j1-3, j1-6 when the time was 65 s and 70 s, respectively. And the ceiling temperature rise reached the maximum extension time. The reason was that the cables were placed directly in the j series oil pool and the air capacity of the cables was fully supported for 150 s, resulting in the release of multiple streams of heat from the burning cables of the 18.3 cm × 18.3 cm oil pool.

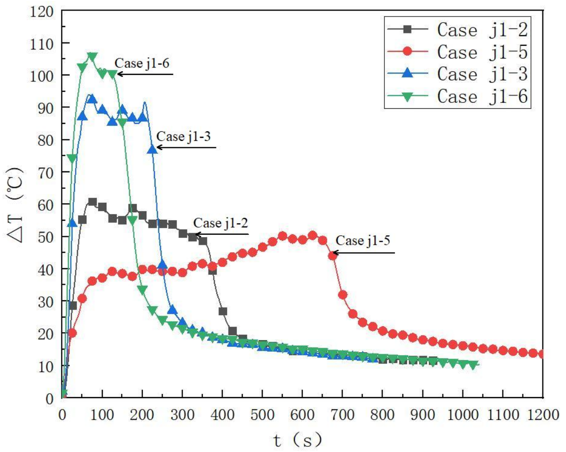

Fig. 2. Influence of ZRYJV cable plugging and natural ventilation on ceiling temperature rise at 0.5 m from fire source in the cable tunnel

The next step was to investigate the impact of closed cable compartment and natural ventilation below the ceiling temperature of cable compartments when using RVVR cables. As shown in Fig. 3, it can be seen at 975 s and 735 s that the ceiling temperature is 35.9 ℃ and 47.0 ℃, respectively. After 395 s and 330 s respectively, the maximum ceiling temperature rise 0.5 m away from the fire source in case j2-3 for natural ventilation and in case j2-4 for enclosed condition is 65.1 ℃ and 73.6 ℃. After passing through 80 s and 70 s respectively, the maximum ceiling temperature rise 0.5 m away from fire source in case j2-5 for natural ventilation and in case j2-6 for enclosed condition is 113.1 ℃ and 126.9 ℃. Therefore, when it placing RVVR type cables, compared to natural ventilation, the temperature rise below the ceiling of the enclosed cable compartment was higher, and the time was shorter. Because in the series j2 experiments, the cables were placed on the oil pool, reducing the distance between cable and the oil pool, resulting in more complete combustion of the cables. The oxygen content in the air of the enclosed cable compartment was sufficient to support combustion in a short period of time, leading to heat accumulation.

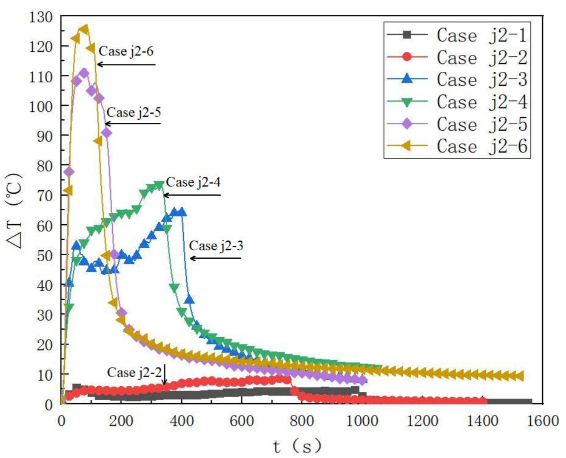

Fig. 3. Effect of RVVR cable on the temperature difference below the ceiling near 0.5 m from the fire source under plugging and natural ventilation in the cable tunnel

In Fig. 4, after 625 s and 330 s respectively, the maximum temperature rise below the ceiling in case j1-5 and in case j2-4 were 50.4 ℃ and 73.6 ℃, respectively. The results showed that the ceiling temperature rise of ZRYJV type cables was greater than that of RVVR type cables during combustion, due to the fact that ZRYJV type cables had more combustibles after being ignited.

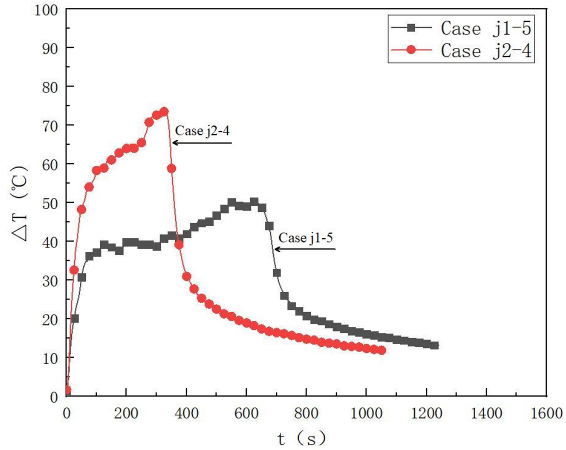

Fig. 4. Plugging strategy in the cable tunnel temperature difference below the ceiling of different cable types near 0.5 m from fire source

C. HRR near wall of enclosed cable compartment

The impact of ZRYJV type cables on the fire source power of cable compartments under closed and natural ventilation. In Fig. 5, after 55 s and 620 s respectively, the maximum HRR under natural ventilation in case j1-2 and case j1-5 reached 11.93 kW and 8.85 kW, respectively. When it used oil pool 13 cm × 13 cm, the cable compartment was closed, the maximum HRR was relatively low. After 65 s and 70 s respectively, the maximum HRR under natural ventilation in case j1-3 and closed cable compartment in case j1-6 reached 16.53 kW and 26.57 kW, respectively. When it used oil pool 18.3 cm × 18.3 cm, the maximum HRR is higher when the cable compartment is closed. This is due to the larger size of the oil pool, which allows for more sufficient contact between the surrounding air and fuel, releasing more heat in a shorter period of time.

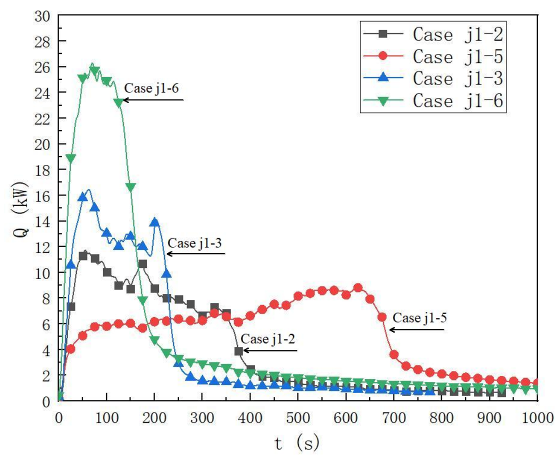

Fig. 5. Influence of ZRYJV cable on the heat release rate below the ceiling under plugging and natural ventilation in the cable tunnel

The following is the impact of RVVR type cables on the HRR of cables under closed cable compartment and natural ventilation. In Fig. 6, it can be seen that through 50 s and 725 s respectively, the maximum natural ventilation in cases j2-1 and j2-2 are 5.52 kW and 8.58 kW, respectively. After 390 s and 325 s, the maximum values of case j2-3 and natural ventilation case j2-4 are 12.95 kW and 16.77 kW, respectively. After 50 seconds and 60 seconds, the maximum HRR under natural ventilation in case j2-5 and closed cable compartment in case j2-6 reached 25.14 kW and 31.34 kW, respectively. Therefore, when placing RVVR type cables, compared to natural ventilation, using a closed cable compartment has a higher HRR and a shorter time. This is because within a short period of 300 s, the oxygen content in the air inside the closed cable compartment is still sufficient to support combustion.

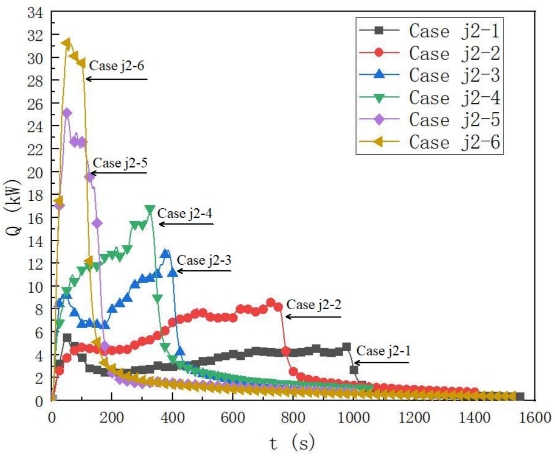

Fig. 6. Influence of RVVR cable on the heat release rate below the ceiling under plugging and natural ventilation in the cable tunnel

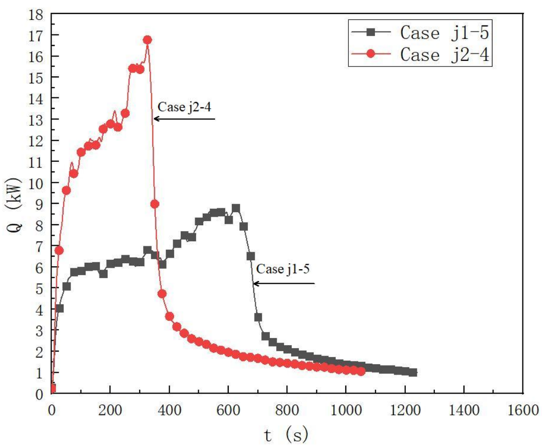

Fig. 7. Plugging strategy in the cable tunnel HRR of different cable types

The following is the impact of cable types in enclosed cable compartments on HRR. As shown in Fig. 7, after 620 s and 325 s respectively, the HRR of ZRYJV cable in case j1-5 and RVVR cable in case j2-4 reached their maximum values of 8.85 kW and 16.77 kW. The ZRYJV type cable has a higher fire source power than the RVVR type, because the ZRYJV type cable has more combustibles after being ignited.

D. Comparison of effects of sealing and natural ventilation on longitudinal temperature distribution

The following is a comparison of the effect of ZRYJV type cable on the longitudinal temperature of the cable chamber under the action of sealed cable chamber and natural ventilation. The longitudinal dimensionless temperature distribution of ZRYJV type cable in the cable tunnel under the action of sealed and natural ventilation is shown in Fig. 8. The non dimensional longitudinal temperature distribution shows a consistent pattern, decreasing with the distance increase from fire source.

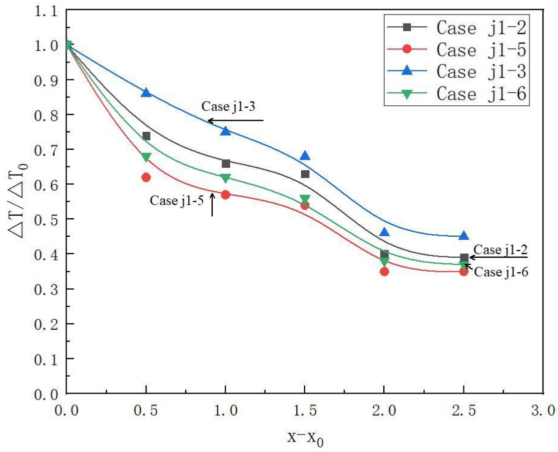

Fig. 8. Longitudinal dimensionless temperature distribution of ZRYJV cable in the cable tunnel under closed and natural ventilation

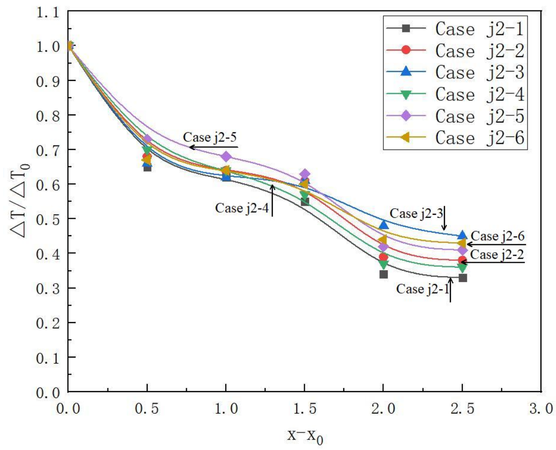

Fig. 9. Longitudinal dimensionless temperature distribution of RVVR cable under sealing and natural ventilation in the cable tunnel

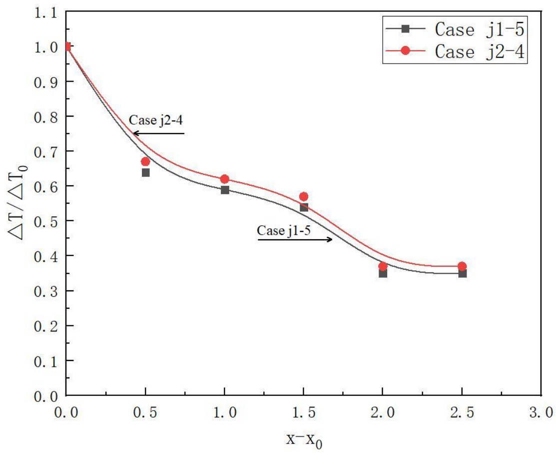

Fig. 10. Sealing strategy in the cable tunnel longitudinal dimensionless temperature distribution of different cable types

The following is a comparison of the effects of RVVR type cables on the longitudinal temperature of the cable compartment under the action of sealing and natural ventilation. As shown in Fig. 9, longitudinal dimensionless temperature distribution of RVVR type cables under the action of sealing and natural ventilation in the cable tunnel. It used oil pool 9.2 cm × 9.2 cm, 13 cm × 13 cm and 18.3 cm × 18.3 cm, the non dimensional longitudinal temperature distribution shows a consistent pattern, which decreases as the distance from the origin of the fire increases.

As shown in Fig. 10, it is longitudinal dimensionless temperature distribution of different cable types under the effect of cable compartment closure. This is due to the constant convective heat exchange of hot smoke with the inner wall of the cable as the distance of the ceiling jet increases. It caused the temperature of the smoke to gradually decreases.

IV. Conclusions

This paper conducted 15 sets of fire experiments using a small-scale utility tunnel in cable compartment experimental platform. This paper investigated the temperature rise, HRR, and dimensionless longitudinal temperature distribution in cable compartments. The main conclusions are as follows:

(1) The effect of sealing and natural ventilation conditions on the fire characteristics in cable tunnels was compared. When RVVR type cables were used, the duration of the fire in sealing cable tunnel was shorter, the ceiling temperature rose higher, and the required time was shorter. The sealing cable compartment had a high HRR, and the HRR reached its maximum value in a short period of time. The temperature of the overhead cable near the hearth of the fire entered the decay stage earlier.

(2) The near wall air characteristics of the sealing cable tunnel were compared with natural ventilation in cable tunnel. RVVR type cables were found to be placed. The average temperature rise rate of the sealing cable tunnel increased with the increase of the dimensionless average HRR. As the dimensionless average HRR increased, the overall dimensionless temperature rise of the sealing cable tunnel showed a decreasing trend. Compared to natural ventilation, sealing cable compartments reduced the average temperature rise rate and dimensionless temperature rise.

(3) This paper compares the effects of sealed cable tunnels and longitudinal ventilation on the fire behavior of cable tunnels. The temperature below the ceiling of a sealed cable tunnel is higher than that of longitudinal ventilation. The lower the vertical ventilation rate, the greater the maximum temperature rise observed at the ceiling at 1.5 meters from the fire. The sealed cable chamber can increase the average temperature rise of the cable tunnel and the dimensionless temperature rise compared to the longitudinal ventilation method. In sealed cable tunnels, the dimensionless patterns of longitudinal temperature distribution for different types of cables coincide and decrease as the distance to the fire origin increases.

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