Study on the Near-wall Fire Characteristics of Enclosed Cable Compartment

Zhenpeng Bai, Xiaohan Zhao, Haowei Yao, Cunxiang Yang, Hengjie Qin

Abstract—**In this paper, a series of fire experimental tests were conducted in a small cable compartment. In this study, the influence of sealing on the fire characteristics of the cable compartment near the wall was analyzed, through the longitudinal distribution of indoor temperature rise, the heat release rate of fire source and the dimensionless temperature below the ceiling. The ignition heat release rate (reservoir type and fuel volume), cable type, cable layer and number of cables per layer were considered. The contribution of this paper is to prevent fire from happening in the cable compartment of utility tunnel and reduce social and economic losses.**

Index Terms—**Experimental study, Fire characteristics, Enclosed cable compartment, Near-wall fire**

I. INTRODUCTION

When a fire occurs in the tunnel, it is very dangerous [1]. When a fire occurs in the cable compartment, the smoke is discharged from the ventilation holes of the shafts at both ends of the utility tunnel [2]. The smoke spreads vertically along the cable compartment. In general, a small fire in the cable compartment may cause a huge disaster [3]. In case of fire, the temperature field in the cable compartment changes with the ventilation velocity and heat release rate (HRR) [4].

Enclosed cable chamber refers to closing the shaft after the cable chamber catches fire. Then, it uses suffocation method to extinguish the fire. After a fire, if a closed shaft and fire door are used to form a closed space in the cable compartment, the external air will be isolated and cannot enter the cable compartment, so as to achieve the purpose of suffocation and fire extinguishing in the cable compartment of the utility tunnel. As a part of the cable compartment is on fire, it is necessary to start the fire extinguishing system after the cable compartment is closed. Therefore, it is necessary to study the fire protection characteristics of the enclosed space of the cable compartment.

In the past, numerical simulation was used to study characteristics of tunnel fire [5]. Zhao et al. [6] proposed a simplified model to simulate jet behavior in the cable compartment. For the radial expansion region, the Alpert equation was simplified, and the simplified solution was obtained. Ji et al. [7] studied the influence of the tunnel aspect ratio on flue gas temperature distribution below the ceiling of the ignition area. The results showed that the tunnel width had little effect on the smoke mass loss rate and the maximum smoke temperature below the ceiling. Vaquelin [8] and Van et al. [9] found that it is a suitable software for fire study for computational fluid dynamics (CFD). The Fire dynamics simulator (FDS) solves the problem of smoke propagation and heat transfer in fire [10]. However, for the simulation of the cable compartment, a lot of grids need to be established, and the simulation time is long.

In the past few years, the number of fire tests has increased significantly in the fatal tunnel fires in Europe [11-12]. In terms of repeatability of fire experiments, the results of the memorial tunnel test were in good agreement with the experimental measurement results of the far field of the fire source [13]. Fan [14] studied the flame length integration model considering the influence of tunnel cross-section and ventilation velocity under the condition of large HRR near the fire source. Meanwhile, Jiang [15] studied the phenomenon of smoke exhaust system in the center of the tunnel, and measured and analyzed the height, temperature and flow rate of the smoke exhaust layer under the smoke exhaust outlet. In summary, CFD simulation method can better analyze the motion law of fluid [16-18]. The above research methods are used to study the fire characteristics in the traditional tunnel field.

The previous study was about closed tunnel fires. Gao et al. [19] conducted numerical research on heat flow propagation and roof temperature distribution in the closed tunnel, focusing on the action mechanism of the closed tunnel. The results showed that for the closed tunnel, the vertical heat plume flow direction was inclined to the closed side due to one-way air supply. Under the restriction of the closed end, the heat flow was deflected and recirculated, resulting in the thickening of the thermal layer in the closed area, which is significantly different from the openings at both ends of the tunnel. Yu Miaomiao [20] studied the utility tunnel with circular section. The closed utility tunnel changed the heat release rate (HRR), and the reservoir was located in the center of the utility tunnel. The longitudinal temperature

Manuscript received October 15, 2021; revised October 25, 2022. This work was supported by the Key Scientific Research Project Plan of Colleges and Universities in Henan Province (23B560003), Doctor Scientific Research Fund of Zhengzhou University of Light Industry (2021BSJJ048), Natural Science Foundation of Henan Province, Zhengzhou City Collaborative Innovation Special Project (Cultivation of Major Projects) (2021ZDPY0108), and Science and Technology Plan Project of Henan Fire Rescue Corps (2021XFYY11).

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distribution below the ceiling of the utility tunnel was studied. The results showed that the longitudinal dimensionless temperature of the vault increased with the increase of dimensionless distance. The fitting formula satisfying the exponential distribution of dimensionless temperature with distance was given. In previous studies, the fire characteristics of closed tunnels have been studied. The fire source was designed by a closed utility tunnel. The research institute was generally set in the middle of the utility tunnel, using a circular section of the cable compartment. However, there are few researches on the temperature distribution and HRR characteristics of the near-wall fire in the enclosed rectangular cable compartments of utility tunnel.

In this paper, the distance between the reservoir and the bottom cable rack, the amount of fuel, the type of reservoir, cable type, the number of layers, the ventilation conditions and the number of cables per layer are considered in the closed cable compartment. In order to study the enclosed environment of cable compartment, the influence mechanism of fire burning time, the temperature rise below the ceiling and the HRR of the cable compartment on the enclosed environment was studied. The cable compartment was completely enclosed. Temperature profiles were measured during the experiment. Cable compartment internal temperature value to study its fire characteristics.

II. Method

A. Physical Model and Fire Scenario

This paper uses the method of small-scale experiment. The platform of small size cable compartment is 6.0 m × 0.4 m × 0.5 m (Height L × Width W × High H). The experimental platform is 0.5 m away from the ground. It is supported by a steel frame. The model scale is 1:6. Figure 1 shows the physical model.

Figure 1. Physical model of cable compartment in utility tunnel

As shown in Table 1, a total of 12 cases were tested in the small-scale cable compartment in utility tunnel. The cable compartment was completely enclosed. From the beginning to the end of the test, the air supply and exhaust shafts were closed, so the cable compartment of the utility tunnel was closed. The combustion state and temperature distribution of the cable were studied under this condition. The ambient temperature was 15 ℃. In this case, the cable was placed on the cable tray frame, and in this case, the cable compartment space enclosed in the cable compartment of utility tunnel was used. In case 5, the fire source height was 0 m. In other cases, the height of fire source was 0.1 m. The cable length was 0.2 m in case 2. The cable length was 0.3 m in cases 5 and 6. The cable length was 0.15 m in other cases.

TABLE 1 TEST CASES OF CABLE COMPARTMENT FIRE BLOCKING STRATEGY

Case	Number of cables per layer	Fuel quantity （ml）	Reservoir type	Cable type	Cable layers
1	2	20	4×21	ZRYJV	2
2	4	20	13×13	RVVR	1
3	4	20	4×21	ZRYJV	1
4	2	20	13×13	ZRYJV	2
5	4	40	9.2×9.2	ZRYJV	1
6	2	20	9.2×9.2	ZRYJV	2
7	4	20	4×21	RVVR	2
8	4	25	13×13	RVVR	2
9	4	20	9.2×9.2	RVVR	2
10	4	20	4×21	RVVR	1
11	4	20	13×13	RVVR	1
12	4	20	9.2×9.2	RVVR	1

The fire source in the utility tunnel was 0.8 m away from one side of the air supply shaft. The fuel was n-heptane. Axial fan was selected. The fan was eg-2.5a-2; 220V, flow rate was 1200 ~ 1740 m^3 /h. The rotating speed was 2800 r/min, and the total fan pressure was 126 ~168 Pa. Cable types included flame retardant XLPE sheathed PVC insulated cable ZRYJV and cable RVVR. The ZRYJV flame retardant cable has 2 cores and an area of 10 mm^2. Flame retardant cable RVVR has 1 core and an area of 10 mm^2.

There were 53 thermocouples arranged in the cable compartment of utility tunnel. Among them, 14 thermocouples were placed on the longitudinal centerline, 21 thermocouples were placed below the ceiling, and 18 thermocouples were placed on the side wall with fire source. There were 13 ventilation velocity measurement points. There were 8 ventilation velocity measurement points below the ceiling. Two ventilation velocity measurement points were set on both sides. There were 3 ventilation velocity measurement points were set on the side wall without ignition source.

B. Theoretical Analysis

The method of theoretical analysis is used to calculate the heat release rate of fire. In order to predict the HRR of cable fire source, the calculation equation of HRR measured in the test is as follows:

$$\dot{Q} = Q_{burner} + Q_{cable} \tag{1}$$

where, Q_{burner} and Q_{cable} are ignition HRR and cable combustion HRR, respectively.

For the test conditions near side wall, Zukosi [21] mirror model can be used to express the equation (1):

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

where, ϑ =1.59.

III. Results And Discussions

A. Burning time of closed cable compartment near wall fire

In order to study the effect of near-wall fire on the combustion time in the enclosed space of cable compartment, the experimental results were selected for analysis. The combustion time of cases 1 ~ 12 was 556 s, 290 s, 920 s, 123 s, 863 s, 315 s, 521 s, 143 s, 235 s, 404 s, 145 s and 270 s, respectively. Case 3 has the longest burning time. Case 4 has the shortest burning time. As the reservoir type of 4 cm×21 cm was used in case 3, ZRYJV cable was used, and 4 cables were arranged in each layer. It used a 13 cm×13 cm reservoir type, with two layers of cables, and in case 4 there were two cables per layer. Therefore, on the cable tray frame in the cable compartment of utility tunnel, there should not be too much cables in each layer, and the number of cable layers should not be too much.

B. Temperature rise below the ceiling of enclosed cable compartment

The maximum temperature rise below the ceiling 0.5 m away from the fire source was investigated. As shown in Figure 2, after 430 s, 110 s and 270 s in cases 1, 4 and 6, the maximum temperature rise was 17.0 ℃, 50.6 ℃ and 28.5 ℃, respectively, which was located 0.5 m below the ceiling of the fire source. For ZRYJV cable, the maximum temperature rise was greater at the bottom of the closed reservoir 13 cm× 13 cm from the ceiling. This is due to lower combustion efficiency of 4 cm ×21 cm and 9.2 cm ×9.2 cm reservoirs.

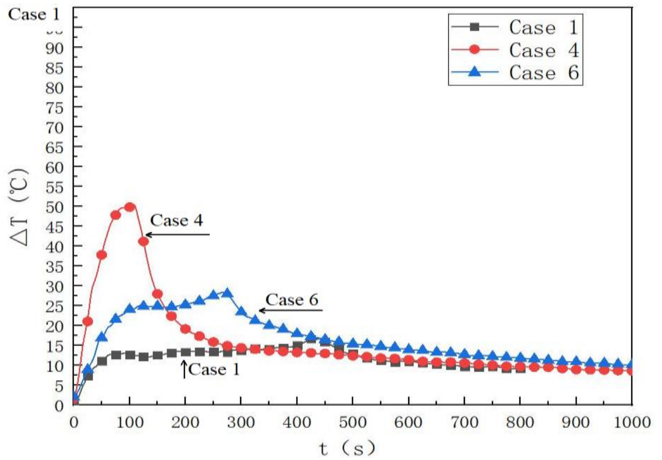

Figure 2. Influence of ZRYJV cable with plugging strategy in cable compartment of utility tunnel on temperature difference below the ceiling near fire source 0.5 m

As shown in Figure 3, it can be seen that after 425 s, 125 s and 225 s, the maximum temperature of cases 10, 11 and 12 rising below the ceiling at a distance of 0.5 m from the fire source were 20.3 ℃, 54.7 ℃ and 29.9 ℃, respectively. For RVVR cable, the maximum temperature rise is larger in the closed bottom reservoir 13 cm×13 cm from the bottom of the ceiling. This is because the combustion efficiency is lower when the reservoir type is 4 cm×21 cm and 9.2 cm× 9.2 cm.

As shown in Figure 4, after 165 s and 125 s, the maximum temperature rise was 39.4 ℃ and 54.7 ℃ below the ceiling 0.5 m away from the fire source in case 2 and case 11. For RVVR cables, when the cable length is 0.15 m and closed, the maximum temperature at the bottom of the ceiling increases greatly. This is because the combustion time of 0.15 m cable is relatively short, and the 0.2 m cable is not completely burned.

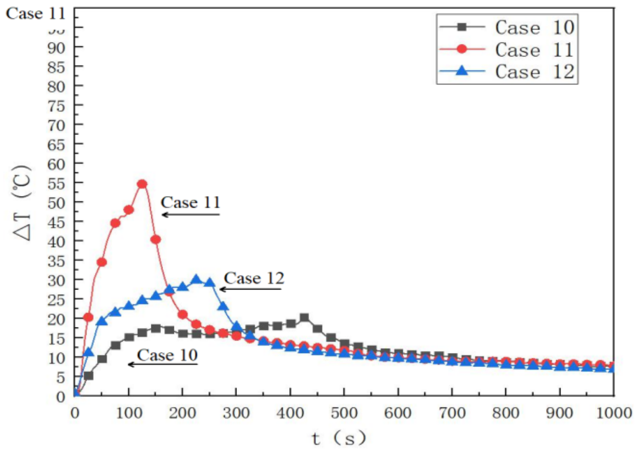

Figure 3. Influence of RVVR cable with plugging strategy in cable compartment of utility tunnel on temperature difference below the ceiling near fire source 0.5 m

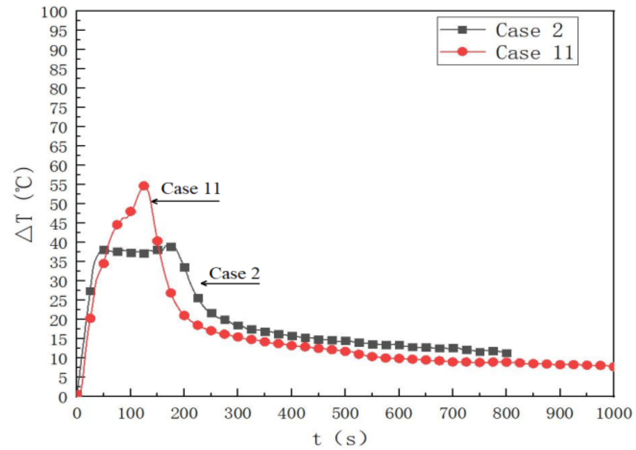

Figure 4. Influence of 1 layer cable with plugging strategy in cable compartment of utility tunnel on temperature difference below the ceiling near fire source 0.5 m

C. HRR near wall of enclosed cable compartment

As shown in Figure 5, after 420 s, 90 s and 115 s, the HRR reaches the maximum value of 2.89 kW, 23.5 kW and 11.6 kW in case 1, case 4 and case 6.

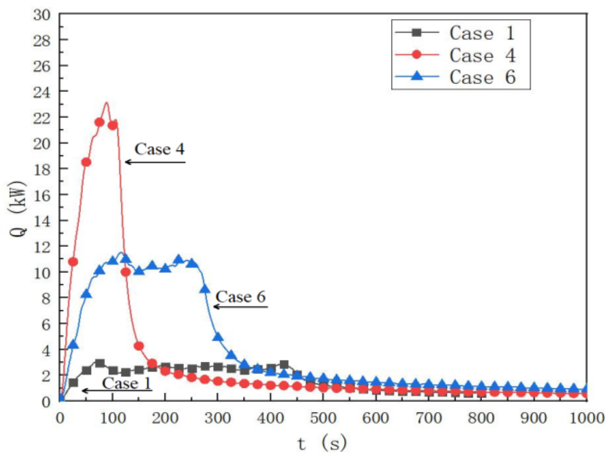

Figure 5. Influence of ZRYJV cable with plugging strategy in cable compartment of utility tunnel on HRR

As shown in Figure 6, after 160 s, 120 s and 165 s, the HRR of cases 10, 11 and 12 reached maximum value of 4.47 kW, 18.20 kW and 12.32 kW. In the ZRYJV cable and RVVR cable experimental tests, the square reservoir was located in the enclosed cable compartment. The HRR of 13 cm×13cm reservoir was high. The experimental results of the two-layer cable showed that the central linear reservoir of the enclosed cable compartment was 4 cm×21 cm. The HRR of fire source of 4 cm×21 cm reservoir was larger than 9.2 cm× 9.2 cm square reservoir. The experimental results of the 1-layer cable showed that the more the number of cable combustion, the greater the HRR, and the HRR has little relationship with the cable length.

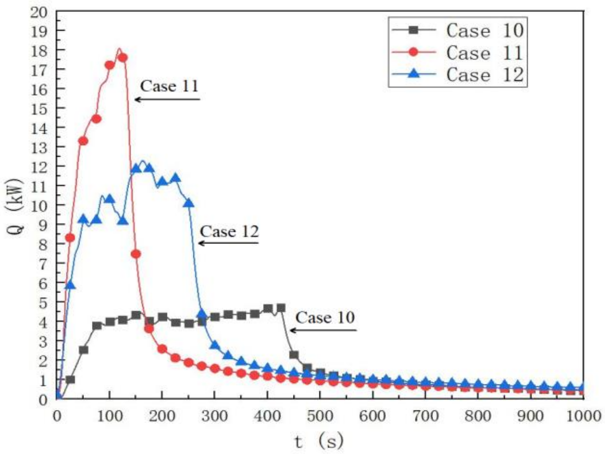

Figure 6. Influence of RVVR cable with plugging strategy in cable compartment of utility tunnel on HRR

As shown in Figure 7, the HRR of case 7 and 9 reached the maximum value of 6.06 kW and 15.1 kW, after 515 s and 130 s. The fuel volume was 20 ml, and the number of cables in each layer was 2. The reservoir type was 13 × 13cm, and the cable type was ZRYJV. The HRR is large, and the time required to reach the maximum HRR is short.

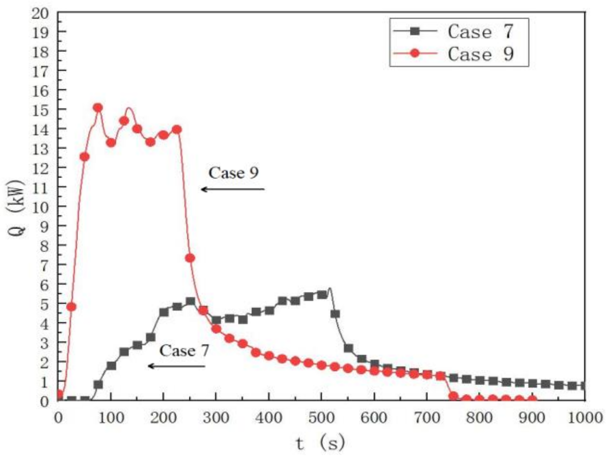

Figure 7. Influence of 2 layers cable with plugging strategy in cable compartment of utility tunnel on HRR

As shown in Figure 8, in case 2 and case 11, the HRR reached its maximum value of 12.2 kW and 18.20 kW after 140 s and 120 s. The HRR of the enclosed cable compartment increases first with time, reaches the maximum value, and then decreases gradually over time.

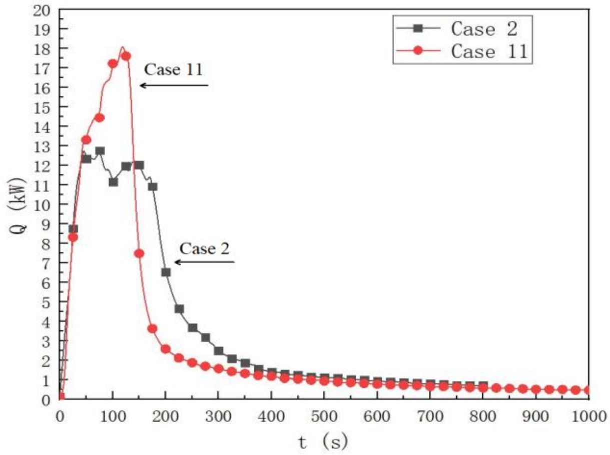

Figure 8. Influence of 1 layer cable with plugging strategy in cable compartment of utility tunnel on HRR

D. Longitudinal temperature distribution of enclosed cable compartment

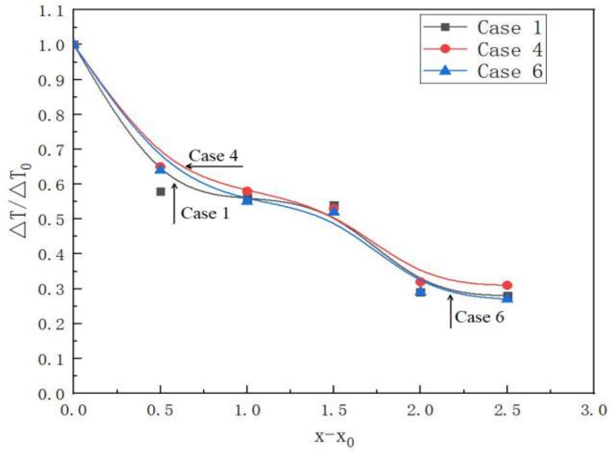

Figure 9. Influence of ZRYJV cable with plugging strategy in cable compartment of utility tunnel on longitudinal distribution of dimensionless temperature

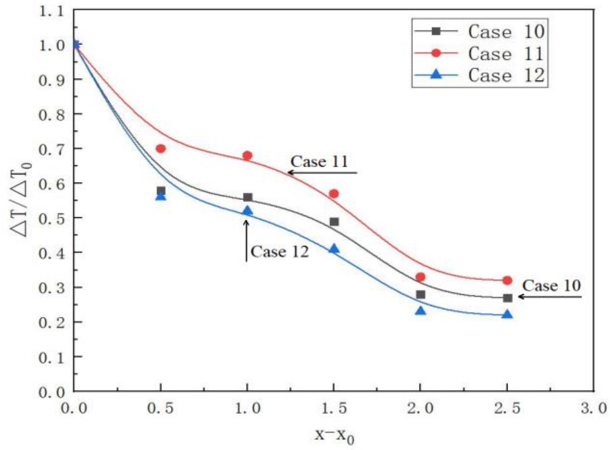

Figure 10. Influence of RVVR cable with plugging strategy in cable compartment of utility tunnel on longitudinal distribution of dimensionless temperature

As shown in Figures 9 ~ 11, the effect of closed cable compartment on the dimensionless longitudinal temperature distribution. The dimensionless longitudinal temperature distribution of ZRYJV cable, RVVR cable and single-layer cable is consistent, and decreases with the increase of distance from the fire source. This is because as the spraying distance from the ceiling increases, the smoke continues to dissipate heat through convection with the walls of the cable compartment and the surrounding air, resulting in a gradual decrease in smoke temperature in the cable compartment.

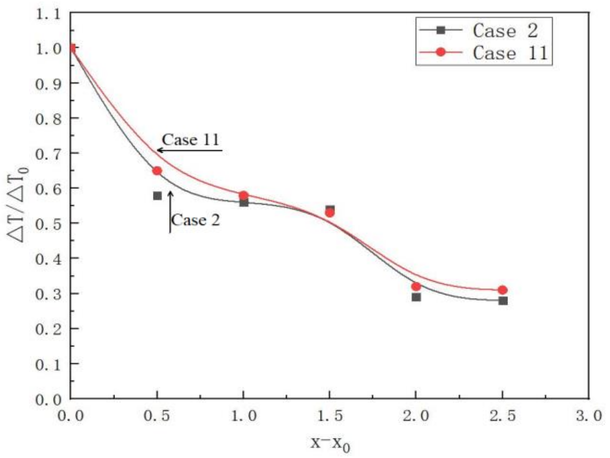

Figure 11. Influence of 1 layer cable with plugging strategy in cable compartment of utility tunnel on longitudinal distribution of dimensionless temperature

IV. Conclusions

In this paper, 12 fire experimental tests were carried out in the small cable compartment of utility tunnel test platform. The longitudinal distribution of temperature rise, HRR and dimensionless temperature below the ceiling in an enclosed space close to the cable compartment wall and 0.5 m away from the fire source is studied. Combined with the HRR of ignition source (reservoir type and fuel quantity), cable type, cable layer and the number of cables per layer, the influence of sealing on the fire characteristics near cable compartment wall is analyzed. The main conclusions are as follows:

(1) The number of cables in each layer and the number of cable layers in the cable compartment shall not be excessive. The longest fire duration is 4 cm×13 cm reservoir type in the enclosed cable compartment. When the longitudinal ventilation velocity is 1.5 m/s, the combustion time of the 9.2 cm × 9.2 cm reservoir type in the enclosed cable compartment is the longest. When the RVVR cable is placed in the enclosed cable compartment, the comparison of the three square reservoir shows that the 9.2 cm×9.2 cm reservoir type as fire source lasts longer.

(2) The size and reservoir type affect the temperature rise below the ceiling and the HRR near-wall fire source in enclosed cable compartment. Compared with the 4 cm×21 cm and 9.2 cm×9.2 cm reservoirs, ZRYJV cable and RVVR cable, the maximum temperature rise below the ceiling of 13 cm×13 cm reservoir is larger, because the opening area is relatively large. The combustion efficiency is relatively high. When the reservoir is 13 cm × 13 cm, the maximum temperature rise below the ceiling is lower than that of natural ventilation. The larger the reservoir scale, the higher the temperature below the ceiling, the higher the HRR, and the shorter the time to reach the maximum. Compared with RVVR cable, ZRYJV cable has larger temperature rise below the ceiling and HRR. This is because the ZRYJV cable is ignited and contains more combustible material.

(3) In this paper, a dimensionless longitudinal temperature distribution model of the enclosed cable compartment in the utility tunnel is established. The dimensionless longitudinal temperature distribution of different types of cables in the enclosed cable compartment is consistent. The dimensionless longitudinal temperature decreases with the increase of the distance from the fire source. According to the experimental results of the maximum HRR of the small-scale model, the HRR of the full-scale model can be calculated.

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