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Study on Fire Evacuation of Long Section Tunnels in Guangzhou Metro

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Abstract. Guangzhou rail transit lines have intercity and subway trains in the same line, and some lines operate suburban EMUs. Obtain the best train fire evacuation rescue mode through theoretical analysis; Through numerical simulation, the available safe evacuation time and necessary safe evacuation time are obtained under different fire source positions and evacuation opening distances, and the evacuation safety of personnel is analyzed to provide decision-making basis for their safe evacuation facility setting plan. The results show that: in the case of fire, The subway evacuation mode should be adopted; When the fire occurs, the fire source position of the train should be stopped between the two evacuation openings as much as possible; The distance between the horizontal passages of the emergency rescue point is set to 20m to meet the safety evacuation requirements of train personnel.

Keywords. Subway, tunnel, fire, evacuation

1. Introduction

Guangzhou rail transit lines have intercity and subway co-line and public transportation operations. Some subway lines are similar to urban lines and operate through intercity railways. Therefore, the evacuation modes can be divided into intercity railways, suburban railways and subways. In order to ensure the safe evacuation of personnel, the distance between the evacuation openings is a key factor, and the distance between the horizontal passages of the emergency rescue points needs to be simulated and optimized.

Compared with single-line operation, the train operation organization of collinear operation is more complicated, the passenger flow of trains is uneven, the line operation organization affects each other, and the fault affects a large range [1]. Relevant specifications [2-4] do not specify the evacuation and rescue methods and parameter settings when intercity, city trains and subway trains are collinear, so it is necessary to study the evacuation of people in subway tunnel fires.

Existing researches [5-9] mainly focus on the evacuation of people during fire in ordinary railway tunnels. There are few studies on the safety of people evacuation in subway tunnels with intercity and subway co-line, bus-like operation, and some lines

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are similar to urban lines. In addition, the research on the behavioral parameters such as the evacuation speed and the evacuation route of the railway tunnel train under the condition of fire is also the focus of the evacuation research [10-11]. Therefore, we will study the disaster prevention and rescue technology for Guangzhou rail transit single-hole and single-track tunnels, form a relatively complete disaster prevention design method and control technology for long subway tunnels, and promote the popularization and application of similar projects.

Taking Guangzhou rail transit single-hole single-track tunnel as the research object, comparing the similarities and differences of evacuation systems between intercity railways, suburban railways and subways, the evacuation mode of personnel is clarified; FDS software and Pathfinder software are used to simulate the available safe evacuation time and necessary safety for personnel. The evacuation time, combined with the simulation results, analyzes the safety of passenger evacuation under different fire conditions and different evacuation paths, determines the optimal spacing of the transverse passages of the tunnel emergency rescue station, and provides a basis for the installation of subway tunnel safety facilities.

2. Discussion on the Mode of Personnel Evacuation

2.1. Similarities and Differences in Evacuation Modes

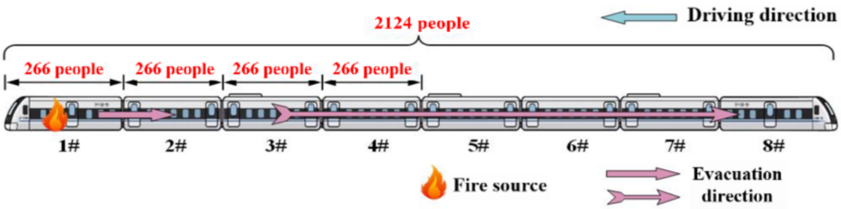
Differences: In case of fire, the intercity railway/suburban railway does not consider the train to stay in the tunnel for evacuation, while the subway considers the train to stop in the interval tunnel for evacuation; The same point: priority is given to driving through the tunnel or stopping at a nearby station for evacuation.

2.2. Feasibility Analysis of Evacuation Mode

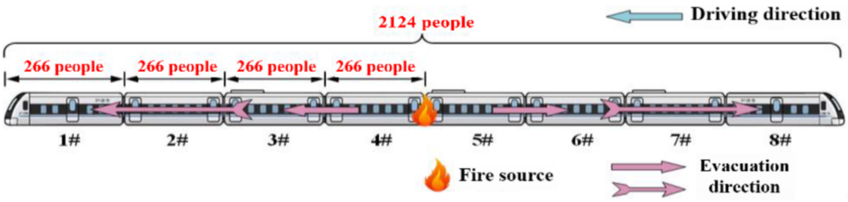
2.2.1. Intercity Railway/Suburban Railway Evacuation Mode

The intercity railway/suburban railway evacuation mode is adopted, and it is necessary to evacuate the passengers in the train car to adjacent cars within the time from the fire occurrence to the time when they drive to the station or outside the cave [2-4]. It adopts 8 marshalled suburban D-type EMUs, and the number of trains is 2124 people per train based on comprehensive vehicle regulations and railway traffic data.

When the fire is located in the head/tail car, take the fire in the head car as an example: the people in the car where the fire occurred are evacuated to the adjacent cars. Ideally, the passengers in the 2nd to 8th cars are evenly distributed. At this time, the density of people in each car is 7 people/m^2, and the evacuation of passengers in the carriage is shown in figure 1(a); When the fire is located in the middle car, take the fire in the fourth car as an example: the people in the fire are evacuated to the adjacent cars. In the ideal state, the passengers in the first to third cars are evenly distributed. At this time, the density of people in each car is 9 people/m^2, and the evacuation of passengers in the carriage is shown in figure 1(b).



(a) Head/tail fire of the train



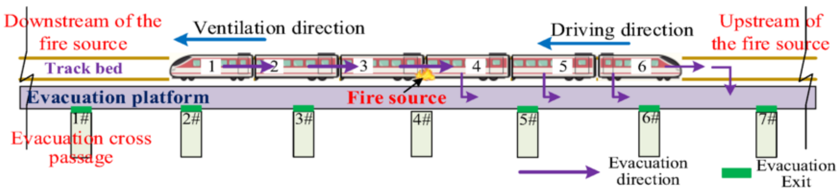
(b) Fire in the middle of the train

Figure 1. Schematic diagram of evacuation of people inside the carriage.

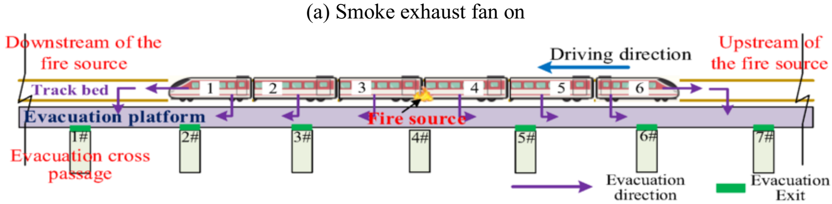
JU Yi [12] conducted an experiment to study the walking speed of people under different population densities. The results showed that when the personnel density reaches 7 people/m^2, the personnel are already in a state of almost immobility. In addition, "Fire Safety Engineering" [13] pointed out that the personnel density exceeds 3.8 people/m^2, and evacuation will not be possible. Therefore, the intercity railway/suburban railway evacuation mode cannot guarantee the safety of personnel, and the evacuation mode is not feasible.

2.2.2. Subway Evacuation Mode

If the subway evacuation mode is adopted, it may be considered to park the train in the section tunnel for evacuation. Using 6 marshalled Type A vehicles, the evacuation paths of personnel can be divided into the following two types according to whether ventilation and smoke exhausting are enabled in the tunnel section [14], as shown in figures 2(a) and 2(b).



(a) Smoke exhaust fan on



(b) Smoke exhaust fan off

Figure 2. Passenger evacuation routes.

When the smoke exhaust fan is turned on, the evacuation direction of passengers is opposite to the longitudinal ventilation direction of the tunnel, which can ensure the safety of personnel evacuation in principle; When the exhaust fan is turned off, the flue gas in the tunnel will spread naturally. Through the tunnel design and civil construction, the evacuation of passengers can be completed before any environmental control index reaches the critical condition, which can ensure the safety of evacuation. Therefore, the subway evacuation mode can ensure the safety of personnel, and the evacuation mode is feasible.

3. Guidelines for Safe Evacuation of People in Tunnel Train Fires

3.1. Available Safe Evacuation Time T_{ASET}

The time required for a fire to endanger the safety of passengers is T_{ASET}. When the temperature at a height of 2 meters at a certain position of the tunnel reaches one of the temperature greater than 60 °C, the visibility is less than 10 meters, and the CO concentration is greater than 500 ppm, it can be considered that the personnel are in a dangerous state [15], and T_{ASET} is obtained.

3.2. Required Safe Evacuation Time T_{RSET}

The time from the fire to the time when all passengers in the train enter the safe area is T_{RSET}. T_{RSET} = fire alarm time + personnel pre-action time + evacuation walking time, where the sum of fire alarm time and personnel pre-action time can be set to 120s [14]. The evacuation travel time is the time it takes for passengers to travel from the train to the safe area, which is calculated by Pathfinder simulation.

3.3. Evacuation Safety Standards

The condition for the parameters of tunnel safety facilities to meet the requirements is that after the train fires, all passengers reach the safe area before the harmful factors generated by the fire source endanger their lives, that is, $T_{\mathrm{ASET}}>T_{\mathrm{RSET}}$ [16].

4. Safety Analysis of Personnel Evacuation in Subway Train Fire

To simulate the flow and control of fire smoke in a 3.9km subway tunnel, and the width of the evacuation platform is 0.7m. The subway train adopts 6 group A-type cars, which are 140m long, 3m wide and 3.8m high. The train is located in the middle of the tunnel. At this time, the escape distance of passengers is the longest, the flow path of smoke is the farthest, and the control of smoke is the most unfavorable.

4.1. Numerical Simulation of Fire Smoke

The subway tunnel model is established by FDS software, and T_{ASET} is obtained by analysis.

4.1.1. Flue Gas Numerical Modeling Parameters

The fire simulation event is set as the fire on the external electrical line of the subway train, the fire source is located at the bottom of the middle of the train, the fire is a rapid growth t^2, the fire growth rate is 0.04689kw/s^2, and the initial temperature is 20 °C. The grid size of the fire source area is 0.25m (X axis) × 0.25m (Y axis) × 0.25m (Z axis), and the model size is shown in figure 3.

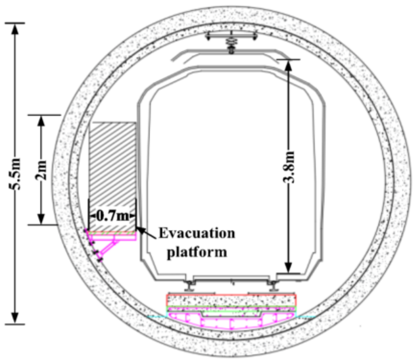


Figure 3. Schematic diagram of the fire simulation model of the tunnel (right line).

4.1.2. Simulation Working Condition Design

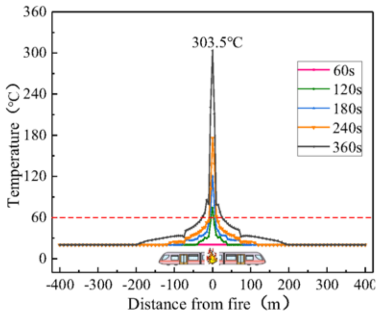
The fire scale of a train in Guangzhou Rail Transit is designed as 5MW, considering a design safety factor of 1.5 times, and the fire heat release rate is taken as 7.5MW. To set up emergency rescue points to replace the intermediate air shafts, the key is whether the personnel can be evacuated within the available evacuation time in a natural ventilation environment. Therefore, the simulation conditions only consider the available safe evacuation time in natural ventilation. The specific fire simulation conditions are shown in table 1.

Table 1. Fire simulation scene design.

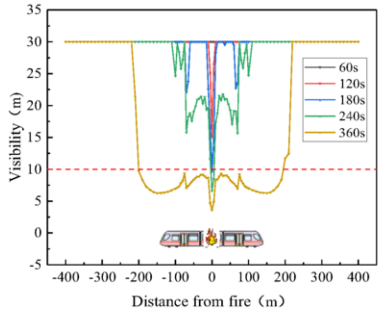
Scene number	Evacuation mode	Fire power/MW	Train speed/km•h^{-1}	Ventilation
A1	Evacuate in the tunnel	7.5	0	Natural ventilation

4.1.3. Analysis of Flue Gas Simulation Results

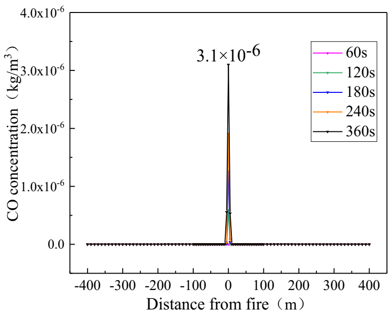
Figure 4 shows the change curves of temperature, visibility and CO concentration at a height of 2m above the evacuation platform. It can be seen from figure 4(a) that the temperature distribution on both sides of the fire source is symmetrical and decreases with the increase of the distance from the fire source. Only the temperature near the fire source exceeds 60 °C. It can be seen from figure 4(b) that the visibility on both sides of the fire source is symmetrically distributed. When the fire occurs for 360s, the visibility $V_z \leq 10$m at a height of 2m above the evacuation platform on the downstream side of the fire source develops to 110m away from the fire source. It was no longer possible to meet the evacuation requirements. From figure 4(c), the CO concentration on both sides of the fire source is symmetrically distributed, always below 500 ppm. In summary, the T_{ASET} is 309s when the tunnel is naturally ventilated, as shown in figure 4(d).



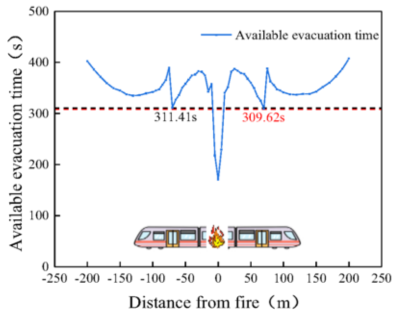
(a) Temperature change at 2m height of evacuation platform



(b) Visibility change at 2m height of evacuation platform



(c) Changes of CO concentration at 2m height of evacuation platform



(d) Tunnel personnel available safe evacuation time

Figure 4. Analysis of fire hazard in the middle of the train under the condition of natural smoke exhaust.

4.2. Personnel Evacuation Simulation

4.2.1. Personnel Evacuation Parameters

The subway train consists of 6 A-cars, with a capacity of 1860 people. There are 5 evacuation doors on one side of each car of the train, with a width of 1.4m. The width of the evacuation opening in the tunnel is 2m.

The proportion of passengers in the train and the horizontal walking speed are set according to the "Code for Design of Railway Tunnel Disaster Prevention, Evacuation and Rescue Engineering"[15].

4.2.2. Evacuation Scene Design

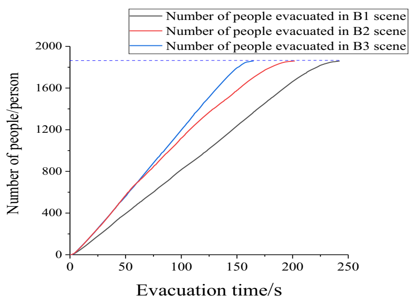
According to the location of the train fire source, different evacuation methods and different horizontal passage distances, a total of 12 sets of scenarios were designed for simulation analysis, as shown in table 2.

Table 2. Simulation scene design of personnel evacuation in emergency rescue points.

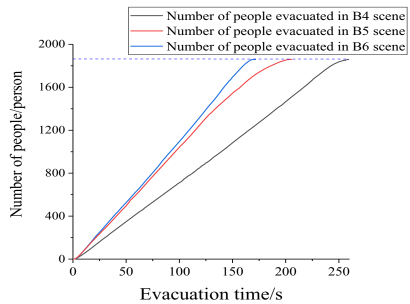
Scene number	The stop position of the train on fire	Evacuation method	Ventilation	Evacuation channel spacing/m
B1	Between two evacuation exits	Evacuation platform and track bed jointly evacuate	Natural ventilation	20
B2				25
B3				30
B4		Evacuation platform only		20
B5				25
B6				30
B7	At the exit	Evacuation platform and track bed jointly evacuate		20
B8				25
B9				30
B10		Evacuation platform only		20
B11				25
B12				30

4.2.3. Evacuation Simulation Calculation Results and Analysis

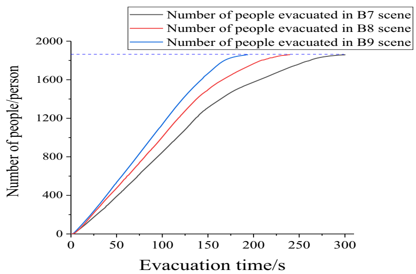
By simulating the evacuation process of emergency rescue points in the case of tunnel fire, the curve of the evacuated number with time under each working condition is shown in figure 5(a) ~ figure 5(d).



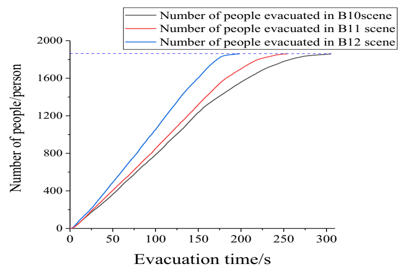
(a) Changes in the number of people evacuated over time in scenarios B1-B3



(b) Changes in the number of people evacuated over time in scenarios B4-B6



(c) Changes in the number of people evacuated over time in scenarios B7-B9



(d) Changes in the number of people evacuated over time in scenarios B10-B12

Figure 5. Safety analysis of personnel evacuation from emergency rescue points.

Figure 5(a) ~ figure 5(d) showed roughly the same law, and the personnel evacuation time increased with the increase of the horizontal channel spacing. When the fire source is directly opposite to the evacuation port, the evacuation time is longer than the time required for the fire source to be located in the middle of the two evacuation ports. The evacuation time of the evacuation method using the evacuation platform and the ballast bed is slightly lower than that of using the evacuation platform only.

Considering the fire alarm time and personnel pre-action time, compare the size of T_{REST} and T_{AEST}, and judge whether the passengers can evacuate safely when the subway tunnel train fires, see table 3.

Table 3. Safety analysis of personnel evacuation during fire.

Scene number	T_{REST}（s）	T_{AEST}（s）	$T_{AEST}>T_{REST}$	Safe or not
B1	284.28	309	Yes	Safe
B2	321.78		No	Unsafe
B3	362.28		No	Unsafe
B4	291.03		Yes	Safe
B5	325.03		No	Unsafe
B6	379.53		No	Unsafe
B7	313.28		No	Unsafe
B8	359.03		No	Unsafe
B9	420.53		No	Unsafe
B10	317.78		No	Unsafe
B11	373.53		No	Unsafe
B12	425.53		No	Unsafe

5. Conclusion and Suggestion

1) In the case of the intercity railway/suburban railway evacuation mode, when a fire occurs in the train, passengers cannot be safely and effectively evacuated to adjacent carriages during the running process of the on-fire train; In the case of subway evacuation mode, reasonable planning from tunnel design, civil construction and other aspects can ensure the safety of personnel evacuation in principle. Therefore, when intercity trains and subways are collinear in rail transit, the trains should adopt the subway evacuation mode when a fire occurs.

2) When the tunnel smoke spreads freely during the fire, the available safe evacuation time TASET is 309s; TREST increases with the increase of the distance between the evacuation openings. When the horizontal channel spacing is set to 25m and 30m, T_{REST} is greater than T_{AEST}, which cannot meet the requirements for safe evacuation of personnel; When the horizontal channel spacing is 20m, personnel can be protected from the threat of fire smoke.

3) Under the same evacuation method and distance between evacuation openings, when the fire is located at an evacuation opening, the evacuation opening cannot be used for personnel evacuation. At this time, the path required for personnel evacuation is longer, and the time required for safe evacuation of personnel is longer, and its T_{REST} is larger

4) When considering setting up emergency rescue points to replace the intermediate air shafts in the long tunnels of Guangzhou Rail Transit, it is recommended to set the distance between the evacuation passages to 20m, which can meet the requirements for safe evacuation of personnel.

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