Performance of smoke confinement during fire accident in subway station

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Abstract: Fire accidents often lead to tremendous losses and smoke has been reported to be the main cause of these heavy casualties. Accordingly, smoke movement can influence escape and smoke confinement is particular significant. Fire Dynamics Simulator software (FDS) was utilized to carry out complementary full scale numerical simulations of fire accident in a subway station. Different measure of smoke prevention and exhaust were adopted and the difference of smoke confinement among the measure was compared. According to the smoke temperature, hung wall had a good role during early stage of fire accident. However, the performance became worse with smoke accumulation. If the hung wall were adopted, smoke was exhausted from basement 2 and air was supplied into the basement 1 at the same time, the efficacy of smoke confinement was the best. The mechanical exhaust rate had obvious implications for the smoke diffusion.

1 Introduction

During the urban construction, metro has a rapid increase to relieve traffic congestion. Subways are well known for their advantages such as: high speed, low energy consumption and so on. Most of subway stations belong to underground buildings. Once there is a fire accident, smoke diffuse rapidly, which play a bad role on evacuation and lead to heavy casualties and property losses[1,2]. For example, in 2005, fire broke out at subway station in London, England and resulted in the deaths of 56 people, and an additional 700 injuries. In 2015, because of an electrical wiring problem, there was a fire accident that took place at Doris square subway in Washington, D.C., USA and the subway train was quickly filled with smoke, which resulted in the deaths of 1 people, and an additional 81 injuries[3]. According to statistical data, toxic smoke is the leading cause of death. During fire accident in subway station, due to the smoke flowing and a few emergency exit, the ratio reach to 85% of the people killed[4]. Consequently, major fire accidents underscore the importance of fire safety in subway stations and it is necessary to enhance the efficacy of smoke control system to maintain a safe evacuation path for the passengers.

During fire accident, passengers and staffs access to the metro hall via the staircase to evacuate. Due to the thermal buoyancy, the smoke flow upward, which is very frustrated for the firefighter’s rescue operations and passenger’s evacuation. The evacuation performance of a stairwell is thus extremely important for the safety and lives of the people when metro hall is on fire. So, it is important to control of smoke diffusion into stairwell and exhaust smoke to prevent smoke accumulation. Based on previous studies, hung wall and operating ventilation system is beneficial effect in damage limitation during fire accident[5]. Then the paper comes to its main point: comprehensive combination of hung wall and operating ventilation system.

2 Methods
2.1 Description of the research object

The research was conducted in a typical subway interchange station, as shown in Fig. 1., which had three stories underground. The station hall was a cross-shaped concourse in basement 1 and the dimension was 105m L x 40m W x 5m H. Four exits from basement 1 played an important role on leading to open ground. At the same time, passengers could set down and pick up in basements 2 and 3, with the dimensions of 125m L X 24m W X 5m H and 48m L X 24m W X 5m H, respectively.

![Fig.1. Ventilation system of the station (unit: m):](image)

(a) basement 1, (b) basement 2 and (c) basement 3.

There was one line in basements 2 and 3, respectively and the two lines were vertical. The direction of the line in basement 2 was east–west and the direction in basement 3 was north–south. In addition, there were vents uniformly installed under the ceiling of each basement and the layout of these vents is shown in Fig. 1. The dimensions of the vents were 1m X 1m. Some vents were as inlets and some vents were as outlets. During a fire incident the ventilation system, used during normal operation, had to be able to exhaust the smoke and control the smoke diffusion. During fire accident, outlets played role on exhaust smoke and inlets played role on sending fresh air. The screen door system was set and the fire accident broken out in the station was researched.

2.2 Description of the research method

The Fire Dynamics Simulator (FDS) code was used to simulate the heat and smoke propagation phenomena with different measure of smoke confinement in case of fire[6]. FDS was developed by the National Institute of Standards to research fire-driven fluid flow and could achieve the visualization. The software is professional fire simulation software and the simulation result is consistent with living result. CFD include three types: direct numerical simulation (DNS), Reynolds averaged Navie-Stokes equation (RANS) and large eddy simulation (LES), respectively. Scholars liked to utilize the LES model to simulate the smoke flow and the simulation results were proved accurately. So in the following numerical simulation, the LES model was adopted to research the heat and smoke spread. In LES model, the turbulent Prandtl number Pr, Smagorinsky number Cs and the turbulent Schmidt number Sc were set as 0.4, 0.18 and 0.3, no less than 1 m3/(min·m2) when the station is on fire[7]. Consequently, the velocity of the smoke outlets in basement 2 was set 2 m/s and the velocity of air supply outlets in basement 1 was set 0.5 m/s. The value of HRR was set 6MW. On the basis of simulation result, the cases with different conditions were discussed and comparative analysis was conducted. Case 1 was set as the reference case, where the vent was closed and the hung wall wasn’t set. Cases 2, 3, and 4 represented different operations of the smoke confinement.

3 Simulation result and discussion

The fire broke out in platform and FDS software was used to simulate the smoke diffusion in the station.
Fig. 2. Comparison of Temperature contour of the plane X = 5.5m after fire ignited 200 s (unit: °C): (a) no measures; (b) the height of the hung wall is 500mm; (c) hung wall+ smoke exhausted from basement 2 and air supplied into the basement; (d) the height of the hung wall is 800mm

As shown in Fig.2a., there was no smoke control measure, a mount of smoke was produced and flowed upward due to buoyancy. When the smoke reached the entrance of stairwell, the smoke diffused into the basement 1. Consequently, the temperature in basement 1 was apparently higher than the temperature in basement 3. Once the hung wall was set, the smoke was confined and accumulated in basement 2, so the thickness of smoke was gradually increasing. Once the smoke surpass hung wall, the smoke diffused into the whole basement 2 and passed over the entrance of stairwell into the basement 1. Consequently, when the fire persisted for 200s, the temperature in basement 1 increased as shown in Fig.2b, d. If hung wall was installed and the mechanical ventilation was activated, the temperature in Fig.2c. was significantly lower than the temperature in Fig.2b, d. The principal reason for this difference was smoke exhausted from basement 2 and air supplied into the basement, which formed pressure difference to block smoke diffusion.

Table 1. Conditions of experiment cases.

| Case | Hung wall | Exhaust smoke velocity | Supply air velocity |
|------|-----------|------------------------|--------------------|
| 1    | 800mm     | 2 m/s                  | 0.5 m/s            |
| 2    | 500mm     | 3 m/s                  | 0.5 m/s            |
| 3    | 500mm     | 4 m/s                  | 0.5 m/s            |
| 4    | 500mm     | 2 m/s                  | 0.75 m/s           |
| 5    | 500mm     | 2 m/s                  | 1 m/s              |

As shown in Fig.3., analyses and comparison the diffusion regularity of fire smoke with different measure were conducted. Because the fire source was on the right of the station, amount of smoke diffused in basement 2 and the temperature was very high near fire source. When there wasn’t measure operated, the smoke flowed upward into basement 1 due to buoyancy. Consequently, the temperature was highest in Fig.3a. When the hung wall was set, the smoke was confined in basement 2 and the less smoke flowed into basement 1. Once the smoke exhausted from basement 2 and air supplied into the basement 1, the air flowed downward because of pressure difference, which was unfavorable for smoke diffusion into the upper floor. At the same time, part of the smoke was exhausted. So, the temperature in Fig.3c. was the lowest in whole station.

The efficacy of smoke confinement was best when the hung wall and mechanical ventilation were operated. To enhance the efficacy, the effect of the height of hung wall and mechanical ventilation rate was researched. As shown in Table 1, five different sets of conditions were considered in the simulation. The height of hung wall was 800mm in Case1. Cases 2, 3, 4 and 5 represented different operations of the ventilation. As shown in Fig.4., the temperature in case 3 was lower than the temperature in other cases and the difference became more pronounced with the fire duration. Comparison of temperature contour of the plane Y = 0m on basement 1 was conducted as shown in Fig.5. The area affected by the smoke diffusion was smallest in case 3. Consequently, the rate of smoke exhaust resulted in more obvious influence on smoke confinement.

![Fig. 4. Comparison of smoke temperature of the plane Y = 0m on basement 1](https://doi.org/10.1051/e3sconf/202235602036)
4. Conclusions

A numerical simulation were performed to research the smoke diffusion with different smoke confinement modes. In this paper, the influences of the effect of hung wall and mechanical ventilation was discussed. According to simulation results, hung wall really played a good role in preventing smoke diffusion at fire early stage. With the duration of the fire accident, more and more smoke accumulated, which disable smoke confinement. If hung wall was installed and the mechanical ventilation was activated, the efficacy of smoke confinement was best. It was obvious that the efficacy became better with the increase of the rate of smoke exhaust.

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