Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia

Transportation Research Procedia 00 (2018) 000–000

www.elsevier.com/locate/procedia

World Conference on Transport Research - WCTR 2019 Mumbai 26-31 May 2019

Study on the Feasibility of Downward Evacuation in Metro Station When the Station Hall Catch Fire

Heng Yu[a]*, Yimin Wang[a], Peiyun Qiu[b], Jiacheng Chen[b]

[a]*School of Civil Engineering & Transportation, South China University of Technology, Guangzhou, 510641, China.*
[b]*Guangzhou Metro Group Co. Ltd. Guangzhou,510308, China*

Abstract

Fire in metro stations is a serious disaster which threatens the safety of passengers and staff. As more and more deep-buried metro stations appear, it's more difficult for people in the station hall and on the platform to evacuate in an emergency in these deep-buried stations. If people in the station hall choose to evacuate to the outside when fire appears in the station hall, the direction of smoke flow is in coincident with the direction of evacuation, which is unfavourable for the evacuation as well as rescue from outside. Can platform below station hall be used as a shelter when the station hall catch fire? In this paper, the numerical method is used to demonstrate the feasibility of downward evacuation under the condition that fire appears in the station hall. At first, safety evacuation criteria are made to judge the feasibility of evacuation. Then, numerical models are established by FDS software, and the concerned results include smoke movement, temperature, the concentration of carbon monoxide and visibility are taken into consideration to demonstrate the feasibility of downward evacuation. Also, different locations, different heat release rate of fires in the station hall are calculated and analysed. Results show that the downward evacuation to the platform is feasible during a fire in the station hall under the condition that the smoke exhausting system in the station hall can work properly and has enough power.

Keywords: metro station, evacuation, fire, smoke, numerical simulation

1. Introduction

Most metro stations are located in relatively confined underground spaces, fires in buildings like this can usually result in serious injuries and property damages. For example, fire in the King's Cross metro station in London in 1987 and Daegu metro station fire in 2004 both caused over 100 deaths and injuries (K. Moodie, 1992; Hong, 2004). Why so many deaths and injuries can be caused by fires in metro stations? There are several most important reasons. First, the metro system is very important for public transportation in the cities, the transportation capacity can be very large, and some metro stations can be very crowded (Shi et al, 2012. He et al, 2016). Second, most metro stations are located underground with limited accesses to the outside, these accesses can become "chimneys" when the fire burns out, whether evacuation or rescue is not easy in such conditions. At last, the smoke and poisonous gas produced by a fire can make it very difficult to find escape routes for passengers (Karf et al, 2016). Nowadays, the metro system is an important means of transportation in many cities, a large number of passengers will take a metro to work or for leisure in cities with metro system (Zhong et al, 2008). However, fires can burst out in a metro station by arson, terrorist attack, and flammable items, and many metro station fires have been reported, so fire in the metro station is a kind of disaster that should be concerned for the safety of the public.

Researchers have done some research about the metro station evacuation under the condition of fire. However, more attention was paid to the conditions of fires happen in the platform, tunnel or train instead of fires in the station hall. People generally hold the idea that if people can evacuate to the station hall, then they will be safe for the station hall is usually close to the outside. But actually, in order to avoid the interaction between lines or reduce the impact on ground traffic and buildings, more and more new metro lines and stations are designed to be deeply buried(Gao et al, 2006; Zhong et al, 2008). For station deep buried under the ground, the station hall is not always a safe place when a fire happens. Besides, many passengers enter and exit the station hall with their luggage, also there are many types of electrical equipment in the station hall, so there are a lot of hidden dangers of fire in a station hall. When fire burst out in the station hall, the evacuation route of passengers and working staff are in coincidence with the direction of smoke spreading, also there is a conflict between the directions of evacuation and rescue. Can downward evacuation to the platform be possible when a fire happens in the station hall? This is a question worthy of research.

In this paper, some criteria are made according to related specifications, norms, and literature at first. Then the numerical simulation method was adopted to create a metro station model, the feasibility of downward evacuation in the condition of fire happens station hall is simulated. Fire cases with different locations, heat release rates were also simulated. Whether the height of smoke, the temperature, the concentration of poisonous gas and the visibility in each case can meet the requirement of safe evacuation criteria were analyzed. The results show that: when fire appears in the station hall, the smoke exhausting system in the station hall should be opened while the smoke exhausting system in the platform layer should be closed. The opening of the platform screen door (PSD) affect the smoke spread limitedly, so the PSD can be opened during a station hall fire, so passengers can be evacuated by metro trains. The smoke height, temperature, CO concentration and visibility during a fire with HRR of 10MW in the station hall can satisfy the requirements of the safety evacuation criteria, so it can be considered that downward evacuation during a station hall fire is feasible under certain conditions.

2. Safe evacuation criteria

When a fire happens in the station hall, all the people in the station hall should be evacuated in a short time before the smoke or temperature can hurt them, and the shorter the time is, the safer passengers will be. So the safe evacuation time should be determined at first. Cites in China mainly adopts *Code for Design of Metro (GB 50157-2013)* for the design and construction of metro stations. According to this code, all passengers and staff should be evacuated to the safe place in 6 minutes after fire begins, so 6 minutes is selected to be the safe evacuation time in this paper.

If people want to evacuate from the fire site safely, some environmental conditions are required. Data shows that the products of fire include smoke, temperature, poisonous gases, and visibility are the most important factors that influence the evacuation rate of people (Zarboutis *et al*, 2004; Kuligowski, 2016). So the factors listed above are chosen to formulate the evacuation criteria in this paper.

2.1. Smoke Height

The height of smoke is considered to be an important factor that affects the evacuation. People can evacuate safely only when the height of smoke keep above a certain height. According to Shi et al (2008), the safety height of smoke can be calculated by Equation (1).

$$H_s=1.6+0.1H \qquad (1)$$

In this equation,

H_s means the safety height of smoke (m).

H means the interior space height of building in the fire site (m).

If the actual height of the smoke layer in the fire is higher than H_s, then the passengers in the building are considered to be safe (Zhong et al, 2003). The number 1.6 in Equation (1) is the average height of evacuating passengers. In the numerical model, the height of the station hall is 4.2m, so the safety height of smoke in this station hall is 2.02 m.

2.2. Temperature

According to the *Standard for Fixed Guideway Transit and Passenger Rail Systems* (*NFPA*), the highest temperature on the evacuation route should be lower than 60℃, and the average temperature of the station should be lower than 49℃.

2.3. Concentration of CO

Not only high temperature and smoke will be produced by the combustion of flammable materials in the station, but poisonous gases are also another important harmful product. Common poisonous gases produced by fire include carbon monoxide (CO), sulfur dioxide (SO_2), hydrogen sulfide (H_2S) and other kinds of gases. Among them, CO is most dangerous to the human body. In 2000, based on the experimental results, Mike concluded the effects of different CO concentrations on the human evacuation speed as listed in Table1 (Milke. J. A, 2000).

Table 1. Effect of carbon monoxide concentration on personnel evacuation speed

Concentration of CO (%)	Exposure time(Minute)	Cumulative dose	movement speed reduction value(m/s)
>0.1	1	>0.1	0.05
	2	>0.2	0.1
	n	>0.1n	0.05n
>0.15	1	>0.15	0.1
	2	>0.3	0.2
	n	>0.15n	0.1n
>0.2	1	>0.2	0.15
	2	>0.4	0.3
	n	>0.2n	0.15n
>0.25	People fainting or death, moving speed becomes 0 m/s		

According to the data listed in Table 1, the effect of fire smoke toxicity on evacuation can be neglected when the CO concentration of the fire smoke is less than 0.1%. When the concentration of CO is higher than 0.25% (2500 ppm), it will affect the movement of personnel seriously, resulting in fainting or death.

On the other hand, according to the *Standard for Fixed Guideway Transit and Passenger Rail Systems (NFPA)*, the concentration of CO in the space of fire site should be less than 1500 ppm in 6 minutes. So 1500 ppm is selected as the limit value of CO for the safe evacuation in this paper, and 1500 ppm is equal with $1.875e^{-3}$ kg/m^3.

2.4. Visibility

In order to ensure the right evacuation route can be found under emergency, evacuation guide signs are usually installed in the metro station. In the condition of fire, the visibility of evacuation guide signs will be reduced by the smoke produced by the fire. When the light extinction coefficient is larger than 1.2 m^{-1}, the evacuation speed will slow down to 0.3 m/s due to low visibility according to the research of Jin T (1985). et al. So Visibility is also an important factor that affects the passengers' evacuation. According to the *Chinese Code for Design of Metro (GB 50157-2013)*, visibility of 10 meters should be guaranteed under the condition of fire. So in this paper, 10 m is chosen to be the allowable value of visibility of fire in the station hall.

To sum up, if the requirements listed below can be satisfied, the downward evacuation during a fire in the station hall can be considered to be operational:

1. The height of the smoke should be higher than 2.02 m in 6 minutes after the fire begins.
2. After 6 minutes of fire begin, the highest temperature on the evacuation route to the platform should be lower than 60℃.
3. The concentration of CO should be less than $1.875e^{-3}$ kg/m^3 in 6 minutes after the fire begins.
4. The visibility in the station hall should be no less than 10 m in 6 minutes after the fire begins.

3. Numerical modeling

The numerical method was selected to carry out research work in this paper for it is not easy to carry out field experiments in a real metro station. The Fire Dynamics Simulator (FDS) Pyrosim was used for the numerical calculations (McGrattan et al, 2015).

3.1. Parameters of the model

3.1.1 Fire resource

Fire resources with different heat release rates (HRR) will cause different amounts of smoke and different sizes of fire, so it is very important to choose the appropriate HRR for the fire source used in the numerical model. In general, flame retardant materials are used in the decoration of metro stations. Besides, fire may also be caused by luggage or explosives, so the fire caused by luggage and fire caused by the explosion also need to be considered.

According to the statistics of Hansell. G. O et al (1994), the heat release rate of fire in crowded places can be 2.0~2.5 MW. While the heat release rate of fire caused by the explosion is much bigger than fire caused by luggage. So fires with HRR of 2.5 MW、5 MW and 10 MW are set in the numerical models.

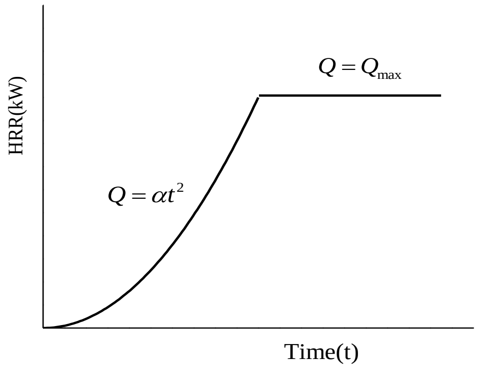


Figure 1. The growth of HRR in t^2 fire model

The non-steady fire HRR growth model, t^2 model was adopted in this paper. In the t^2 model, during a period after the fire begins, the HRR grows along with time and can be calculated by equation (2) (Gunnar et al, 1989). After a certain time, the HRR will enter a steady state as shown in Figure 1.

$$Q = \alpha t^2 \tag{2}$$

Q, heat release rate (HRR), *kW*.
α, fire power growth factor, kW/s^2.
t, burning time, *s*.

The growth rate of HRR can be determined by the parameter *α*, as listed in Table 2. The fire used in the models is set to be with very fast speed growth, the parameter *α* is 0.1878. As mentioned before, the HRR of fires used in the models are 2.5 MW、5 MW and 10 MW, so the fires used in the model will grow to a stable stage in 115 s, 163 s, and 230 s respectively according to Equation (2).

Table 2. Fire growth with different power growth factor

Fire growth	slow	middle	fast	very fast
Growth factor	0.002931	0.01127	0.04689	0.1878

3.1.2 Fire time

According to the *Chinese Code for Design of Metro (GB 50157-2013)*, all the people in the fire site should be evacuated to a safe area in 6 minutes. In this paper, if the smoke height, highest temperature, concentration of CO and visibility in the station hall in 6 minutes after fire begins can satisfy the criteria made above, then it can be assumed that people in the station hall can be safely evacuated. So the calculating fire time of the models was set to be 360 seconds, and the data of smoke height, highest temperature, and concentration of CO and visibility in the station at the last moment of the calculation will be extracted and analyzed.

3.1.3 Fire exhausting system

The smoke exhausting system of platform and station hall are both considered in the numerical models. 24 smoke vents are respectively set at the ceilings of the platform and the station hall. They are opened or closed in different cases. The total capacities of the smoke exhausting system of platform and station hall are both 120 m^3/s, which means that the exhausting capacity of each vent is 5 m^3/s. The location of the smoke vents is shown in

Figure 2. The layout of smoke vents in the ceiling of the platform is the same as that at the ceiling of the station hall.

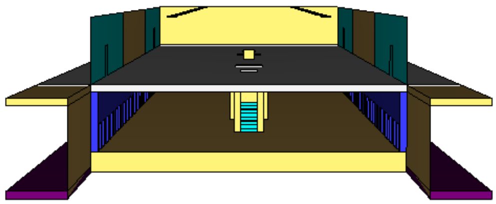
3.1.3 Environment settings

The platform is regarded as a shelter of passengers and working staff in this paper. For most metro stations are relatively confined spaces which located underground, so it’s set to be no air flow in the station. And the original temperature in the station is set to be 20℃. The maximum visibility in the station hall is 30 m at the beginning.

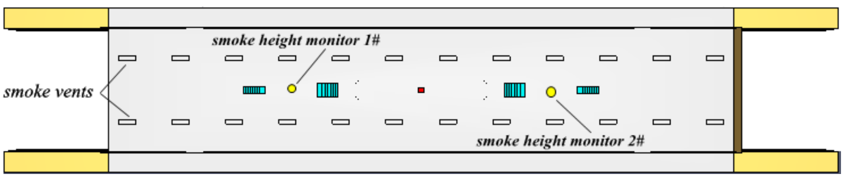
3.1.4 Establishment of 3-D model

The structure of a typical metro station was selected to establish the numerical models. The station is divided into two layers, platform layer, and station hall layer. The two layers were connected by two staircases and two escalators. When the fire happens, the escalator will be shut down and be used as an evacuation route together with the staircases.

The platform is an island platform with two 3.3-meters-wide tunnels on each side. The length, width, and height of the platform are 120 m, 23.4m, and 5.7m respectively. The staircase exits on the floor of the station hall are 4 meters long and 1.5 meters wide, and the exits of the escalators are 4 meters long and 2.5 meters wide. Besides, the platform screen doors (PSD) are also established in the models, they can be opened or closed. The finished numerical model is shown in Figure 2.



(a) Side view



(b) Top view

Figure 2. Finished numerical model of metro station

In order to ensure the calculation accuracy, a finer meshing was used in the numerical models. Table 3 shows the mesh size used in the model.

Table 3. Model mesh size of the metro station models

Mesh boundary length (m)	Division method	Cell numbers	Cell size
x: 160 y: 31.5 z:11.5	Uniform	489600	0.4(x)×0.4 (y)×0.5(z)

3.1.5 Monitoring devices

In order to extract the calculating results from the models, monitoring devices need to be installed in the numerical model. First, two smoke layer height monitors were installed at the middle points of staircases and escalators as shown in Figure 2. Then a slice was set at the height of 2.02 above the floor of the station hall, so the temperature, the concentration of CO and the visibility at this height of the station hall can be obtained.

3.2. Case setting

In order to analyze the feasibility of downward evacuation in different conditions of fires happen in the station hall, 7 cases were set. The serial number of these cases are Case 1, Case 2… Case 7. The information of these cases is listed in Table 4. In these cases, if the exhausting system is set to be open, it will start to work in 30 seconds after the fire begins.

Table 4. Seven cases of numerical models

No.	Fire location	HRR (MW)	Smoke exhausting system of platform	Smoke exhausting system of station hall	PSD
Case 1	position 1	2.5	open	open	close
Case 2	position 1	2.5	shut down	open	close
Case 3	position 1	2.5	shut down	open	open
Case 4	position 1	5	shut down	open	open
Case 5	position 2	5	shut down	open	open
Case 6	position 1	10	shut down	open	open

Fires may begin in different locations of the station hall in the actual situation. Two locations of fire first begin are considered in this paper, that is position 1 in the center and position 2 in the corner of the station hall. The two locations are shown in Figure 3.

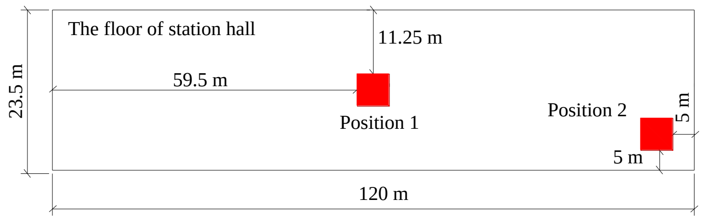


Figure 3. The two position of fire source in different cases (not to scale)

4. Results and discussions

4.1. Effect of platform smoking exhausting system

The smoke height at different times in Case 1 and Case 2 are shown in Figure 4 and Figure 5 respectively. The only difference between Case 1 and Case 2 is the smoke exhausting system in the platform layer of Case 1 is open, while the smoke exhausting system in the platform layer of Case 2 is closed. The lowest smoke heights are 2.3 m and 2.8m in Case 1 and Case 2 respectively. The smoke distribution in the station hall in Case 1 and Case 2 at 360 s after the fire begins are shown in Figure 6 and Figure 7.

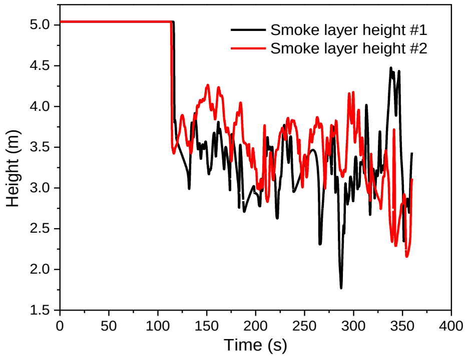


Figure 4. Smoke height change in Case 1

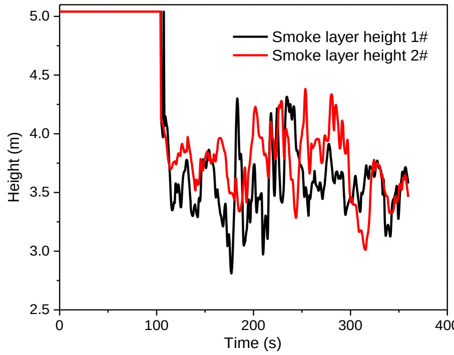


Figure 5. Smoke height change in Case 2

As can be seen from Figure 6 and Figure 7, when the smoke exhausting system in the platform layer is open in Case 1, the smoke in the station hall is thicker at 360 s after the fire began. This is because if the smoke exhausting system in the platform layer is open, then a downward current will appear so the smoke in the station hall will spread into the platform layer more easily. This is not good for the people who want to evacuate to the platform. So when a fire happens in the station hall, the smoke exhausting system on the ceiling of the platform layer should be shut down.

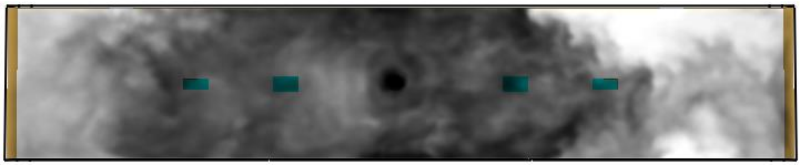


Figure 6. Smoke distribution in the station hall in Case 1 at 360 s

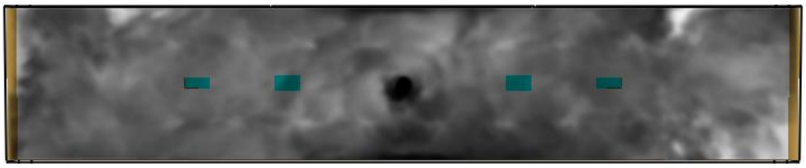


Figure 7. Smoke distribution in the station hall in Case 2 at 360s

4.2. Effect of PSD

Figure 8 shows the smoke height change along time in Case 3 and Figure 9 shows the smoke distribution in the station hall in Case 3. In Case 3, the PSD keeps open during the whole progress, and this is the only difference between Case 2 and Case 3. By comparing Figure 8 with Figure 5, Figure 9 with Figure 7, it can be found that the opening of PSD has little effect on the spread of smoke in the station hall. All through the smoke height decreased compared with that in Case 2, the lowest smoke height monitored in Case3 is 3.16 m, still higher than the safety height of 2.02. According to the analysis above, during a fire in the station hall, the PSD on the platform can be opened. So passengers can evacuate to the platform and then they can take a metro train to escape from the fire station.

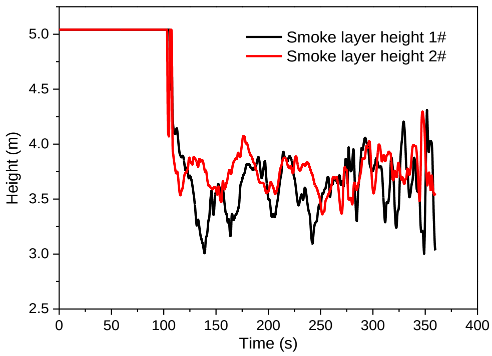


Figure 8. Smoke height change in Case 3

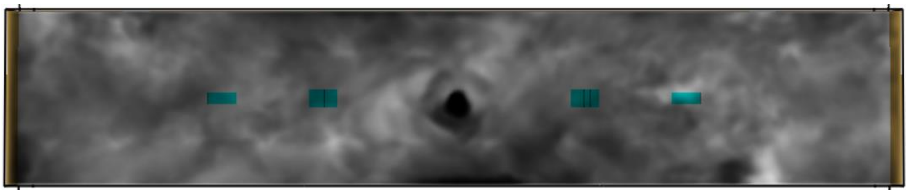


Figure 9. Smoke distribution in the station hall in Case 3

4.3. Effect of fire location

The only difference between Case 4 and Case 5 is the location of the fires. The fire source is located in the center of the station hall in Case 4, while the fire location of Case 5 is in the corner. The smoke height change trends in these two cases are shown in Figure 10 and Figure 11. In Case 4, when the fire first begins at the center of the station hall, the height of smoke at 1# and 2# decreased at the same time, and the average height of them both varies between 3.0 m~3.75m majorly.

In Case 5, the device 2#, which is near the fire corner. And the height of smoke at this place decreased earlier than that at 1#. The average smoke height monitored at 1# varies between 2.75 m~3.5 m, while it is 3.25 m~3.75 m at 2#. This means when the location is further to the fire source, the smoke height will be lower.

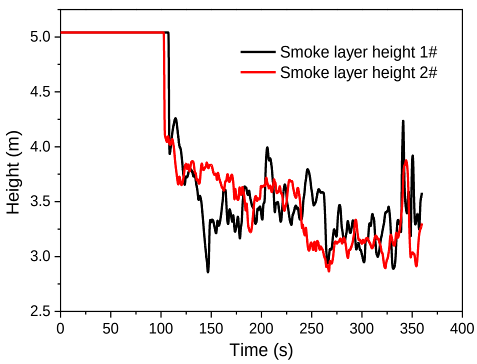


Figure 10. Smoke height change in Case 4

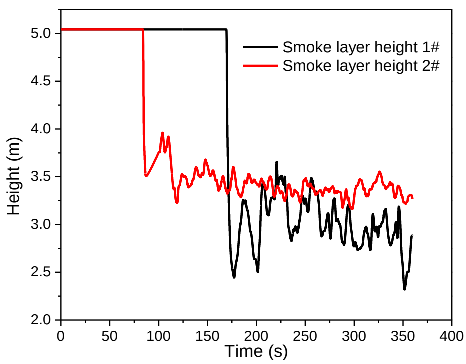


Figure 11. Smoke height change in Case 5

4.4. *Effect of HRR*

The HRR in Case 3, Case 4 and Case 6 are 2.5 MW, 5MW and 10 MW, respectively. And the other conditions in these three cases are all the same. By comparing the height change in these three cases, the effect of HRR can be analyzed.

Figure 12 shows the smoke height change in the station hall of Case 6. As can be seen from the figure, the smoke height varies between 3.0~3.75 m during the calculating period, the lowest height of the smoke is 2.9 m, which is higher than the safety height of 2.02 m. The smoke height in Case 3 varies between 3.25 m~4.25 m, and the average height in Case 4 varies between 3.0~4.0 m. So the higher the HRR of fire source, the lower the smoke height in the station hall. Fortunately, the heights in all these three cases are higher than the safety height.

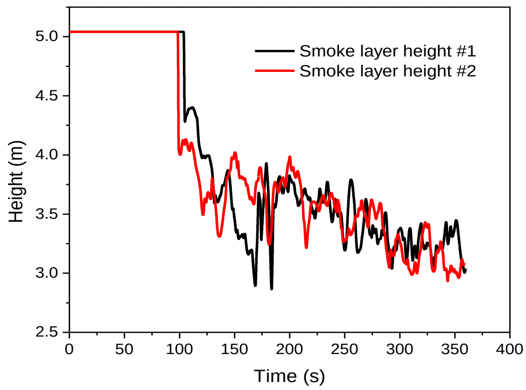


Figure 12. Smoke height change in Case 6

4.5. *Safe evacuation judgment*

The HRR in Case 6 is the biggest in all the cases, so Case 6 can be considered to be the most dangerous condition in all the cases. The calculating results of Case 6 are chosen to see if the downward evacuation during a station hall fire can meet the safety evacuation criteria or not.

The distribution of temperature at the height of 2.02 m above the floor of the station hall is shown in Figure 13. It can be seen that the highest temperature detected in the station hall is 30℃, which is 10℃ above the original temperature. The corners of the station hall and the area above the fire source have higher temperature compared with other places. In general, after 6 minutes of the fire begins, the temperature in the station hall is lower than the 40℃, which is sufficient for the safe evacuation.

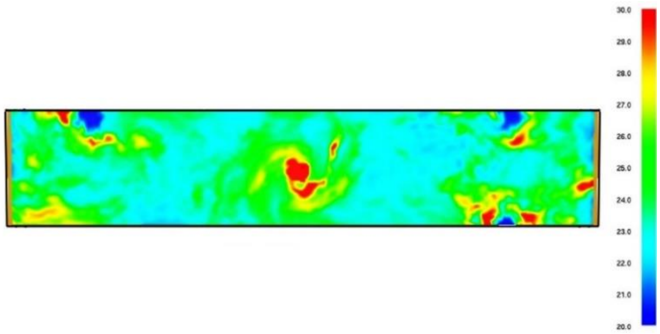


Figure 13. Temperature (℃) 2.02 meters above the floor of station hall in Case 6(360 s)

The concentration of CO of the slice 2.02 meters above the floor of the station hall is shown in Figure 14. According to the criteria, 1.875e^{-3} kg/m^{3} is the highest concentration of CO allowed for safe evacuation. As shown in Figure 15, more CO gathering at the corners of the station hall, and the highest concentration of CO is 3.5e^{-5} kg/m^{3} 360 s after fire begins, which if far less than the limited value of CO concentration.

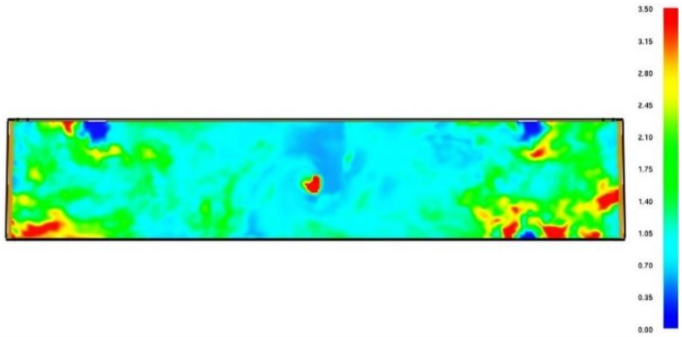


Figure 14. The concentration of CO (e^{-5}kg/m^{3}) 2.02 meters above the floor of station hall in Case 6(360 s)

According to the criteria made above, the visibility in the station hall should be no less than 10 m in 6 minutes after the fire begins. The visibility of slice 2.02 m above the floor of station hall in Case 6 is selected to see if the criteria can be satisfied or not. It can be seen for Figure 15 that the minimum visibility after 6 minutes of fire begins is 3.5 m, which is less than the required 10 m. However, the area with less visibility is mostly the corners of the station hall, while the staircases down to the platform are at the center, so the area with lower visibility has little impact on the evacuation downward to evacuation.

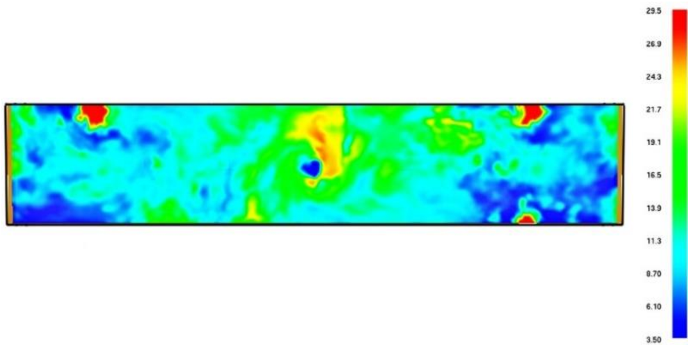


Figure 15. The visibility (m) of slice 2.02 meters above the floor of station hall in Case 6(360 s)

5. Conclusions

This paper investigated the feasibility of downward evacuation when the fire happens in the station hall numerical models established by FDS software. In order to make a judgment to the feasibility of downward evacuation to the platform when the fire happens in the station hall, criteria were formulated by summarizing the former researcher's work at first. The height of smoke, the temperature, the concentration of CO and visibility in the station hall were taken into account in the criteria.

Based on the criteria formulated, the authors assumed that if the smoke height, the temperature, the concentration of CO, and the visibility in the station hall can satisfy these criteria in 6 minutes after the fire begins, the passenger and staff can evacuate to the platform safely. Based on the numerical results, the following conclusions can be obtained:

1. During a fire in the station hall of a metro station, the smoke exhausting system in the platform layer should be closed if the platform is used as an evacuation shelter, for the opening of the exhausting system in the platform layer will make more smoke spread into the platform layer.

2. The opening of PSD has little effect on the spread of smoke during a fire in the station hall, so PSD can be open in order to transfer the passengers by metro trains.

3. Compare with the fire starts at the center of station hall, the fire starts at the corner of station hall can be more dangerous because the smoke height will be much lower, and this is unfavorable for the evacuation.

4. During a fire in the station hall, the platform can be used as a shelter under certain conditions. This means the downward evacuation to the platform is feasible during a fire with HRR less than 10MW happens in station hall under the condition that the smoke exhausting system in the station hall can work properly and has enough power.

6. Future works

Different types of fires in the station hall of a typical metro station is considered in this paper, and the feasibility of downward evacuation under the condition of fire in the station hall is judged by the numerical model. Questions listed below will be considered in the work of the next stage:

1. Only a metro station with a simple structure is modeled in this paper. A metro station with complex structure will be considered in the future.

2. 6 minutes is considered as the safe evacuation time for the people in the station hall according to the criterion in this paper, the safe evacuation time will be modified if field test can be carried out in the future.

Acknowledgements

The authors would like to thank the Ministry of Science and Technology (P. R. China) for supporting the funding for the “Research on Safety Risk Assessment and Emergency Support Technology for Urban Area” Project (National Key R&D Program of China. No. 2016YFC0802500), and also wish to thank all participating project partners. Heng Yu also would like to say thanks to the China Scholarship Council for its financial aid.

References

K. Moodie. The King’s Cross fire: damage assessment and overview of the technical investigation. Fire Safety Journal. 18(1992) 13-33.

Shi Congling, Zhong Maohua, Nong Xingzhong, Shi Jiehong, Feng Guoguan. Modeling and safety strategy of passenger evacuation in a metro station in China. Safety Science. 50(2012)1319-1332.

He, Lin, Q. Liang, and S. Fang, Challenges and innovative solutions in urban rail transit network operations and management: China’s Guangzhou Metro experience, Urban Rail Transit 2.1(2016):33-45.

Hong W-H. The progress and controlling situation of Daegu subway fire disaster. In: Sixth Asia-Oceania symposium on fire science and technology, Daegu, Korea, Mar. 17–20, 2004.

Karl Fridolf, Daniel Nilsson and Hakan Frantzich. Evacuation of a Metro Train in an Underground Rail Transportation System: Flow Rate Capacity of Train Exits, Tunnel Walking Speeds and Exit Choice. Fire Technology, 2016, 52(5):1481-1518.

Maohua Zhong, Congling Shi, Xuwei Tu et al. Study of the human evacuation simulation of metro fire safety analysis in China. Journal of Loss Prevention in the Process Industries 21(2008)287-298

Gao J X, Shi C L, Zhong M H. Smoke control design of deep buried metro station. Journal of Safety Science & Technology, 6(2006)39-44.(In Chinese)

Maohua, Zhong., et al. "Reliability analysis on platform fire smoke control in deep buried island metro station." The 2008 International Symposium on Safety Science and Technology.2008.

GB 50157-2003, Code for Design of Metro, National Standard of China

Nikos Zarboutis, Nicolas Marmaras. Searching efficient plans for emergency rescue through simulation: the case of a metro fire. Cognition, Technology & Work (2004) 6:117-126.

Kuligowski, Erica D. Human Behavior in Fire. SFPE Handbook of Fire Protection Engineering. Springer New York, 2016, pp.2070-2114

Shi Congling, et al. Train Fire Smoke Control in Deep Buried Island Metro Station. The 2008 international symposium on safety science and technology.

Zhong Maohua, Fan Weicheng, and Liu Tiemin. Safety Evaluation of Engineering and Construction Projects in China. Journal of Loss Prevention in the Process Industries, 16 (2003) 201–207.

NFPA. “Standard for fixed guideway transit and passenger rail systems”. NFPA-130. 2014

Milke. J. A .Evaluating the early development of smoke hazard from fires in large spaces. ASHRAE Trans, 2000. 106(1):627–636

Jin T, Yamada T. Irritating Effects of Fire Smoke on Visibility [J]. Fire Science & Technology, 1985, 5(1):2159-64

McGrattan, Kevin, et al.2015. Fire Dynamic Simulator User’s Guide, Sixth Edition. National Institute of Standard and Technology, Gaithersburg, Maryland, USA. NIST Special Publication 1019

Hansell G O, Morgan H P. Design approaches for smoke control in atrium buildings. Buildings Research Establishing Report (BR- 258), UK.1994.

Gunnar Heskestad. Michael A. Delichatsios. The initial convective flow in fire. Fire Safety Journal. Volume 15, Issue 6, 1989, 471-475.