Numerical Simulation on Smoke Propagation and Fire Separation in Electric Power Cable Tunnel

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Abstract. The smoke propagation process in an electric power cable tunnel was investigated numerically, and the effects of fire separation on the fire development were also explored. The numerical simulations were conducted by using the Fire Dynamics Simulation (FDS) in the present study. The electric power cable tunnel was insisted of four working wells and three tunnel sections, and the total length of this tunnel was 561 m. According to the simulation results, the smoke propagated fast in the electric power cable tunnel when there was no fire separation inside the tunnel, and the temperature of the whole tunnel increased obviously. The fire separation is an effective method to confine the fire smoke into one fire compartment. However, the flame would migrate in the whole fire compartment, mainly due to the lack of oxygen. The working well was affected by the high-temperature flame even the fire happened in the tunnel section. The temperature of the 2# working well reached almost 1000°C when the fire initially located at the 1# tunnel section in the present study.

1. Introduction

The cable tunnel is important in electric power system, since it is the main channel for long distance transmission of the electric power. There are usually large amounts of cables laying in the electric power cable tunnel. Once one of the cables is ignited due to electric fault, the other cables are likely to be ignited and finally caused the cable tunnel fires. The fires in electric power cable tunnel not only affect the normal supply of electricity, but also bring threats to the security of the entire electric grid. Therefore, studies on fire safety of the electric power cable tunnel is necessary to be conducted.

The electric fires have earned much concern. Babrauskas [1] indicated that the main reasons for electric fires included arc fault, overheating of the core and external heating. Hagimoto et al. [2], Stoliarov et al. [3] and Dunki-Jacobs [4] put attentions on the mechanism and cause of the electric fires. Niu et al [5], Wang et al. [6] and Zhang et al. [7] revealed the fire hazard of cables by using small-scale experimental instrument. However, the smoke movement in electric power cable tunnel under fire accident as well as the effects of fire separation method on smoke control have not receive enough attentions.
2. Numerical method and Simulation model

The numerical simulations were conducted by using the Fire Dynamic Simulators (FDS), which is developed by the National Institute of Standards and Technology based upon the field modelling method. FDS is an effective way to investigate fire process and smoke propagation, and has been adopted in many fire related researches [8-10].

The sketch of electric power cable tunnel is illustrated in Figure 1. The tunnel model was consisted of four working wells (1# working well to 4# working well) and three tunnel sections (1# tunnel section to 3# tunnel section). The lengths of 1# tunnel section, 2# tunnel section and 3# tunnel section were 224 m, 68 m and 178 m, respectively. The shape of the tunnel was rounded. The diameter of the tunnel was 2.2 m, and the lower edge of the tunnel was located at 1.1 m.

![Figure 1. Sketch of the electric power cable tunnel model](image)

Four fire scenarios were investigated in this study. In fire scenario 1 and 2, there were no fire separation installed in the electric power cable tunnel, and the smoke could propagate unrestrictedly in the whole tunnel area. The fire source was located at 2# tunnel section and 2# working well in scenario 1 and 2, respectively. The fire separation was included in scenario 3 and 4. The fire source was located at 2# tunnel section and 2# working well in scenario 3 and 4, respectively. In all of the four scenarios, the heat release rate of fire was set as 2MW in the simulations.

3. Smoke Propagation in Power Cable Tunnel

3.1. Smoke propagation under the fire source in tunnel

The smoke propagation in the electric power cable tunnel with the fire source located at 2# tunnel section are shown in Figure 2. At 35 s after fire, the 2# tunnel section, which contained the fire source, was filled of smoke and the smoke has spread into the 2# and 3# working wells. The 2# and 3# working wells were full of smoke at 120 s, and the smoke has already spread into the 1# and 3# tunnel sections. The 1# and 4# working well were contaminated with smoke at 320 s. The whole electric power cable tunnel was full of smoke after 540 s, and the concentration of the smoke keep increase with the process of fire. It is observed that the smoke spread very fast in the in the electric power cable tunnel when the fire source located at the 2# tunnel section. It is mainly due to that there is no fire separation set in tunnel in this fire scenario.

When fire happened in the electric power cable tunnel, the heat accumulated in the tunnel and the temperature increased gradually. At first, the temperature rise was only limited in the area around the fire source. With the smoke propagation in the tunnel, the temperature rise almost appeared in the whole electric power cable tunnel. The temperature of the tunnel with the fire source located at 2# tunnel section is illustrated in Figure 3. At 220 s, the temperature of the
whole 2# tunnel section was almost larger than 700 °C, under which the fault of cable would happen in a short time. At 540 s, the temperatures of both 2# work well and 3# working well were above 700 °C. The temperature inside the tunnel increase continually, and the temperature of 1# and 4# working well, which were over 200 m away from the location of the fire source, was above 100 °C at 1200 s. According to the Figure 2, the increase of temperature in the tunnel was quickly.

![Figure 2. Smoke propagation in the electric power cable tunnel with the fire source located at 2# tunnel section](image)

3.2. Smoke propagation under the fire source in working well

When the fire source was located at 2# working well, the smoke propagation in the power cable tunnel is shown in Figure 3. The 2# working well was filled with smoke soon after the fire came out. The fire smoke spread into the 3# working well after 120 s, and it was filled with smoke at 180 s. At 540 s, the smoke has spread into the 1# working well, and the whole power cable tunnel was almost charged with smoke after 1200 s. The temperature rise inside the electric power cable tunnel is illustrated in Figure 4. At 30 s, the temperature of 2# working well was higher than 700°C. The temperature of the 3# working well began to increase at 120 s. At 1200 s, the temperature of 3# working well, which was about 70 m away from the fire source, reached 700°C.

It can be found that the smoke propagation quickly in the electric power cable tunnel in fire scenario 1 and 2, since there was no fire separation and the smoke flowed unrestrictedly in the electric power cable tunnel. When fires happened, the heat accumulated quickly in the tunnel because of the structure of tunnel was long and narrow. The rise of temperature provided sufficient force for smoke propagation. To confine the contaminated area of smoke in the tunnel, the effective fire separation should be set and well designed.
4. Fire Hazard of Tunnel with Fire Separation

4.1. Flame spread in tunnel with fire separation

The fireproof door is usually installed in the power cable tunnel as the fire separation. The distance between two adjacent fireproof doors is about 100 m. The total length of the power cable tunnel was 561 m, so there were four fireproof doors installed. The 1# tunnel section, 2# working well and 2# tunnel section were included in a fire compartment that confined by two fireproof doors. The fire compartment contained both the tunnel section and the working well, therefore, the flame and smoke spread in this fire compartment should be investigated.

When the fire source located at the 1# tunnel section, the flame spread in this tunnel section is shown in Figure 6. The flame burned steady at first as shown in Figure 6(a). Then the oxygen concentration around fire decreased due to the combustion. At 60 s, the flame began to spread toward the two sides of tunnel due to the lack of oxygen in the fire area. The spread of flame became more severe at 280 s. At 420 s, the flame in the origin fire location was almost extinguished, and the flame spread into the 2# working well. It showed that the working well would be affected by the high-temperature flame even the fire source was initially located at the tunnel section.

When the fire source located at the 2# working well, the flame spread in this working well is shown in Figure 7. The flame was steady at the initial stage of fire. The steady stage of flame was longer in scenario 4 than that in scenario 3, which might due to the fact that the height of working well was higher than the height of tunnel section. The flame was stretched at 320 s, since the oxygen concentration was not sufficient around the fire. With the decrease of oxygen concentration, the flame spread toward the tunnel sections on both sides. It implies that the tunnel section would also be influenced by the flame when the initial fire location was in the working well.
4.2. Smoke propagate in tunnel with fire separation

The smoke propagation in tunnel with fire separation when the fire source was located at 1# tunnel section is shown in Figure 8. The smoke spread into the 2# working well within 9 s. The smoke in the 2# working well descended almost to the floor level at 100 s. After 120 s, this fire compartment was almost filled with smoke totally. The temperature of the 2# working well versus time in scenarios 3 is illustrated in Figure 9. The temperature of the upper space of 2# working well increased soon after the ignition, since the smoke spread into the 2# working well within 9 s, as shown in Figure 8(a). The temperature at the lower space of 2# working well kept low within 100 s. After 100s, the temperature of lower space of 2# working well increased obviously because of the smoke descended to the lower space. The temperature of the 2# working well trended to uniform after 300s, and it reached to 1000 °C at 600 s.

When the fire source was located at the 2# working well, the smoke propagation in tunnel with fire separation is shown in Fig. 10. The smoke could not be confined in the initial fire working well and began to spread into the tunnel sections on both side after 20 s. The smoke reached to the fireproof doors at both sides of the tunnel at about 60 s. The smoke began to flow back after it reached to the fireproof door, and the whole fire compartment was filled with smoke at 120 s. The temperature of the 2# working well versus time in fire scenario 4 is illustrated in Figure 11. The temperature of 2# working well increased quickly after the ignition. The temperatures of the upper and lower spaces the working well became almost uniformed after 150 s. The temperature of the whole working well reached 1200 °C at 300 s.

![Figure 6. Flame spread in the 1# tunnel section in fire scenario 3](image)

![Figure 7. Flame spread in the 2# working well in fire scenario 4](image)

![Figure 8. Smoke propagation in tunnel with fire separation (fire scenario 3)](image)
According to the above discussion, the fire separation is an effective way to confine the spread of smoke in electric power cable tunnel. However, the tunnel section and working well might be contained in the same fire compartment. When the fire happened in the tunnel section, the flame would spread into the working well due to the lack of oxygen, and caused extremely high temperature rise in the working well. Since the working well is very important for the electric power cable tunnel, the currently-used fire separation need further improve. When the fire source was located at the working well, the tunnel section would be affected by the flame as well.

5. Conclusions
The smoke propagation in the long electric power cable tunnel was investigated numerically. The effects of fire separation on flame behavior and burning process were also explored. The results
showed that the smoke propagated quick in the power cable tunnel without fire separation, and the temperature of the whole tunnel increased obviously. The fire separation is an effective way to confine the fire smoke into the fire compartment. However, the flame would migrate in the whole fire compartment, mainly due to the lack of oxygen. The working well might be affected by the high-temperature flame even the fire happened in the tunnel section. The temperature of the 2# working well reached almost 1000°C when the fire initially located at 1# tunnel section in the present study.

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