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CFD Analysis of Fire Characteristics on Subway Junction Station

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ABSTRACT: In order to enhance fire protection level of subway station in Shanghai, this paper mainly analyzed fire distribution characteristics of a certain subway junction station, including temperature, visibility and CO density. Based on CFD simulation method, four fire scenarios were constructed during the simulation analysis. The fire sources were located in the vicinity of stairs and in train carriage of the subway platform respectively. Hence, the corresponding results are quite useful for fire safety design and management of subway junction station.

1 INTRODUCTION

With the development of modern cities, the subway is playing a more and more important role in urban transportation. It makes our life and manufacture more convenient and comfortable, but on the other hand, the subway fire as the main disaster happened quite frequently. We should realize that the subway station is not only the underground construction but also the public gathering place. Because of large passenger flow volume and special management environment, it is very difficult to effectively deal with such disasters as fires in subway station. Once the fire takes place in the subway station, it will result in a large number of death and injury as well as great property damage. The smoke, high temperature and lack of oxygen caused by subway fire are the main reasons that lead to personnel casualties and property loss. In order to enhance fire protection level of subway station in Shanghai, this paper mainly analyzed fire distribution characteristics of a certain subway junction station, including temperature, visibility and CO density. Based on CFD (Computational Fluid Dynamics) simulation method, two fire scenarios were constructed during the simulation analysis. The fire sources were located in the vicinity of stairs and in train carriage of the subway platform respectively. Meanwhile, the corresponding results are quite useful for fire safety design and management of subway station.

2 DESIGN OF FIRE SCENARIO FOR CFD

2.1 Brief Introduction of FDS

In these simulations, FDS (Fire Dynamics Simulator) 4.06 which was released by NIST(National Institute of Standards and Technology, USA) was used. FDS is a Computational Fluid Dynamics (CFD) model with LES(Large Eddy Simulation)of fire-driven fluid flow. The model solves numerically a form of the Navier-Stokes equations appropriate for low-speed, thermally-driven flow with an emphasis on smoke and heat transport from fires. The partial derivatives of the conservation equations of mass, momentum and energy are approximated as finite differences, and the solution is updated in time on a three-dimensional, rectilinear grid. Thermal radiation is computed using a finite volume technique on the same grid as the flow solver.

2.2 Brief Introduction of a Certain Subway Junction Station in Shanghai

The total building area of this subway junction station is 17487 m^2, including station hall, station platform, station lane, equipment and management rooms, ground passageway (number: 5, total width: 24.56m) and so on. The station is 12.5m deep. The hall is on the 1st floor underground with 6649 square meters, 165.3m long, 21.6m wide and 4.2m high, consist of passenger distributing area, equipment and management rooms, inlets and outlets etc. The platform is on the 2nd floor underground with 4017 square meters, 183.7m long, 14m wide and 4.8m high. The corresponding management rooms are located on both sides of the platform. A louver opens through the ground in the middle part of the platform. There are four stairs in the central section. Each stair is about 3.5m wide with 31 steps (height of each step:0.135m), and there is an escalate beside it. The size of platform shield door is 2.0×2.2m. The planes of the station hall and platform were shown in Fig.1 and Fig.2.

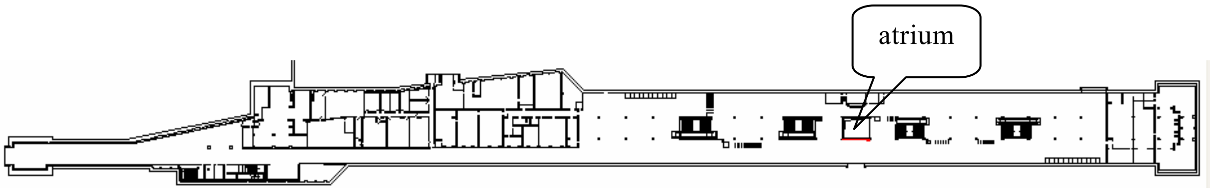

Fig.1 The plan sketch of subway junction station hall

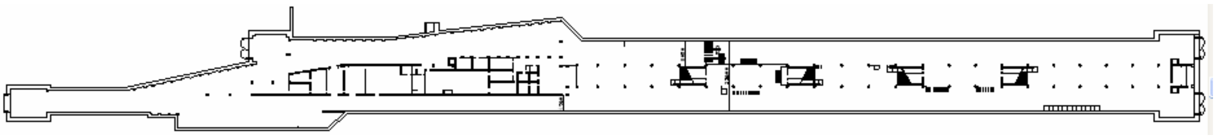

Fig.2 The plan sketch of subway junction station platform

2.3 Fire Simulation Scenario of the Subway Junction Station

As for fire simulation scenario of the subway station, the maximum HRR was conservatively set as 1.5MW for platform baggage fire. Assumed that equipment at the base of subway train carriage could catch fire, the train fire was also simulated in the analysis. The HRR of 10.5MW was adopted for train fire, referring to the conclusion completed by some other researchers. Four fire scenarios in the subway platform were considered (as shown in Fig.3), including: (1) scenario 1: baggage fire located at the area behind the second stair (ST2) in the platform (1.5MW); (2) scenario 2:baggage fire located at the area behind the third stair (ST3) in the platform (1.5MW); (3) scenario 3: baggage fire located at the area behind the fourth stair (ST4) in the platform (1.5MW); (4) scenario 4: train fire located at the bottom of the carriage and the shield door of the subway station destroyed by fire (10.5MW). Considering the worst condition, the sprinkle and ventilation were out of work during the discussion. In the four scenarios, rapid t-square fire was adopted and the corresponding HRR curve was shown in Fig.4.

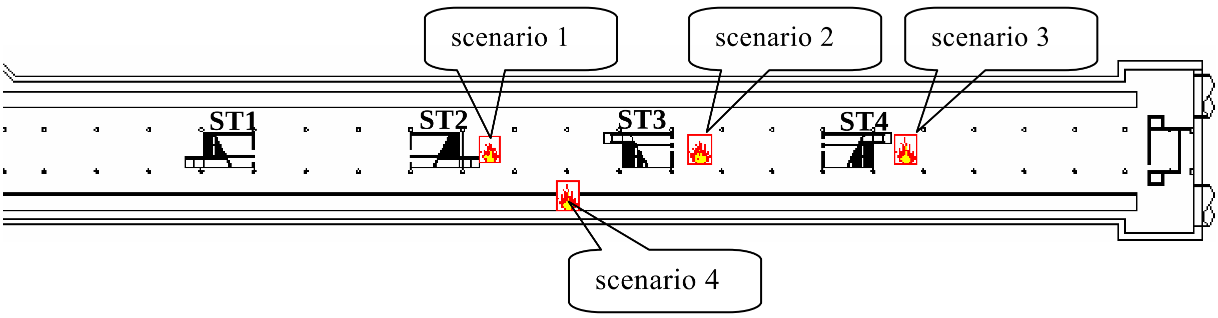

Fig.3 Fire scenarios of subway junction station platform

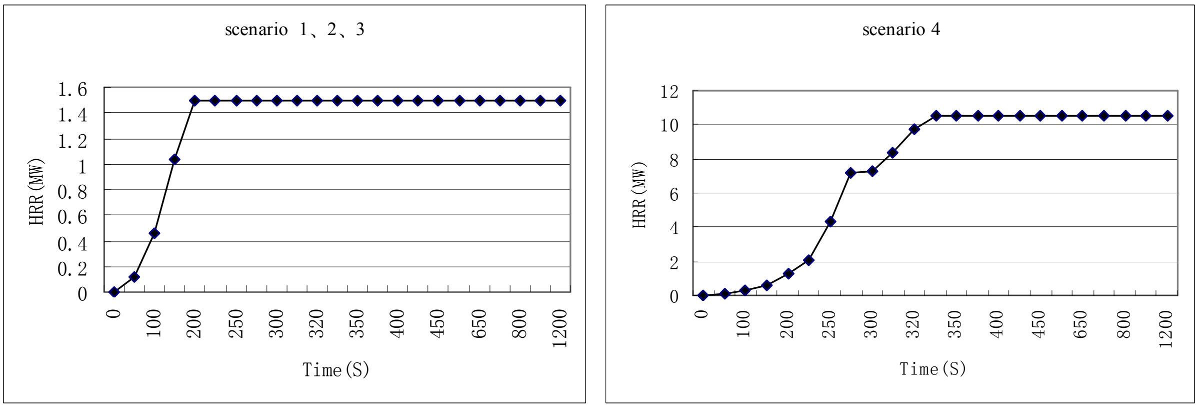

Fig.4 Heat Release Rate curve of fire scenario

2.4 Model of CFD Simulation

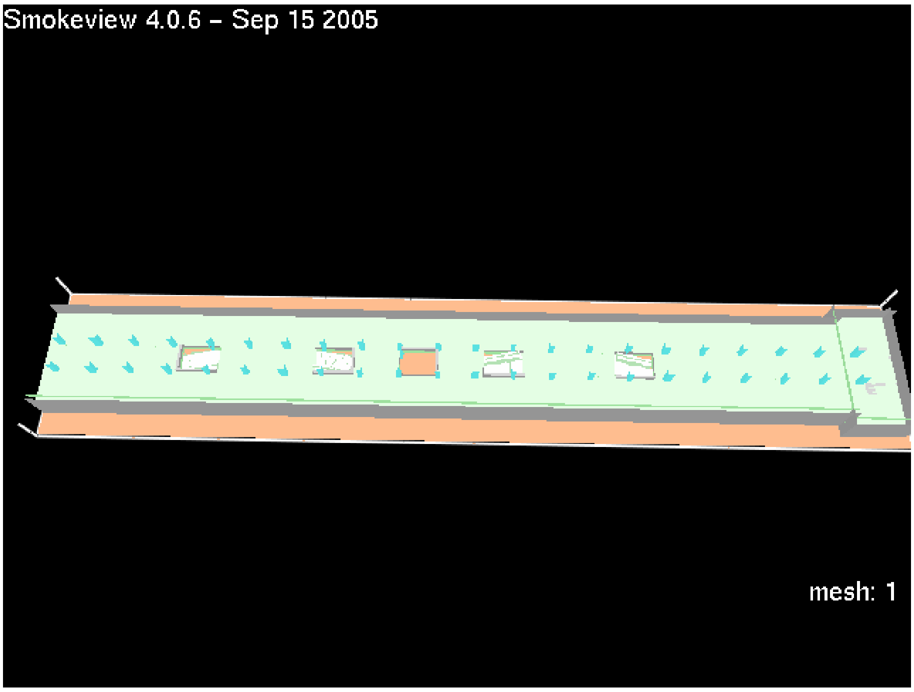

Fig.5 CFD simulation model

3 RESULTS OF CFD SIMULATION

3.1 Temperature Distribution Characteristics in Subway Fire

As soon as the baggage fire began to burn in the vicinity of stairs during the simulation, the fire flame gradually enhanced. As time went on, the temperature gradually rose because of the heat continuously gathering. Simulation result of temperature at 2.1m height above platform surface in scenario 1 (t=400s) were shown in Fig.6.

Once the train fire began to burn at the bottom of the carriage during the simulation, the hot fire flame spread to the platform through shield door. The fire flame temperature gradually increased because of heat accumulation. The temperature simulated at 2.1m height above platform surface in scenario 4 (t=400s) were shown in Fig.7.

As for the first three fire scenarios (baggage fire), the environmental temperature that we concerned at 2.1m height above steps of the stairs reached the highest value at the position which were those the 5th or 6th step of corresponding stairs (scenario 1: ST2, scenario 2: ST3, ST4, scenario 3: ST4) near the fire source (It was at the position of 2.8m~2.9m height above the platform surface). In connection with the last fire scenario (train fire), the environmental temperature that we concerned at relative 2.1m height above steps of the stairs reached the highest value at the position which were those the 5th or 6th step of corresponding stairs (ST2, ST3) near the fire source (It was at the position of 2.8m~2.9m height above the platform surface). Temperature-time curves of the subway fire at the location of 2.1m height above the 5th or 6th step of corresponding stairs were shown in Fig.8 and Fig.9.

Generally, the temperature of baggage fire achieved its maximum value of 170℃ in about 7min and that of train fire reached its maximum value of 730℃ nearly 4min later after fire happened.

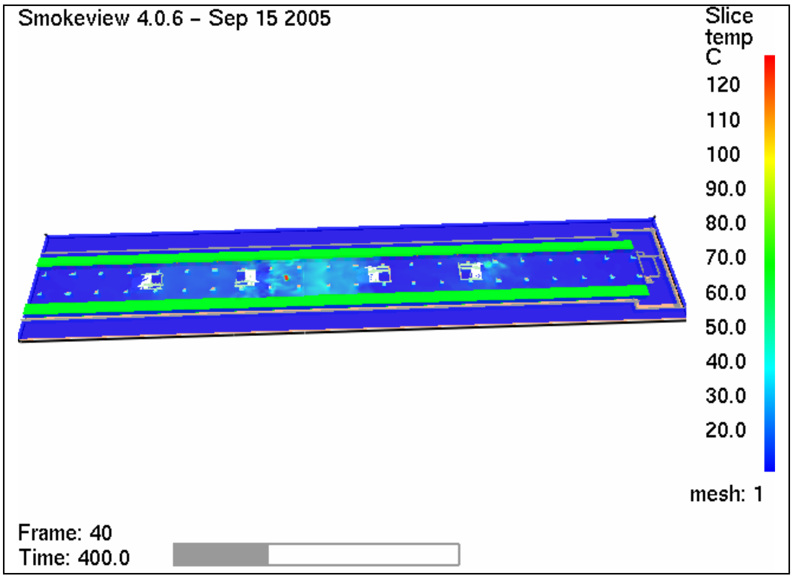

Fig.6 Simulation result of temperature at 2.1 m height above platform surface in scenario 1 (t=400s)

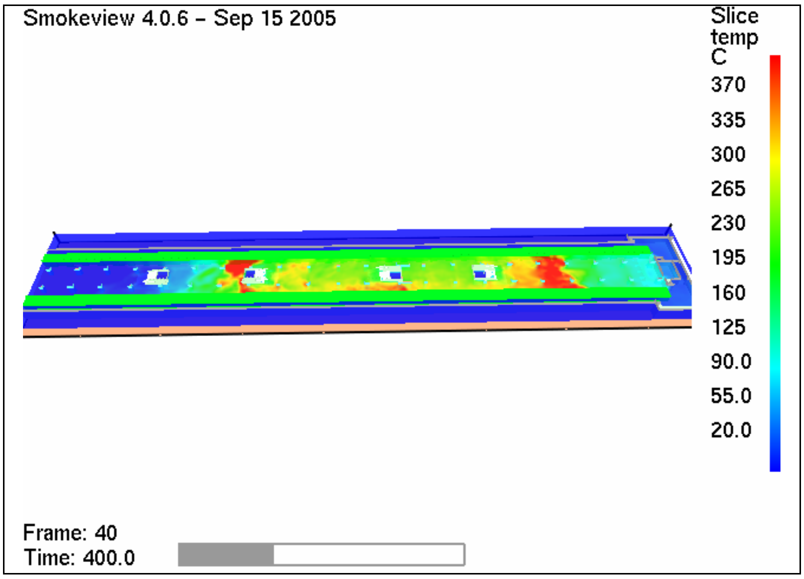

Fig.7 simulation result of temperature at 2.1 m height above platform surface in scenario 4 (t=400s)

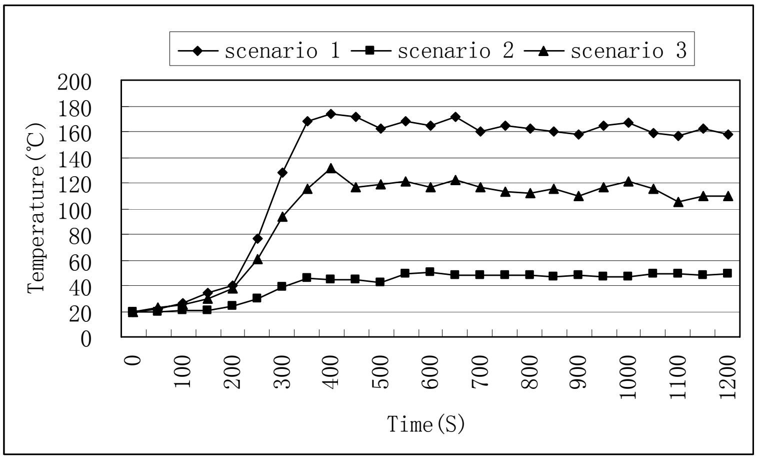

Fig.8 Temperature-time curve of baggage fire at the location of 2.1m height above steps of the stairs

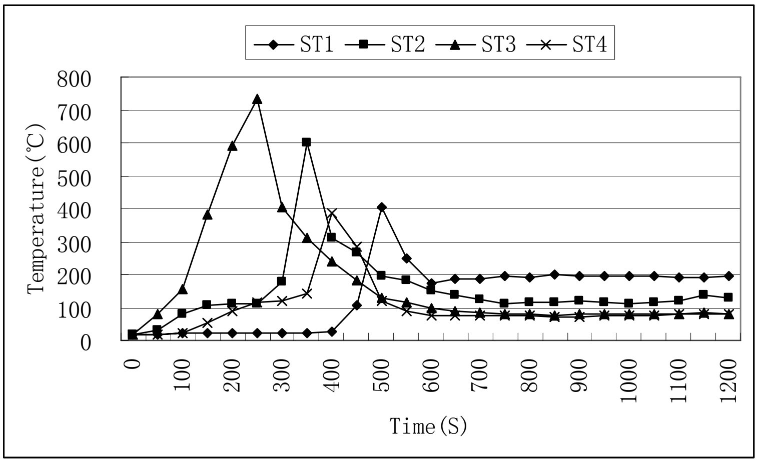

Fig.9 Temperature-time curve of train fire at the location of 2.1m height above steps of the stairs

3.2 Visibility Distribution Characteristics in Subway Fire

Smoke from baggage fire source spread in the platform and then quickly rose to the subway station hall and the atrium through the space above stairs by buoyancy. Besides, the smoke in the hall also extended to the platform through stairs away from the fire source. The movement of smoke emerged to be stable in about 400s. Owing to increasing of smoke thickness, visibility decreased rapidly. Simulation result of smoke distribution in scenario 1 (t=200s) was shown in Fig.10.

With respect to train carriage fire, the temperature of smoke layer in the area of fire source increased gradually, hot smoke diffused in the carriage. At the same time, it entered into the platform through the shield door and then rose to the hall through the space above stairs and the atrium. The movement of smoke went in steady state about 500s later. The corresponding visibility lowered quickly. Simulation result of smoke distribution in scenario 4 (t=200s) was shown in Fig.11.

Aimed at the first three fire scenarios of baggage fires, the visibility reached the lowest value at the position which were at relative 2.1m height above the 5th or 6th step of corresponding stairs (scenario 1: ST2; scenario 2: ST3, ST4; scenario 3: ST4) near the fire source. These positions were 2.8m~2.9m high above the platform surface. The visibility of train fire reached the lowest value at the position which was at relative 2.1m height above the 5th or 6th step of corresponding stairs (ST2, ST3) near the fire source. It was just almost the same as that of baggage fires. Visibility-time curves of the subway fire at the location of 2.1m height above the 5th or 6th step of corresponding stairs were shown in Fig.12 and Fig.13 respectively.

In general, the minimum value of visibility for baggage fire emerged in almost 5min and that of train fire about 4min.

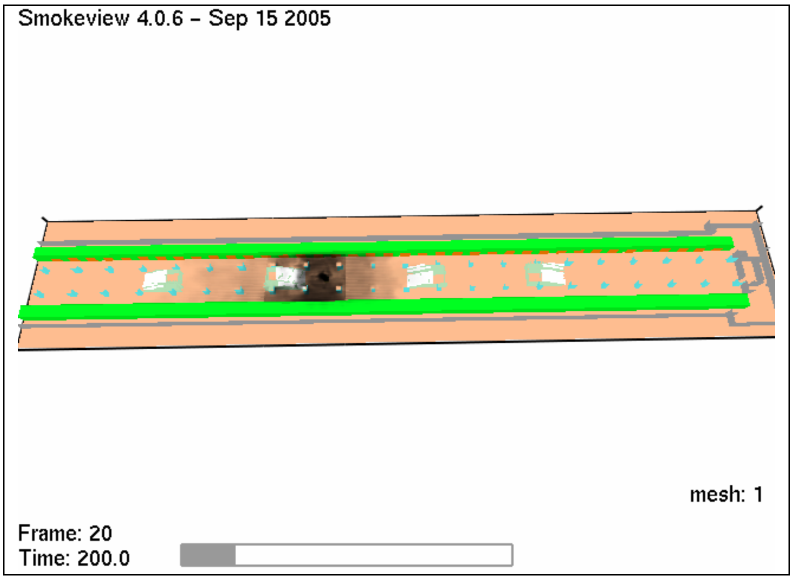

Fig.10 Smoke distribution in scenario 1 (t=200s)

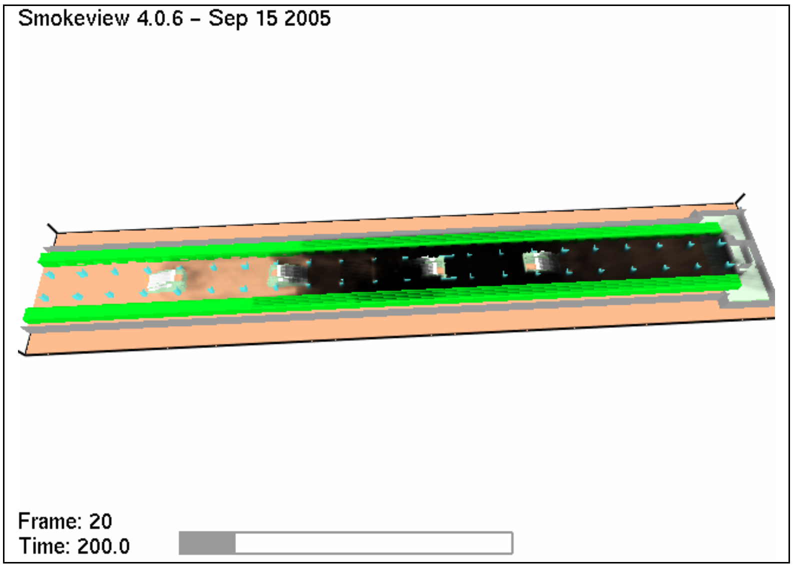

Fig.11 Smoke distribution in scenario 4 (t=200s)

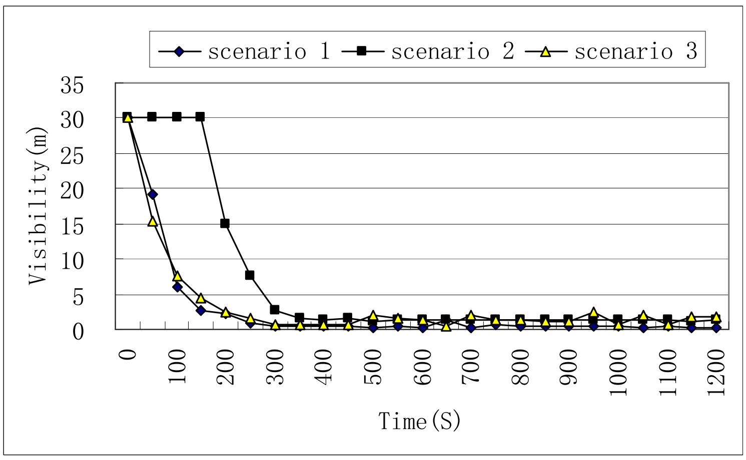

Fig.12 Visibility-time curve of baggage fire at the location of 2.1m height above steps of the stairs

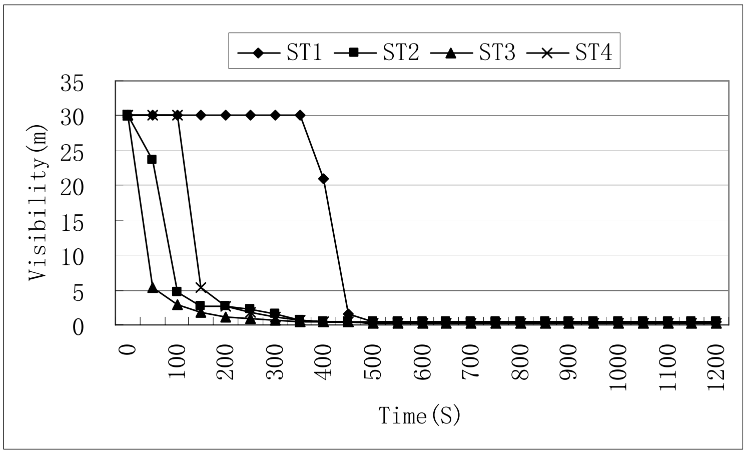

Fig.13 Visibility-time curve of train fire at the location of 2.1m height above steps of the stairs

3.3 CO Thickness Distribution Characteristics in Subway Fire

During the combustion process of baggage fire, the CO thickness changed within a narrow range at the early stage of fire. Not until a certain time later did the value of that increase sharply. Simulation result of CO thickness in scenario 1 (t=400s) was shown in Fig.14.

The CO thickness also varied slightly in the beginning period of train fire, its value almost maintained zero. Yet some time later, the CO thickness climbed sharply and reached maximum value in a short time, and then remained stable. Simulation result of CO thickness in scenario 4 (t=400s) was shown in Fig.15.

With regard to the highest value of the CO thickness at relative 2.1m height, the first three fire scenarios of baggage fire were located among the area above the 5th or 6th step of corresponding stairs (scenario 1: ST2; scenario 2: ST3, ST4; scenario 3: ST4) near the fire source. They were also at the position of 2.8m~2.9m height above the platform surface. The relevant situation for the CO thickness of train fire achieved its highest value at the position which was at relative 2.1m height above the 5th or 6th step of corresponding stairs (ST2, ST3) near the fire source. The CO thickness-time curves of the subway fire at the location of 2.1 m height above the 5th or 6th step of corresponding stairs were shown in Fig.16 and Fig.17.

To sum up, the CO thickness of baggage fire in subway junction station attained maximum value of 630ppm in about 7min and that for train fire got up to its maximum value of 645ppm almost 4min later as the fire took place.

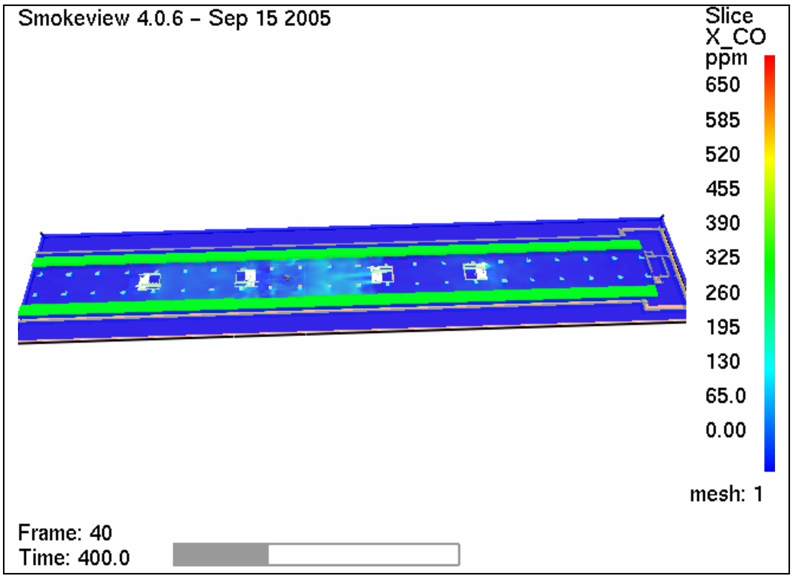

Fig.14 CO thickness distribution at 2.1 m height above platform surface in scenario 1 (t=400s)

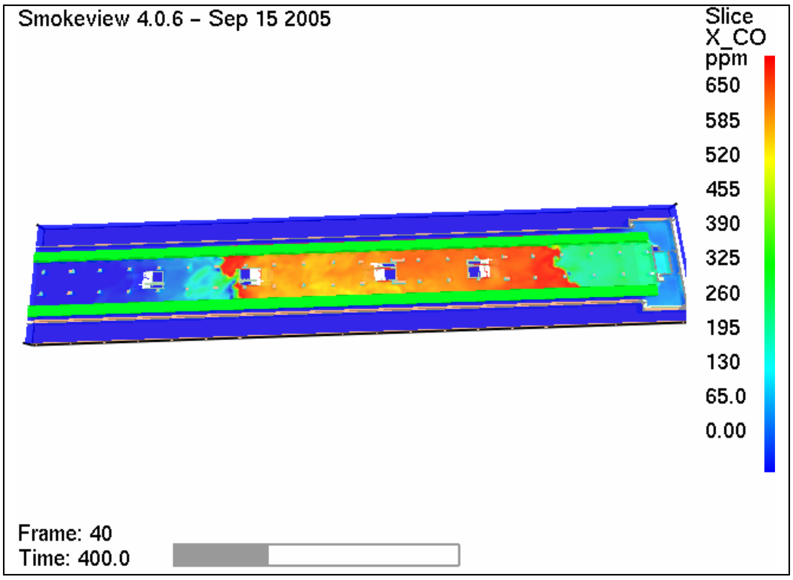

Fig.15 CO thickness distribution at 2.1 m height above platform surface in scenario 4 (t=400s)

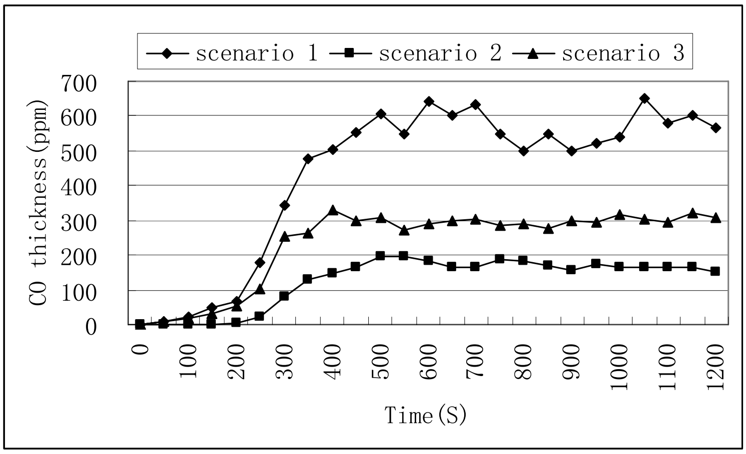

Fig.16 CO thickness-time curve of baggage fire at the location of 2.1m height above steps of the stairs

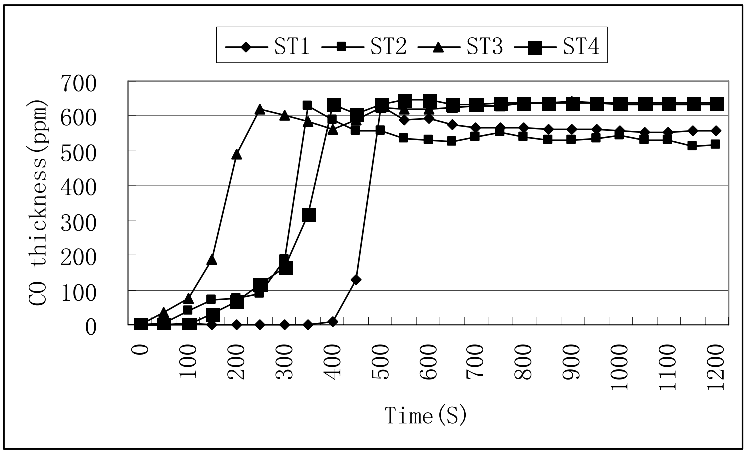

Fig.17 CO thickness-time curve of train fire at the location of 2.1m height above steps of the stairs

4 CONCLUSION

(1) Under the condition that the sprinkle and ventilation system were out of work, the larger the fire intensity, the higher the temperature and CO thickness and the lower the visibility in subway station fires.

(2) The location of subway station fires (such as baggage fire near platform stairs) had a great influence on distribution characteristics of temperature, visibility as well as CO thickness, which were at the position of relative 2.1m height above the station platform.

(3) As for the location of relative 2.1m height, the environmental temperature, visibility and CO thickness resulted from the subway station fires almost reached the highest (lowest) value at the position which was the 5th or 6th step of the stair. It was at 2.8m~2.9m height above the platform surface.

(4) In terms of baggage fires and aimed at relative 2.1m height, the environmental temperature reached 80℃ in 5min after the fire began to burn and achieved maximum value of 170℃ in about 7min. The visibility attained 10m in 2~4min and got to minimum values in almost 8min. The CO thickness achieved maximum value of 630ppm in nearly 6min and did not exceed 800ppm during the simulation.

(5) Considering train fire and directed at relative 2.1m height, the environmental temperature reached 80℃ in 2~3min once the fire took place and got up to its maximum value of 730℃ in 4min or so. The visibility achieved 10m in 1~7min and attained its minimum value in about 8min. The CO thickness reached its maximum value of 645ppm in about 4~8min and did not exceed 800ppm during the simulation.

(6) The change rate of temperature, visibility as well as CO thickness at the position of relative 2.1m height above the platform surface was less than that 2.1m height above the 5th or 6th step of the stair.

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