Simulation Analysis of Safe Evacuation in a Railway Tunnel Emergency Rescue Station

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Abstract. This paper in order to improve the design parameters of evacuation passageway of emergency rescue stations in long railway tunnel based on the principle of the minimum evacuation time and best evacuation route, and study the impact of evacuation speed on evacuation time due to personnel panic. The evacuation time in different combinations of parameters of spacing and width of evacuation passageway and width of platform is calculated by Pathfinder simulation software considering characteristics, speed and path of evacuation. The simulation takes the fire accident of 18 marshalled passenger trains in an emergency rescue station in tunnel as an example. The study results show that: 1) Due to the panic mentality, the evacuation speed will increase, so the population flow rate will increase and the evacuation time will be shorter. 2) The optimal distance for the evacuation passageway of the emergency rescue station is 50m, the optimal width is 3.5m, and the platform width should not be less than 2.5m.

1. Introduction
With the continuous increase in the number of long tunnels and large-scale tunnel groups, people are paying more and more attention to the evacuation of people after a fire in a tunnel. According to TB 10020-2017: Tunnels or tunnel groups with a length of 20km or more shall be provided with emergency rescue stations, the distance between emergency rescue stations shall not be greater than 20km [1]. Much research has been carried out on emergency rescue stations at home and abroad. However, the high construction cost of emergency rescue stations has become the focus of tunnel disaster prevention and rescue design, and the related parameter standards for reducing the cost of emergency rescue stations must be under the premise of ensuring the safe evacuation of personnel. At the same time, scholars at home and abroad have done a lot of research on the issue of evacuation of personnel at emergency rescue stations in railway tunnels.

Xu Zhisheng et al. [2] used Pathfinder software to simulate the personnel return route and the evacuation process at different evacuation exit distances during a tunnel train fire, analyzed the necessary evacuation time and its influencing factors, and selected the best evacuation mode; Wang Mingnian et al. [3] derived the calculation formula for the evacuation time of people, proposed the control standards for the safety evacuation time of railway tunnel personnel, the maximum number of overloaded trains in various types of disaster prevention evacuation facilities is given; Zhang Hao [4] put forward the behavior characteristics of people in the fire as the basis for whether they can escape safely based on Pathfinder; Caliendo et al. [5] found that people evacuation from the tunnel would be safe when the time before starting to walk is short and the walking speed is a rather high; Ronchi et al. [6] combined the use of a simplified egress modelling method and advanced agent-based simulations.
of evacuation, this approach is deemed to facilitate fire evacuation safety assessment in underground physics research facilities by optimizing the simulation of relevant fire risk scenarios; Nagatani et al. [7] studied the escape of personnel in dark environments and obtained the characteristics, and evacuation time of personnel in a basically invisible environment.

This article conducts research on the evacuation of emergency rescue stations on long railways and determines the design ideas and design methods based on Pathfinder. Not only can it ensure the safety of personnel evacuation when the accident train is parked at the emergency rescue station, but also the cost of the emergency rescue station can be controlled, which has a guiding role in guiding the design of railway tunnel emergency rescue stations [8]. Many researchers in China use Pathfinder software to conduct evacuation research. Tian Xin [9] used Pathfinder evacuation software to simulate and compare the evacuation of subway trains and subway stations, and concluded that platform evacuation is better than tunnel evacuation; Xu Yangjiu et al. [10] used Pathfinder's SFPE (society of fire protection engineers) mode to calculate the time required for evacuation of all employees after a fire accident; Li Tiansheng et al. [11] used Pathfinder software to perform a real-world evacuation simulation of an underground transportation hub in Chongqing; Liu Songtai et al. [12] used pathfinder software to simulate five possible evacuation paths after a train fire in a double-hole single track tunnel; These all show that Pathfinder software has an important role in the simulation of personnel evacuation.

2. Methodology

2.1. Software introduction

Pathfinder software is a simulator based on crowd evacuation and movement simulation. It is mainly used to simulate fire and people evacuation in various emergency situations. It uses technologies in the field of computer graphics simulation and game characters to perform virtual drills on the movements of each individual in multiple groups, so that it can accurately determine the escape path and escape time of each individual when a fire occurs [13][14]. In the created simulation model, functions such as setting personnel parameters, adding evacuation channels, and adding obstacles are provided to make the simulation environment more consistent with the layout of emergency rescue stations. Based on Pathfinder software for simulation, people will choose the safest shortest evacuation route (the best evacuation route) when they evacuate.

2.2. Model building

The basic parameters of personnel in Pathfinder software include shoulder width, height and evacuation speed. The accurate setting of the shoulder width can make the evacuation result closer to the escape situation in the real fire situation. The human body parameters in this paper mainly select the average value of adult males, adult females, children and the elderly.

The overall evacuation speed of the crowd will affect the accuracy of the final evacuation time. In this model, considering the psychological panic factors of the personnel, the emergency evacuation speed of different types of personnel under the influence of panic in the tunnel is variable. But the personnel parameters of evacuation speed considering psychological panic are only used for distance for the two compartments near the fire; the parameters of the personnel as shown in Table 1.

| Personnel  | Evacuation speed of people in railway tunnel (m/s) | Evacuation speed considering psychological panic (m/s) | Proportion (%) | Shoulder width (cm) |
|------------|--------------------------------------------------|-----------------------------------------------------|----------------|---------------------|
| Adult male | 1                                                | 1.37                                                | 45             | 45.58               |
| Adult female | 0.8                                            | 1.1                                                  | 40             | 44.58               |
| Child      | 0.67                                             | 0.92                                                | 7              | 35                  |
| Seniors    | 0.6                                              | 0.82                                                | 8              | 45                  |

The spacing of the evacuation passageway is 4 parameters: 50m, 60m, 70m and 80m. The width of the evacuation passageway is 5 parameters: 2m, 2.5m, 3m, 3.5m and 4m. There are 20 combinations
of calculated values. When calculating each combination, it is assumed that the width of the emergency rescue station platform is normal (2.5m) and does not affect the evacuation speed of the personnel. The evacuation model of the emergency rescue station is shown in Figure 1.

Figure 1. Schematic diagram of emergency rescue station

In the calculation of the model, the behavioural response characteristics of personnel, the effective width of the evacuation passageway, and the exit blocking situation have been considered. The specific parameters are as follows: 1) The height of the emergency rescue platform (the distance from the floor of the carriage to the platform) is set to 0.3m. The width of the platform is set to 2.5m, and the length of the emergency rescue platform is set to 500m. There are a total of 18 train cars, each with a length of 25.5m, and the total length of the train is 459m. 2) The number of each car is set at 118 people (full load). Exit doors are opened on both sides of the train in one direction (facing the evacuation passageway), the door size is 1m.

3. Result analysis
During the Pathfinder simulation of personnel evacuation experiments, considered the psychological panic factors of the personnel. In order to study the effect of different evacuation speeds on the overall evacuation time, a simulation experiment was performed. In one working condition, the stair01_1_1_3 door 1 and door 2 is the exit of the compartment close to the source of the fire, and it is used for people evacuating at speed considering psychological panic; The stair01 door 1 and door 2 is the exit of the compartment far away the source of the fire, and it is used for people evacuating at speed of people in railway tunnel; Each compartment has the same number of passengers, the results of flow rate in the model simulation are shown in Figure 2.

Figure 2. Flow rates for selected doors

It can be found from Figure 3: People have different psychology, so the evacuation speed is different. Due to the panic mentality, the evacuation speed of the personnel near the source of fire increase, the population flow rate at the stair01_1_1_3 door 1 and door 2 will increase, and the evacuation time will be shorter. On the contrary, considering the evacuation of people at normal speed in the tunnel, the flow rate at the stair01 door 1 and door 2 will decrease, and the evacuation time will increase, which will affect the overall evacuation time. As can be seen from Figure 2, the former takes
12s less time than the latter. The evacuation time of the personnel is determined by all personnel, so appropriately increasing the personnel speed, the evacuation time will reduce, and the safety is higher.

The necessary safety evacuation times for personnel evacuation in the case of different evacuation passageway spacing and width combinations is shown in Table 2.

Table 2. Evacuation time under combinations of different spacing and width of evacuation passageway

| Working condition | Spacing of evacuation passageway (m) | Width of evacuation passageway (m) | Evacuation time (s) |
|-------------------|-------------------------------------|-----------------------------------|---------------------|
| 1                 | 50                                  | 2                                 | 159                 |
| 2                 | 50                                  | 2.5                               | 155                 |
| 3                 | 50                                  | 3                                 | 152                 |
| 4                 | 50                                  | 3.5                               | 151                 |
| 5                 | 50                                  | 4                                 | 151                 |
| 6                 | 60                                  | 2                                 | 180                 |
| 7                 | 60                                  | 2.5                               | 162                 |
| 8                 | 60                                  | 3                                 | 154                 |
| 9                 | 60                                  | 3.5                               | 153                 |
| 10                | 60                                  | 4                                 | 153                 |
| 11                | 70                                  | 2                                 | 223                 |
| 12                | 70                                  | 2.5                               | 196                 |
| 13                | 70                                  | 3                                 | 175                 |
| 14                | 70                                  | 3.5                               | 168                 |
| 15                | 70                                  | 4                                 | 168                 |
| 16                | 80                                  | 2                                 | 238                 |
| 17                | 80                                  | 2.5                               | 215                 |
| 18                | 80                                  | 3                                 | 203                 |
| 19                | 80                                  | 3.5                               | 173                 |
| 20                | 80                                  | 4                                 | 173                 |

It can be known from Table 3: In general, the spacing of evacuation passageway is greater, the necessary safety evacuation time for personnel evacuation will be longer; the width of the evacuation passageway is smaller, the evacuation time also will be more.

(1) When the spacing of evacuation passageway is 50 m and the width is 3.5 m, the required safe evacuation time for personnel evacuation is 151 s, and the evacuation time does not change when the width increases.

(2) When the spacing of evacuation passageway is 60 m and the width is 3.5 m, the required safe evacuation time for personnel evacuation is 153 s, and the evacuation time does not change when the width increases.

(3) When the spacing of evacuation passageway is 70 m and the width is 3.5 m, the required safe evacuation time for personnel evacuation is 168 s, and the evacuation time does not change when the width increases.

(4) When the spacing of evacuation passageway is 80 m and the width is 3.5 m, the required safe evacuation time for personnel evacuation is 173 s, and the evacuation time does not change when the width increases.

The relationships between evacuation passageway width and evacuation time is shown in Figure 3.
Figure 3. Relationships between evacuation passageway width and required evacuation time

It can be known from Figure 3: When the width of evacuation passageway increase to 3m, the evacuation time does not change obviously when the width increases. When the spacing of evacuation passageway is 50m and the width of evacuation passageway is 3.5m, the evacuation time is 151s, which is the least under all combinations of spacing and width of evacuation passageway, and the construction cost is relatively low by comparison. This will ensure a minimum evacuation time.

At this time, a combination which the spacing of evacuation passageway is 50m and the width of evacuation passageway is 3.5m is selected as the parameter to study the influence of the platform width on the evacuation time. Evacuation time under different widths of emergency rescue station platform is shown in Table 3.

| Condition | Widths of emergency rescue station platform (m) | Evacuation time (s) |
|-----------|-----------------------------------------------|---------------------|
| 1         | 2                                             | 169                 |
| 2         | 2.5                                           | 151                 |
| 3         | 3                                             | 146                 |
| 4         | 3.5                                           | 141                 |
| 5         | 4                                             | 141                 |

According to Table 3: When the spacing of evacuation passageway is 50m and the width of evacuation passageway is 3.5m, as the platform width increasing, the corresponding evacuation time required for personnel evacuation is decreasing; When the width is greater than 2.5 m, the decrease in the time required for safe evacuation of personnel is no longer obvious.

4. Conclusion
Based on the Pathfinder simulation software, a passenger train fire accident was studied, and personnel were parked and evacuated in an emergency rescue station in a tunnel. By designing and studying the parameters of evacuation passageway of an emergency rescue station in railway tunnel, the following main conclusions were obtained:

(1) Due to the panic mentality, the evacuation speed will increase, so the population flow rate will increase and the evacuation time will be shorter.

(2) The optimal distance for the evacuation transverse passage of the emergency rescue station is 50m, the optimal width is 3.5m, and the platform width should not be less than 2.5m.
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