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Study on law of personnel evacuation in deep buried metro station based on the characteristics of fire smoke spreading

Yu Cai[a,*], Zhen-yao Lin[a], Jun Mao[b], Guang Bai[b], Jia-wei Hu[b]

[a]*School of Science,Beijing Jiaotong University, Beijing 100044, China*
[b]*School of Civil Engineering,Beijing Jiaotong University, Beijing 100044, China*

Abstract

With the improvement of people's life and the rapid development of urban traffic, the subway has the advantages of convenience and celerity, to a large extent, which greatly eases the traffic congestion phenomenon. With the attendant, the safety of the subway environment becomes vital. Many engineers focus on the study of the fire prevention and safety to escape. In this paper, a comprehensive study on the fire smoke spreading and the evacuation of the people in the deep buried metro model is carried out. First, the deep buried metro model is modeled on the STEPS software, and the personnel evacuation rule is obtained. According to the evacuation situation, the corresponding fire smoke monitoring points are built in the fire scenario which is set up on FDS+Evac software. Then, FDS+Evac program is used to simulate the evacuation in a fire scenario. It has not only analyzed the real time effect that the characteristics of fire smoke spread have on the personnel evacuation, but also improved the accuracy of the subway fire safety evaluation.

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Keywords: deep buried metro station, fire smoke spreading, personnel evacuation, STEPS, FDS+Evac

Nomenclature

HRR	the heat release rate
Q	quantity of heat
i	variable

1. Introduction

With the increase of the population of the city, the traffic jam is becoming more and more serious. The underground transportation system is the first choice for most people to travel. Because of the huge traffic, the subway will cause serious damage if it is dangerous. Among the many factors that threaten the safety of subway, the fire is the most influential factor. In case of subway fire, large quantities of smoke are likely to spread rapidly to entire subway station due to stack effect and space confinement. It has been found that passenger’s evacuation path usually coincides with smoke spread path. Smoke would reduce occupants’ visibility and cause fatalities by suffocation. Many catastrophic fires in subway stations caused heavy casualties.

The deep buried metro, a special internal building structure, when the danger occurs, the timely and effective personnel evacuation guidance becomes particularly important, can avoid the loss of life and property. The personnel evacuation is a complex subject which refers to structure of the building, fire development and human behavior in the building. With the rapid progress of computer technology, a large number of evacuation models have been developed and researches in this field begin to enter a new stage. In present, several researches have been carried out to study the personnel evacuation in fire

* Corresponding author. Tel.: +86-18813093053
E-mail address: caiyu2014@126.com

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scenario. However, the real time effect of smoke spread on personnel evacuation in the deep buried metro has rarely been conducted. This paper will set up the personnel evacuation of deep buried metro by STEPS to summary the rule. Then a comprehensive model which contains smoke spread and personnel evacuation is set up by FDS+Evac.

The research group is undertaking a project of Beijing Municipal Science and Technology Commission: Deep subway station fire research design, simulation and application. This paper will be based on the deep buried metro's SketchUp model to study. Finally, fire simulation and evacuation simulation are performed simultaneously to evaluate life safety in the deep buried metro station by FDS+Evac software.

2. Emergency evacuation model by STEPS

2.1. Introduction to STEPS

STEPS (Simulation of Transient Evacuation and Pedestrian Movements) is a three-dimensional evacuation software, can simulate the office area, shopping centers, sports and subway stations, etc., these places are: simple transportation in the normal circumstances, rapid evacuation in emergency. By creating a real-time three-dimensional simulation graphical form that is easy to understand, it can help to identify the preferred export and natural bottlenecks, but also can predict the evacuation time and route according to different working conditions.

STEPS simulation software model is based on the fine grid system. Software is to divide the building into a myriad of small grid system, and then the wall and other obstacles to the passage of obstacles, different types of personnel can be placed in advance to the designated area [1].

2.2. Overview of evacuation simulation model

Because the SketchUp model of the deep buried metro is difficult to be used in STEPS, in order to facilitate the simulation, the station model should be simplified according to certain rules [2]. The model of the deep buried metro station is established by STEPS, in which some accessory structures are ignored, such as the station house, the track zone, the platform screen door and the ticket office on the lobby floor. The impact of the pillars on the platform, the automatic ticket barriers and metal fences on the lobby floor are considered in the model.

The deep buried metro station has three storeys below the ground level, 158.75m long×130.5m width×44.5m high as shown in Fig 1. There are three choices for passengers from platform to the station hall.

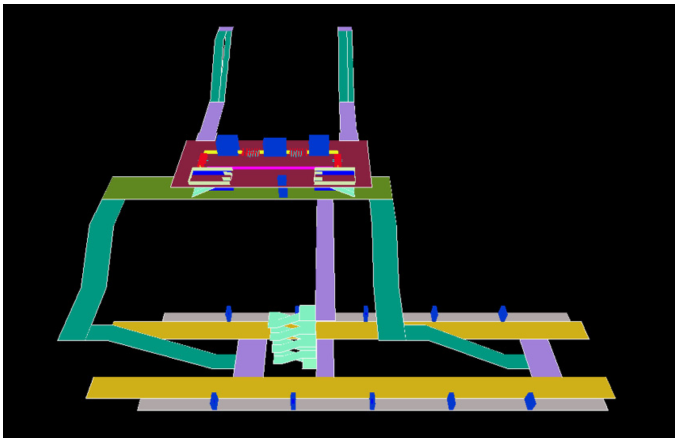


Fig. 1. The geometry of the deep buried metro station.

2.3. The characteristic parameters for simulation

1. Occupant features. According to the default setting in STEPS and the actual situation, people group is located in the subway by the male and female ratio 1:1. And the characteristic parameters of occupants set in STEPS is shown in Table 1.

Table 1. The characteristic parameters of occupants

Occupant Type	Shoulder Width/m	Body Thickness/m	Height/m
Adult males	0.5	0.26	1.75
Adult females	0.44	0.27	1.65

The walking characteristics of the crowd have been studied by researchers from both domestic and abroad and some standard population parameters have been formed. The brisk walking speed of the crowd is about 0.80-1.5m/s, and the normal walking speed is 0.72 to 1.35m/s [3]. Specific parameters are shown in Table 2.

Table 2. The walking speed of occupants of different types at different places [4]

Occupant Type	Transfer passage/m/s	Stairs up /m/s	Stairs down /m/s	Platform/m/s	Lobby /floor/m/s
Adult males	1.39	0.75	0.95	1.56	1.58
Adult females	1.22	0.66	0.83	1.41	1.43

The evacuation capability of the stairs and exits is determined based on the NFPA130. The capacity of the escalator is 2.67p/s/m under normal circumstances and 2.4p/s/m in case of fire according to the Code for Design of Subway. In emergency, all escalators are out of service and used as a pedestrian staircase in order to be conservative.

2. The occupant load. In the model, the most unfavourable situation is considered first, which the subway cars are in full load. Combined with the smoke spread model in FDS, the situation that there is only one stopped train is set. The number of passengers on a train in full load: 1398/person. The number of waiting passengers and staff on the platform: 500/person. The number of passengers and staff on the lobby floor, stairs and passages: 1440/person. The total number of persons in the subway station is 3898/person.

2.4. Analysis of calculation results

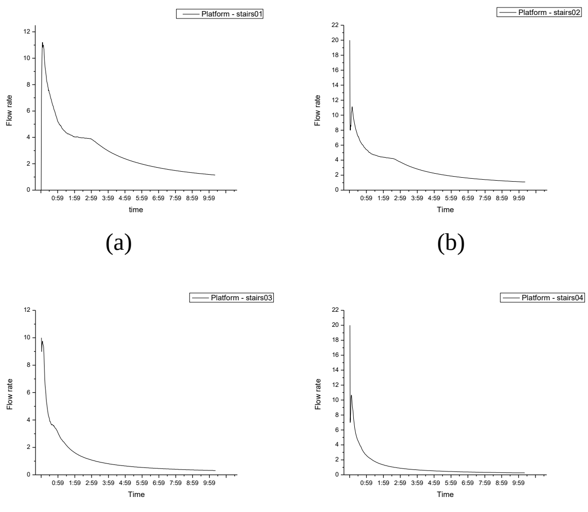
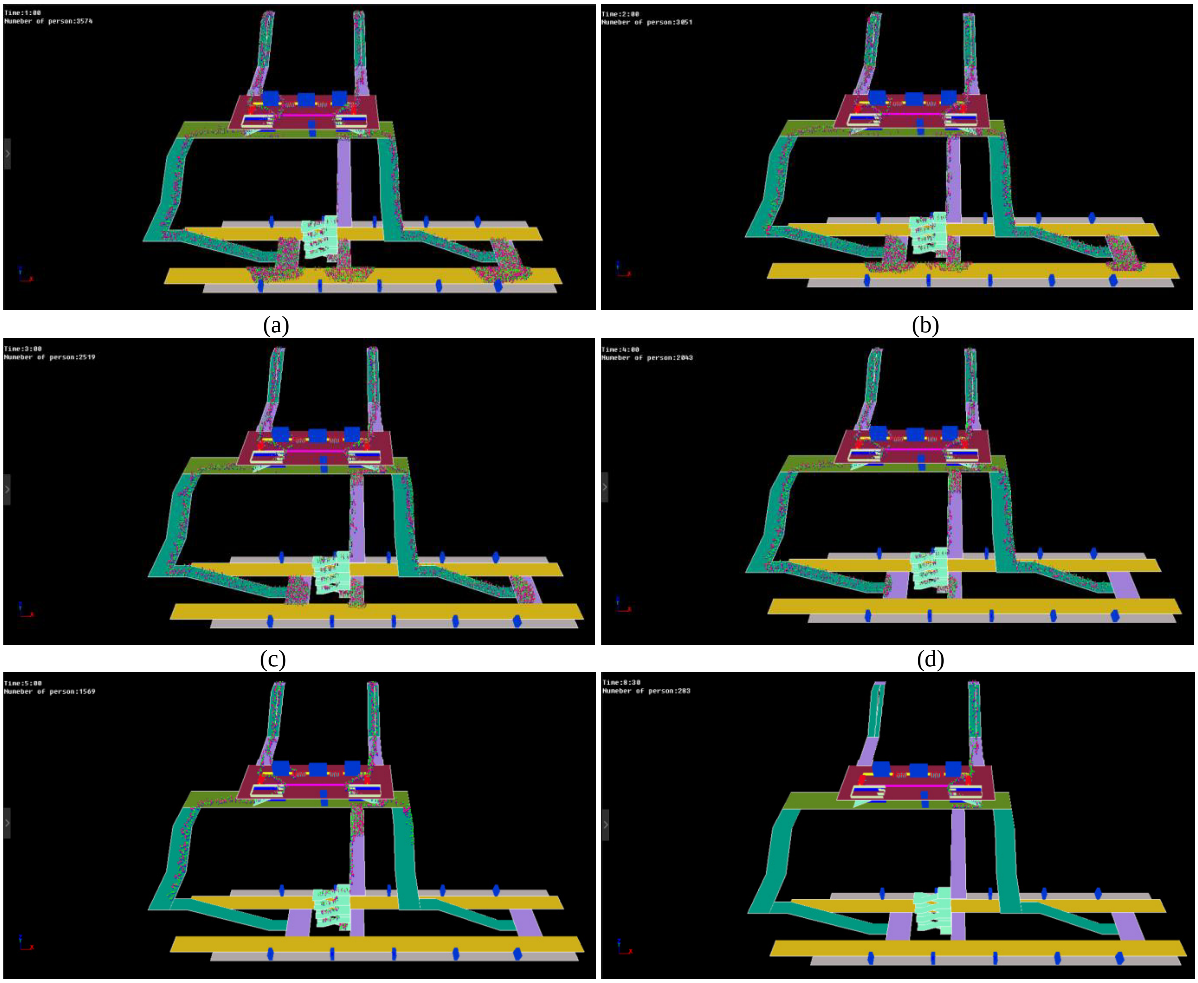


Fig. 2. The four stairs exits' flow rate line charts

Under emergency evacuation, Passengers on the train were all evacuated to the platform at 11s. However, only two stairs toward the lobby floor were available, then it is obvious to see the bottlenecks in the exits from the platform to stairs. In the meantime, the corresponding exits' flow velocity is down from the peak gradually. The four stairs exits' flow velocity line charts are shown in Fig 2. At the same time, some people escape from the middle exit. Although this eased the congestion of the sides, increased the evacuation distance of some occupants, extended the evacuation time on the whole. All occupants on the platform were evacuated completely at 209s and evacuated to the lobby floor at 510s. All occupants are evacuated out of the station at 621s.The egress process in emergency evacuation is shown in Fig 3.



(a) (b) (c) (d) (e) (f)

Fig.3. The Egress Process in Emergency Evacuation. At 60s, 120s, 180s, 240s, 300s, 510s

2.5. Conclusions

Simulation results of the personnel evacuation in the deep buried metro station are analyzed and evacuation strategies are evaluated. The main conclusions are as follows: (1). Evacuation could be completed within the specified time in general case of emergency; safe evacuation is difficult to achieve in special case of emergency. Occupants could not be evacuated completely in 360s. The stairs toward the lobby floor on both sides of the platform are the bottlenecks of evacuation. (2). The routes to escape can give effective guidance to the smoke spread model in FDS+Evac.

3. Evacuation model in fire scenario by FDS+Evac

3.1. Model geometry

The subway station chosen for this study is a typical subway whose platform and station hall is separation with four storeys below the ground level as show in Fig.2. There are two exists leading to the open ground in first basement floor, the cross sectional area of which is 4.5m wide ×3.5m high. The station hall is installed in the second and three basement floor, in other way, the station hall is two stories. The last one is the platform which is in the fourth floor. Link to the station hall and the platform are two escalators, stairs and a lift.

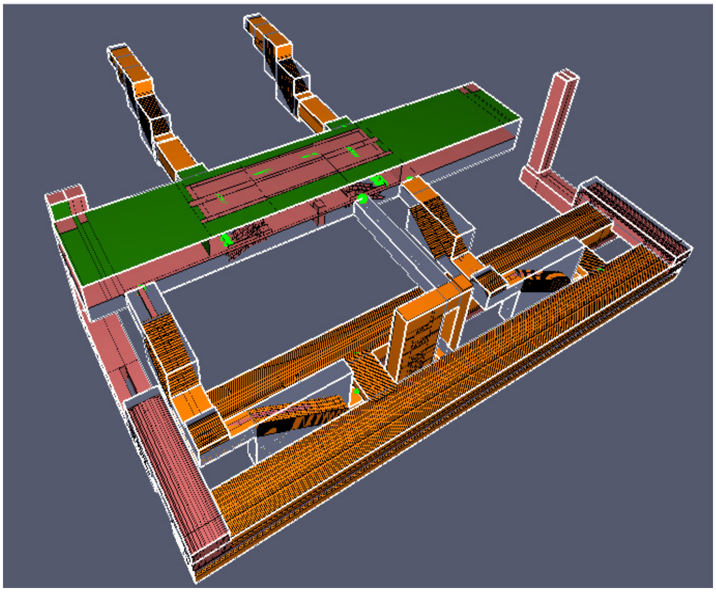


Fig.4.schematic diagram of the subway

3.2. Fire scenario

The heat release rate(HRR) for steady simulation is assumed to be 7.5 kW in this study.For dynamic simulation,HRR is varied with time.The transient HRR form source is modeled by an analytical t^2 -type curve developed by ,as follows:

$$Q(t) = \min\{Q_{\max}, \alpha t^2\} \tag{1}$$

Where t is time(s), $Q_{\max}$ is the maximum HRR (kW),and α is the constant of fire class [5].

The fuel used in this fire simulation is STEEL. The location of the fire is the third section of the subway train.

The setting of Smoke detector is based on the natural evacuation bottlenecks in the simulation results of STEPS show as those small green dots in the Fig.2.

3.3. EVAC model

EVAC is a kind of evacuation simulation software developed by Technical Research Center of Finland (VTT) based on the continuous space model. The first version Evac 1.0 runs separately, while the second version Evac 1.1 is integrated with FDS, name as FDS+Evac, in which simulation results can be presented animatedly with the FDS's own visualization software Smokeview.

The flow control equation of occupants in EVAC is as follow:

$$m_i \left({}^{d^2 x_i(t)}\!/_{dt^2} \right) = f_i(t) + \xi_i(t) \tag{2}$$

Where $x_i(t)$ is on behalf of the position of the agent i at time t, $f_i(t)$ is the force exerted on the agent by the agent in the surroundings, m_i is the mass, which said characteristics of personnel ,and $\xi_i(t)$ is a small random fluctuation force, the last one , $d^2 x_i(t)/dt^2$ is the speed of the agent I [6].

3.4. The fire evacuation simulation model of a individual room model

This model was built to explore the spread of smoke how to affect the evacuation of people. This room, 9.6m long× 8.2m wide×3.0m high. There is a door,1.0m wide×2.0m high for exist show as Fig.5. The heat release rate(HRR) for steady simulation is 100 kW in this study. And, the initial condition of Evacuation is 120 adults in the random position of the room

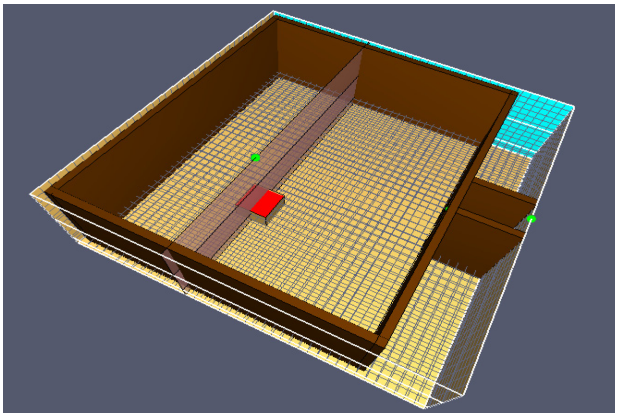


Fig.5.schematic diagram of the individual room

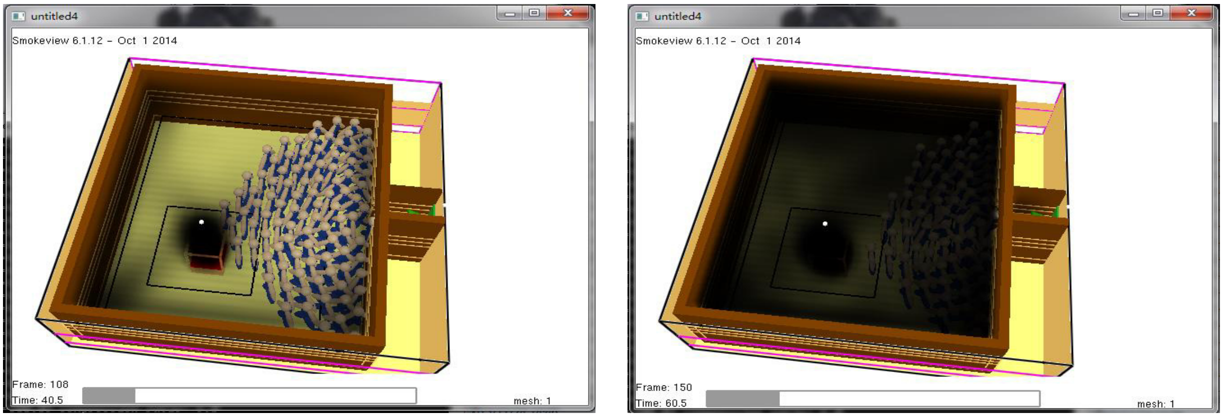


Fig.6.in the Smokeview visually display the contagion of smoke and evacuation at time 40.5s (on the left) and at time 60.5s (on the right)

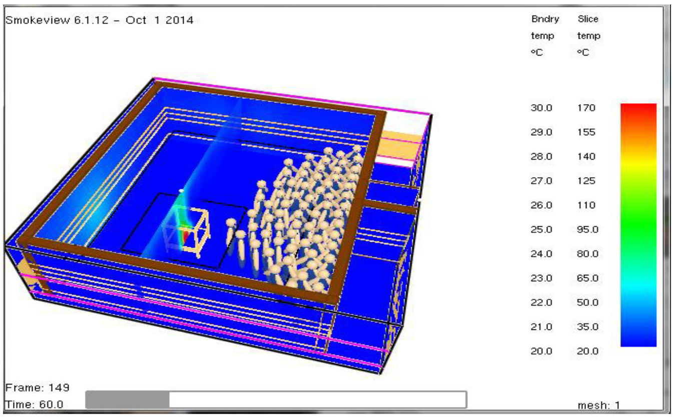


Fig. 7. in the Smokeview visually display the c temperature of walls and the temperature of the slices (x=3.5m) as well as evacuation at time 60.0s

Summary of the test results:

(1)The comprehensive model of the deep buried metro station in FDS is available, and the whole simulation process is visible.

(2)The concentration of smoke and temperature are time-varying,and the rule can be summary from the computing clouds.

4. Conclusions

Preliminary conclusions about the buried metro based on the existing research are as follows:

(1)At the initial moment,the speed of escaping reached quickly the peal,and there are the bottlenecks in the exits.

(2)Fire smoke would hinder the egress process,thus the movement speed of evacuation flow is slowed down.

(3)From the visual video, smoke is easier to spread in the direction of the flow of people evacuating, which makes the bottlenecks more dangerous.

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