# A Comprehensive Study of Two Fire Conditions in a Subway Train Fire: Considering the Failure or Work of the Sprinkler System

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Abstract: Subway fire has a greater risk, and it occupies a large proportion in the subway accidents. Through the analysis of the possibility of subway fire and combustible, the model based on the actual size of one certain railway station in Dalian is established. Several different fire conditions are considered in the model. Different fire numbers and different fire power sources are set in the different fire locations, just as the station, platform, and the train area. Fire temperature, smoke layer height, CO concentration and other fire parameters were analyzed considering the failure or work of the sprinkler system. The need time for the fire evacuation is analyzed in the two conditions. Also risk limits are compared to the scene of the fire parameter. The results show that the sprinkler system can reduce the temperature of the fire, and it is a little difficult to discharge the smoke from the top air outlet due to the rising part of the water droplets, the plume temperature and the velocity decrease, which hinders the smoke emission and accelerates the visibility.

## 1 INTRODUCTION

Since the metro has such advantages as large transportation capacity, high speed, low pollution, less resource occupation, low energy consumption, easy traffic, and comfort, which are in conformity with the principle of sustainable development, it is particularly applicable for big and medium-sized cities. At present, there are over 100 cities all over the world that are operating metros. As of December 31, 2016, the metro lines amounting to a total length of 3168.7 km were opened to traffic in total in Mainland China. By 2015, the metro lines total length in Mainland China will reach 4189 km（Shi et al, 2012）. Today, the metros in Chinese major cities such as Beijing and Shanghai have become one of the most populated metros in the world.

However, due to the heavily overcrowded population and the situation of underground space, there exist a lot of potential risks during the operation of the metro station (Pan and Shi, 2011). A single incident can be devastating, causing death and millions of dollars in property loss. For instance, one recent serious metro accident is the trains rear-end accident of shanghai Metro Line 10 occurred in September 27, 2011. More than 270 passengers were injured in the accident. Subway fire is most frequent and serious in the subway accident statistics. Large quantities of smoke are likely to spread rapidly to entire subway station due to stack effect. Especially, because smoke spread path usually coincide with passenger's evacuation path, it will reduce visibility and can cause fatalities by asphyxiation. Many works were done in this field, just as the smoke flow patterns and emergency rescue in the subway fire. The different ventilation modes for fire in the subway station were studied to clear the influence of the different layout (Luo et al, 2014). Miho proposed a quantitative method to assess road tunnel fire safety based on a numerical simulation of in-smoke evacuation (Miho et al, 2017). Jae performed the fire simulation and evacuation simulation to estimate the effect of the platform screen door and ventilation on passenger's life safety in a subway train fire (Jae et al, 2009). Sanhay performed sensitivity analysis to quantify the influence of ventilation velocity on the fire parameters (Sanhay, 2017). A discrete design method with integrated fire–evacuation model for fire emergency evacuation was used to reduce the simulation time and cost in fire emergency evacuation simulations (Yang et al, 2017).

Generally, fire in a subway station forms a complicated structure. This physical phenomenon involves chemical reaction. And radiation is affected by various parameters, including geometry, tunnel slope, ventilation velocity, sidewalls restriction, and



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pressure of passing air among other influential variables. Some works were done in the paper to quantify the influence of the sprinkler system on the parameters: the maximum temperature, the maximum smoke layer height, the maximum CO concentration, the visibility in the subway fire. Several fire simulation models were developed by using FDS software. The risk of the subway fire can be quantified by comparing with the parameters which got from the simulation and the limits set in the literatures and the laws.

## 2 THE SIMULATION MODEL

The actual model is built based on the actual size of one railway station in Dalian. Figure 1, Figure 2 respectively shows the station floor and platform floor of the subway station.

Figure 1: the station floor

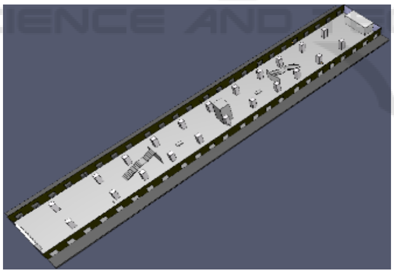

Figure 2: the platform floor

### 2.1 The set limits of the fire parameters

Temperature, CO concentration, visibility are usually used as the basis in the fire analysis. And the shortest time of the three is set for reaching a hazard state in the fire. With reference to "Design for Asylum" and the criteria for quasi-safe areas, the hazard limits are selected as follows:

- Temperature is over 60 °C at 2m height;
- CO concentration is up to 1400ppm at 2.1m height;
- Visibility is less than 10m at 2m height.

### 2.2 Simulation scenarios and parameters

Several fire conditions were set in table 1. The time for the luggage fire in the platform floor and in the station floor to reach the steady combustion is 450s. In order to make the simulation results more accurate, the simulation time is determined as 800s. However, because of the large area of the station and the rapid dissipation of the heat when the fire reaches stable combustion, the simulation time is set as 700s.

Table 1: The fire scenarios

| case | fire scenarios | Stable fire power / MW | Failure of the sprinkler system |
|---|---|---|---|
| 1 | One fire at the centre area of platform floor | 2.5 | No |
| 2 | One fire at the centre area of platform floor | 2.5 | Yes |
| 3 | One fire at the platform staircase entrance | 2.5 | NO |
| 4 | Two fires at the platform staircase entrance | 2.5 | NO |
| 5 | Fire at the ticket area of station floor | 2.5 | NO |
| 6 | Fire at the middle of the train | 7.5 | NO |

## 3 THE RESULT ANALYSIS OF THE SIMULATION

### 3.1 One fire at the centre area of platform floor compared with the failure of the sprinkler system

#### 3.1.1 Smoke spreads

The comparison of smoke spreading in the central station fire with the failure or no failure of sprinkler system is shown in Figure 3.

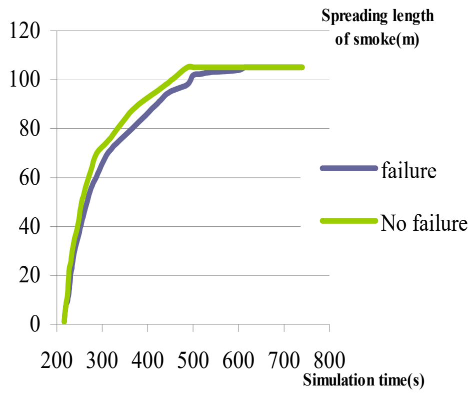


Figure 3: Comparison of smoke spreading in the central station fire with failure or no failure of sprinkler system

Figure 3 shows that the spreading length of fire smoke considering the work of the sprinkler system is wider than the failure of the sprinkler system. The temperature of the whole station area is reduced for the no failure of the sprinkler system. The rate of heat releases from fire sources and smoke spreads slows down. The smoke spreads to the entire platform floor more quickly compared with failure of the sprinkler system. The rising smoke carries some water droplets. And the temperature and speed of the plume are reduced. The smoke is difficult to discharge through the top exhaust vent. So the smoke first spread to the entire platform floor, but the effect is not particularly obvious.

### 3.1.2 The temperature distribution of the platform floor and the height of the smoke layer

When the sprinkler system in the centre area of platform is intact or invalid, the changes of temperature distribution and smoke layer height are shown in Figure 4, Figure 5.

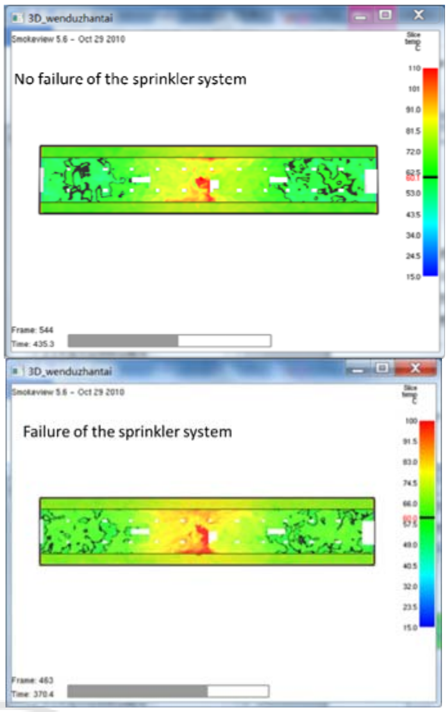


Figure 4: Station floor with a height of 2.1 m and a temperature of 60 ° C

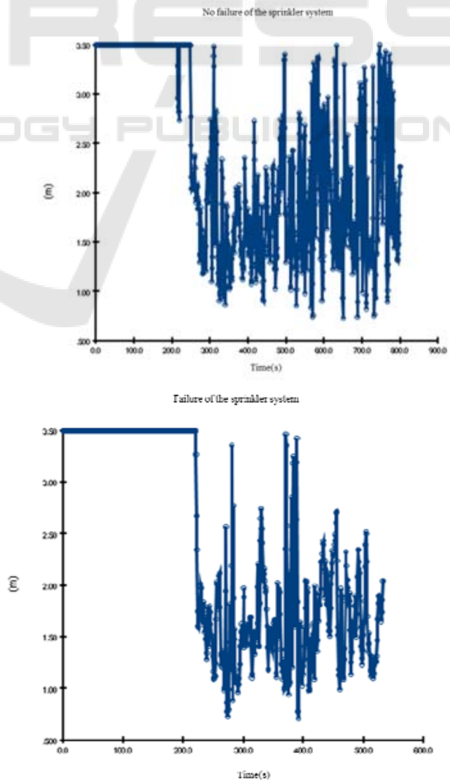


Figure 5: Comparison of smoke layer height changes in the centre area of platform

Figure 4 shows that if the sprinkler system is normal, the spreading time of the fire smoke is 435.3s at a height of 2.1 m when the temperature gets up to 60℃ on both sides of the station stairs. If the sprinkler system is invalid, the time of smoke spread is 370.4s. It is about 65s earlier than the condition of no failure of the sprinkler system. Thus, the role of sprinkler system can reduce the temperature of the fire. According to Figure 5, when the sprinkler system is intact, the height of the smoke layer decreases sharply in about 250s.When the sprinkler system fails, the height of the smoke layer drops sharply in 220s.The time of the smoke layer to reach the minimum height for the failure of the sprinkler system is 210s less than the another condition. The rising smoke particles adsorb part of the water droplets which make plume temperature and velocity decrease. The smoke is difficult to discharge through the top exhaust vent. The smoke layer height changes more compared with the failure of the sprinkler system. There is a higher probability for the smoke layer to be located near the ceiling. Thus, the role of the sprinkler system can hinder the emission of smoke, but not particularly obvious.

### 3.1.3 CO distribution and visibility

When the sprinkler system in the centre area of platform is normal or invalid, the CO distribution and visibility surface at 10m of platform are shown in Figure 6, Figure.7.

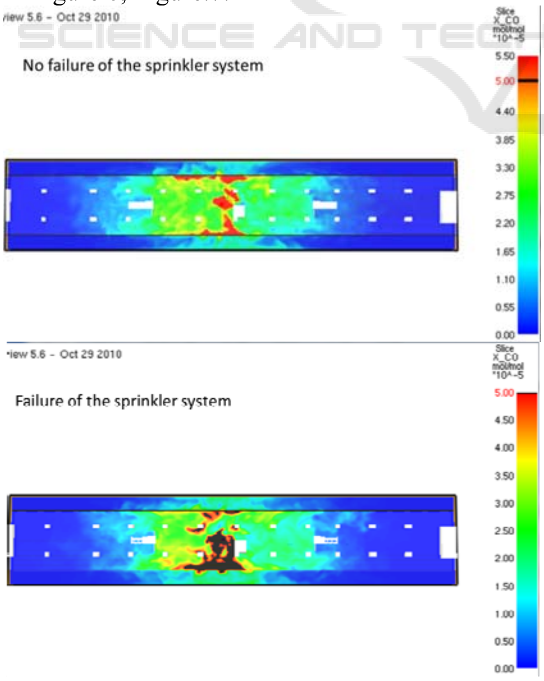


Figure 6: Comparison of CO distribution

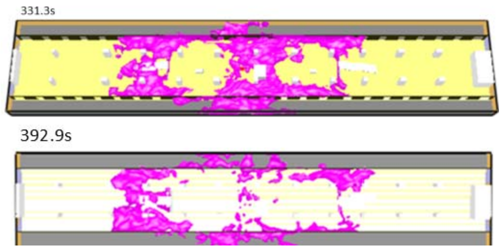


Figure 7: Comparison of the visibility surface at 10m

According to Figure 6, the incomplete combustion of combustibles is increased because of the work of the sprinkler system. And the CO volume fraction is slightly increased, but the value still below the danger limit. According to Figure 7, it almost reaches the same spatial scope comparison of the visibility surface at 10m. The work of the sprinkler system is better than the failure of the sprinkler system. The function of sprinkler system can also accelerate the reduction of visibility.

## 3.2 Comparison of fire parameters in different fire scenarios

Fire parameters for different fire scenarios were analyzed. Take smoke and fire temperature as examples, are shown in Figure 8, Figure 9. According to Figure 8, the time of smoke appearance and the time of smoke spreading to the entire station floor are compared with different fire scenarios. Fire heat release rate increased quickly due to the failure of the sprinkler system. So the smoke first appears earlier in the failure scenarios of sprinkler system. The smoke spreads throughout the floor more quickly in the two fires scenarios. According to Figure 8 and Figure 9, the fire parameters in the middle of train fire are obvious higher than the other one fire scenarios. The smoke spreads throughout the floor earlier than other one fire scenarios. In particular, the temperature is very unfavourable to the escape of personnel.

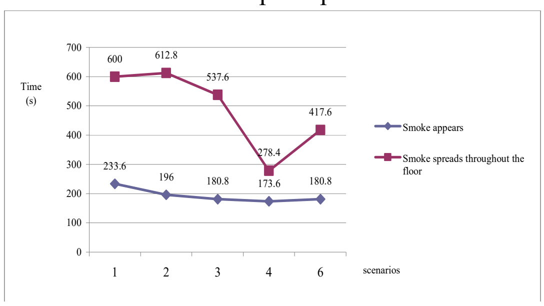


Figure 8: the time comparison of smoke appears and spreads throughout the floor

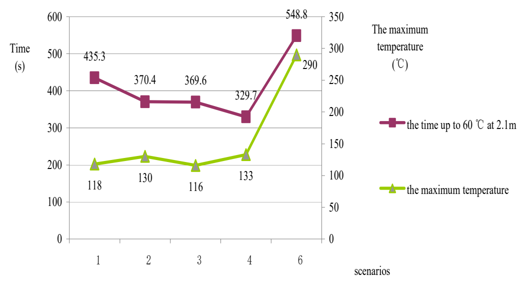


Figure 9: the comparison of the time up to 60 ℃ at 2.1m and the maximum temperature

# 4 CONCLUSIONS

The change of the fire parameters is not obvious with less combustible and a larger space of the subway station. Sprinkler system can reduce the temperature of the fire, but it will be a slight hindrance to discharge the fire smoke. Due to the effect of sprinkler system, the degree of incomplete combustion of combustible material increases and the concentration of CO slightly increases within the dangerous limits. Due to the large amount of combustibles, train fire source power is larger. Its fire source parameters change more obvious.



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# REFERENCES

Shi C L, Zhong M H, Nong X ZH, et al, 2012. Modeling and safety strategy of passenger evacuation in a metro station in China. Safety Science, 50(5): 1319-1332

PAN K, SHI J Y, 2011. Application of Multi-level Extensible Method to Urban Subway Operation Safety Evaluation. Journal of China railway society, 33(5): 14-19. (in Chinese).

Luo N, Li An G, Gao R, et al, 2014. Smoke confinement utilizing the USME ventilation mode for subway station fire. Safety Science, 70: 202-210

Miho S, Nobuyoshi K, Masato H, 2017. Quantitative assessment method for road tunnel fire safety: Development of an evacuation simulation method using CFD-derived smoke behavior. Safety Science, 94:116-127

Jae S R, Hong S R, Won H P, Yong J J, 2009. CFD Simulation and assessment of life safety in a subway train fire[J].Tunnelling and Underground Space Technology,24:447-453

Sanhay K K, 2017. From small-scale tunnel fire simulations to predicting fire dynamics in realistic tunnels[J]. Tunnelling and Underground Space Technology,61:198-204

Yang P ZH, Li CH, Chen D H, 2013. Fire emergency evacuation simulation based on integrated fire–evacuation model with discrete design method. Advances in Engineering Software, 65: 101-111