Study on Fire Evacuation and Smoke Spread of Atrium Metro Station

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Abstract. In recent years, the construction of subway in China is in a period of an rapid development. The passengers are in high density within the subway during the operation time, the problem of safety in emergencies has attracted more and more attentions. The structure of atrium metro station is special, fire partition area in the station is difficult to divide. And there is a hidden danger of fire, which is not easy to realize effective exhaust and smoke control. Once there is a fire the magnitude of injuries will be overwhelmingly disastrous. Therefore, more attention should be paid on pedestrian’s evacuation in subway stations. Therefore, an atrium subway station in Beijing is selected, hot smoke test and STEPS software simulation were carried out. We also analyzed the escape environment and escape routes, reasonable evacuation time is obtained, as well as a reasonable escape strategy.

Introduction

Like other countries in the world, with the continuous and rapid development of the Chinese economy, the urban population is increasing dramatically, imposing a rigorous challenge on the urban transportation systems. The subway has such advantages as large transportation capacity\cite{1-2}, low pollution, high speed, easy traffic, low energy consumption, low resource occupation, and comfort, which are in conformity with the principle of sustainable development. Passengers are in high density within the subway during rush hours. And because there is a large shared space in the atrium area, the ceiling and ground height difference is large. It is easy to the form stack effect. There are a lot of passengers in the station, and high density of smoke\cite{3-4}.Because there is no way to set up the wind tunnel in the atrium area, the traditional mechanical smoke exhaust device can not be set up on the ceiling in the atrium\cite{5}.So when a fire occurs, the high temperature smoke rise to fill the atrium by buoyancy, it will fall into the gas station hall and platform. The evacuation of the atrium subway station should be paid much attention. In this paper, a hot smoke test was carried out on an atrium metro station, and the pedestrian evacuation process was simulated with STEPS\cite{6-8}.

In recent years, the research on the fire safety of atrium metro station has been paid more and more attention by researchers. In 2010, Yu\cite{9} introduced the design of the fire protection system of Shanghai Huamulu Metro station, safety evacuation properties of atrium subway station was simulated and analyzed with Legion pedestrian simulation model and FDS by He\cite{10}.In 2012, Wu calculated for the evacuation time of the atrium metro station according to metro design code; In 2013, Shen\cite{11} made a comparative analysis of the atrium metro station public area prevention design scheme of exhaust system, putting forward the atrium area platform as an independent smoke zone smoke control zoning, according to the specific shape of the atrium, the partition should include the entire atrium area and platform, escalator of hall. In 2014\cite{12}, Hao designed the smoke control system of the atrium subway station, and the effect of the system was verified by FDS simulation.
Hot Smoke Test of Atrium Subway

Experimental Parameters and Arrangement

In order to explore the capacity of smoke control system and smoke control in atrium subway station, and the status of smoke spread and the location of the safety zone in the station, the real situation of the fire was simulated through the hot smoke test: Beijing subway station A is selected. It is a Double-deck Station, the total construction area is 13819m$^2$, station hall public area is 3991m$^2$, which paid area is 1950m$^2$. Platform width 14m, effective platform length is 158m.

![Figure 1. Structure diagram of subway station.](image1)

![Figure 2. Schematic diagram of fire source device.](image2)

Station A hall to take atrium the design concept, the station hall and platform as a whole to coordinate the design, the atrium belongs to the interior space, atrium orifice total area of public area is greater than a third, it is a typical large atrium Metro Station. Due to the atrium of A station, between station and hall formed a high open area, which has a significant influence on the staircase at the wind speed, it is difficult to achieve the specifications of the 1.5m/s downward wind speed, thus, it has certain hidden dangers of fire safety evacuation, so choose the station as the research object.

As shown in Fig 2, Fire location in the platform of the public area, 2xA1 burning disk was used as the test fire source, 95% ethanol as fuel, which stable combustion power of 700kW.

Test Procedure

In this test, the fan start after the ignition, the range of downward wind speed of A’s inlet and outlet is 0.5-1.6m/s, while B’s is 1.7-3.2m/s, A’s average wind speed is 1.1m/s, B’s average wind speed is 2.3m/s. The downward wind speed is 0.4-0.9m/s in escalator of atrium area, the average wind speed is 0.65m/s. Smoke filled the entire atrium after 360s, and settled rapidly, diffuse to the entire station hall and the station. Although the station entrances and exits have a larger amount of downward makeup air, the wind speed is very low in the atrium area, which caused smoke can not be discharged. The fuel combustion was completed after 15min, while the smoke was discharged after 20min.
As shown in Figure 3-4, after the ignition, smoke settled in the same location. We can see that with the combustion of the fuel, the station platform visibility decreased gradually, and the settling velocity of smoke was quickly, the whole platform was full of gas station, where people's vision also got great limits. The following figure is the staircase of hall in atrium area. Smoke has been very strong, it was very difficult to see clearly the situation of the atrium area and the platform. There was a significant difference compared with the situation before the experiment.

**Results and Analysis of Test**

In the test of A station of Beijing metro, when the fan was normally opened, the smoke was not discharged in time, and the settlement phenomenon occurred, the smoke filled the platform and the station hall, hindered the normal evacuation of personnel.

From the statistics, under fire conditions, when the smoke exhaust fan and the air supply fan are normally opened, the downward wind speed on the staircase in the atrium is 0.65m/s, which could not meet the requirements of 1.5m/s in the design code of China subway. Even if the staircase of non atrium area, the max downward wind speed can reach 3m/s. Due to the huge area of the atrium and shared space, there is still a lack of wind of platform.

From the experimental phenomenon, after the start of the fire conditions within the 6min, the smoke has spread, settled, and filled the entire station and the station area. If in accordance with the current standard in China, personnel should evacuate the platform in 6min, arrived at the station hall, but it is still in an extremely dangerous situation; therefore, in order to avoid heavy casualties under fire, evacuation behavior cannot stay in the station exit, the personnel security area should be hall exit.
Evacuation Simulation with STEPS

The full name of STEPS is Simulation of Transient Evacuation and Pedestrian movements, is ANSYS company's software of three-dimensional simulation of evacuation. STEPS as a professional evacuation software, with the ability to simulate a variety of complex evacuation conditions.

![STEPs model diagram and evacuation route of subway A station.](image)

**Table 1. Simulation Results.**

<table>
<thead>
<tr>
<th>Gender</th>
<th>Shoulder breadth(m)</th>
<th>Thickness(m)</th>
<th>Height(m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>0.5</td>
<td>0.26</td>
<td>1.75</td>
</tr>
<tr>
<td>Female</td>
<td>0.44</td>
<td>0.27</td>
<td>1.65</td>
</tr>
</tbody>
</table>

The evacuation of personnel was in accordance with the characteristic parameters of the NFPA130 code, based on the hypothesis of evacuation, the evacuation station staff for all young men and women, the distribution proportion of 50%, respectively, not including the elderly and children, the staff characteristic parameters are as follows:

In the evacuation model, personnel in different walking speed was up also in accordance with the relevant provisions of United States NFPA130 (2014 Edition) , including walking speed on the platform and the station hall is 37.7m/min, namely 0.63m/s, walking speed on the staircase is 14.6m/min, namely 0.24m/s.

The evacuation scene is set to train fire evacuation, evacuation route is to hall exit, at the start of evacuation behavior, the subway station were total  of 3607 passengers, the passenger in train station was 1920 people, There were 767 passengers on the platform, while station hall has 920 passengers, the distribution of its personnel.

In the evacuation process, the relationship between the number of people have been evacuated and the time is showed in Fig 9.

Through the computer simulation, subway station fire condition personnel evacuation behavior is as follows, in the evacuation process, you can clearly see the retention phenomenon of pedestrians on the platform stairs and gates , which affect the evacuation time and evacuation bottlenecks in D exit staircase, the results are close with this the model established in this paper. Its evacuation time is 405s.
Calculation of Evacuation

(1) The calculation of the walking speed of each passage structure

The evacuation personnel density is 1.5 p/m in the platform and hall, personnel density is 2.6 p/m in the upward stairs, according to the walking evacuation time model is calculated as follows:

For hall and platform:

\[ v = 0.25x^2 - 1.23x + 2.02 = 0.25 \times 1.5^2 - 1.23 \times 1.5 + 2.02 = 0.74 \text{m/s} \]  

(1)

For upward stairs:

\[ v = -0.03x^2 - 0.01x + 0.72 = -0.03 \times 2.6^2 - 0.01 \times 2.6 + 0.72 = 0.49 \text{m/s} \]  

(2)

(2) The calculation of the walking time of each path

Put the walking speed 0.74m/s of platform station hall and 0.49m/s of stairs into the calculation, can obtain the walking time of each path:
Table 2. Walking time of each path.

<table>
<thead>
<tr>
<th>Time(s)</th>
<th>Train to stairs of platform</th>
<th>Stairs</th>
<th>Stairs to exit of hall</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
<td>64.41</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td></td>
<td>57.76</td>
<td>27.28</td>
</tr>
<tr>
<td>C</td>
<td></td>
<td></td>
<td>86.78</td>
</tr>
<tr>
<td>D</td>
<td></td>
<td></td>
<td>112.54</td>
</tr>
</tbody>
</table>

(3) Time of through passage

In the subway station, people need to through two passage, the building and the gates of the escalator. Because in the evacuation process, the use proportion of each traffic structure is decided by the staircase capacity, therefore to evacuate personnel through the path of staircase should be equal and it can be calculated by the following formula:

\[ F_A = F_B = F_C = F_D = \frac{Q}{C_A \times B} = \frac{930 \times 60}{0.065 \times 1700 + 0.089 \times 1100} = 267.29\text{ (s)} \]  
\[ F_A = \frac{Q_A}{C_A \times B} = \frac{930 \times 60}{60.5 \times 5} = 184.53\text{ (s)} \]  
\[ F_B = \frac{Q_B}{C_B \times B} = \frac{930 \times 60}{60.5 \times 6} = 153.78\text{ (s)} \]  
\[ F_C = \frac{Q_C}{C_C \times B} = \frac{873 \times 60}{60.5 \times 6} = 144.32\text{ (s)} \]  
\[ F_D = \frac{Q_A}{C_A \times B} = \frac{873 \times 60}{60.5 \times 5} = 173.19\text{ (s)} \]

(4) The waiting time of each path

Through the platform and the gates of the escalator need to wait, can calculate as follows:

(5) evacuation time of each route

\[ T_A = \sum T_A + \sum W_A = 57.76 + 27.28 + 64.41 + 209.53 = 358.98\text{ (s)} \]  
\[ T_B = \sum T_B + \sum W_B = 57.76 + 27.28 + 65.76 + 209.53 = 360.33\text{ (s)} \]  
\[ T_C = \sum T_C + \sum W_C = 57.76 + 27.28 + 86.78 + 209.53 = 381.35\text{ (s)} \]  
\[ T_D = \sum T_D + \sum W_D = 57.76 + 27.28 + 112.54 + 209.53 = 407.11\text{ (s)} \]

(6) Evacuation time of the station A

By comparison, the D path of the evacuation time is the longest, 407.11s, that is, 6.79min. Therefore the final evacuation time of the subway station 6.79min.
Table 3. Comparison of simulation results and calculation results.

<table>
<thead>
<tr>
<th></th>
<th>Evacuation Time(s)</th>
<th>Evacuation Time(min)</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calculation Model</td>
<td>407.1</td>
<td>6.79</td>
<td>—</td>
</tr>
<tr>
<td>STEPS Model</td>
<td>404</td>
<td>6.75</td>
<td>-0.52%</td>
</tr>
</tbody>
</table>

Conclusion

Through the hot smoke test and the application of STEPS, the fire evacuation simulation of the A station of atrium metro station was carried out, and the results were compared with the calculation results of the evacuation model. We draw a conclusion:

1. For the atrium subway station A, the difficulty of smoke control in the fire condition was verified, the average downward wind speed of the atrium floor staircase is 0.65m/s, failed to meet the requirements of 1.5m/s in the Chinese subway design code, which is not conducive to personnel evacuation.
2. In order to effectively avoid the heavy casualties in the case of fire, personnel evacuation behavior should not stop at the platform exit, personnel safety zone should be exit of hall.
3. From the results of the simulation on the STEPS software, the error of the evacuation time and the model calculation result is -0.52%. And the process of evacuation behavior is consistent with the calculation results of the model, it can be considered that the calculation results of the evacuation model established in this paper is effective and accurate. The evacuation time model established by observation test and fitting is in line with the actual situation of subway in China, and it has certain accuracy, which can be referenced for the calculation of evacuation time in practical engineering.

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Reference


