Experimentation of the Subway Smoke Control System

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INTRODUCTION

As a fast, comfortable urban transport tool with big capacity, subway has a history of more than a hundred years. It has been widely adopted in most of the major developed countries or regions and has been playing an important role in easing urban traffic pressure. However, because of the special structure of the subway, in the event of fire, large amount of smoke is generated, heat is not easy to spread, firefighting and rescue work is difficult to be carried out; serious casualties could be caused.

In a subway fire, smoke is the major factor threatening life safety. It not only impedes people's sight for escape, causes suffocation, but also makes the fire-fighting and rescue work difficult[1]. As one of the major fire facilities in subway, Smoke control system plays an irreplaceable role in the guarantee of the safety of people and facilitating the fire-fighting and rescue work. Therefore, field test were done by Tianjin Fire Research Institute of the Ministry of Public Security to analyze the performance of the smoke control system in a new subway before it was put into operation. The field test and numerical simulation analysis could not only provide an objective and accurate evaluation, but also help us to find problems and to put forward suggestions for improvement. The research will also provide basic data for amendments to the related existing technical specifications of China.

1 FIELD TEST PROCEDURE

1.1 Brief introduction to the subway station

The subway station is two-story island-type. The concourse is on the first floor of the underground. It has 4 entrance/exits to the ground, namely 1,2,3 and 4. The second floor of the underground is the platform. Two stairs and two escalators connect the platform and the concourse, namely stair 1 and 2 and escalator 1 and 2. The layout of the concourse and the platform is shown in Figure 1and Figure 2 respectively.

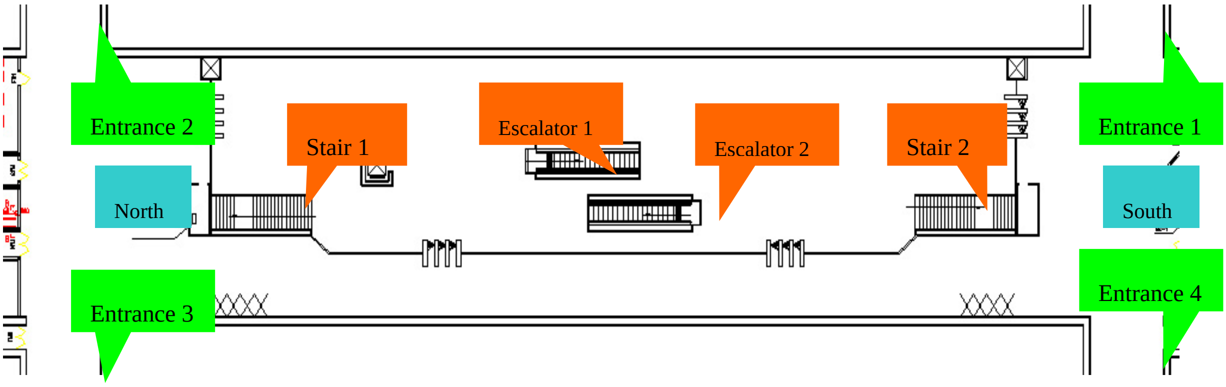

***Fig.1.* Layout of the concourse**

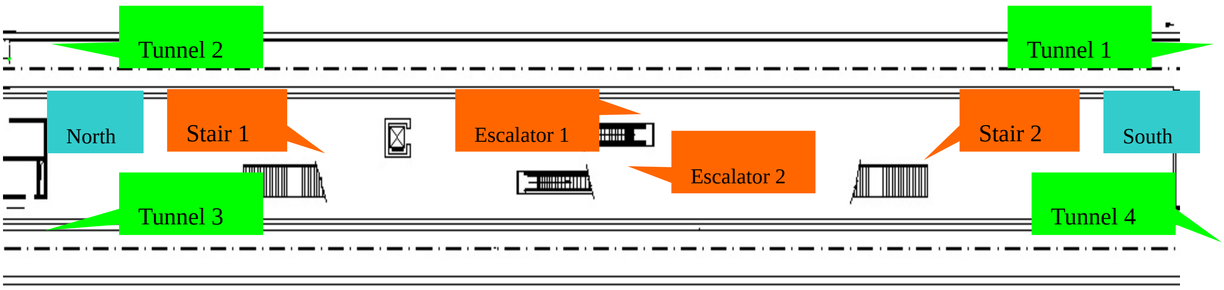

***Fig.2.* Layout of the platform**

According to the design, the platform and the concourse were respectively divided into 2 separate smoke-proof divisions -A, B and C, D, with an area of 537m^2, 560m^2, 854m^2 and 856m^2 respectively. The concourse has exclusive exhaust ducts, arranged in two rows with a total of 52 outlets; the ventilator at the top of the platform, with 66 outlets in two rows, serves as a smoke exhauster for the public area. The exhaust ducts at the top of the two tracks, a total of 108 outlets with 54 outlets for each exhaust duct, also used to exhaust smoke. The main smoke-proof parameters of the station are shown in Table 1:

***Table 1*　Main parameters of smoke proof/exhaust design of the subway station**

Location	Area of smoke-proof division（m^2）		Arrangement of exhausters, exhaust ducts and outlet	
Platform floor	smoke-proof division A	smoke-proof division B	Over platform	Over tracks
	537m^2	560m^2	2 rows of exhaust ducts 33×2 outlets	2 rows of exhaust ducts 54×2 outlets
Concourse floor	smoke-proof division C	smoke-proof division D	2 rows of exhaust ducts 26×2 outlets	
	854m^2	856m^2		

2.2　Test method

On-site tests can check the installation and operation of the smoke prevention/exhaust system of the subway, as well as the difference between the design and actual effects. In order to simulate the real circumstances of the fire, the test were carried out in 2 ways: one is to use smoke cake to produce smoke with industry alcohol auxiliary heating method to increase buoyancy of the smoke. The other is to use wood crib to simulate the actual fire with a certain scale.

Baggage fire commonly occurred in the concourse and platform of subway station. The average fire scale of the common luggage fire was determined as 200kW~400kW according to some related research report[2]. In order to obtain a better repeatability, wood crib fire was applied to simulate the actual fire of this scale.

Wood crib was prepared in accordance with national standard *Characteristics and tests for transportable fire extinguishers*(GB 8109-1987)[3]. Through the results of several different sizes of wood crib fire tests with large-scale calorimeter, the size of the wood crib used in the actual test was defined as: 500mm × 1300mm × 6-layers, the scale of the fire were 0.5MW ~ 0.7MW.

As the smoke produced by wood crib was relatively different from that produced in the actual fire, it wasn't able to get a good result in testing the performance of the station's smoke proof/exhaust system. Therefore, wood crib fire plus smoke cake methods was used in hot smoke test.

2.3 Contents of the full-scale test

According to the purpose of the test as well as the structure of the station, 3 scenarios (smoke-free, cold smoke and hot smoke) were adopted at 2 areas- concourse andplatform.

1）Performance test of ventilation status of the concourse and platform at normal condition: To test the performance of exhaust system and internal environmental status of subway station under normal condition;

2) Smoke-proof division test: in case of fire in platform/concourse, hot and cold smoke tests were carried out at typical locations such as the stair exit, escalator mouth, platform and concourse center so as to test the actual effects of the smoke-proof divisions and smoke-proof Facilities;

3) Cross-section wind speed measurement on the concourse and platform: in case

of fire in platform/ concourse, hot and cold smoke tests were carried out at typical locations such as the stair exit, escalator mouth, platform and concourse center so as to observe the flow of gas and to measure continuously the cross-section wind speed of the stairs and the escalators;

3 Full-scale test of the station

3.1 Concourse fire

3.1.1 ventilation / smoke exhaust system operation mode of the station

In case of concourse fire, the station concourse's ventilation / smoke exhaust system adopts the smoke exhaust mode, to stop air supply and exhaust the smoke of the concourse through the smoke tower to the ground. At the same time, the ventilation/smoke exhaust system adopts the wind blowing mode, so that smoke will not spread to the platform. the fresh air enter the concourse through the entrances/exits of the platform in order to facilitate the evacuation of passengers from the concourse to the ground. The smoke control method of the concourse is as shown in Table 2:

Table 2 **smoke control mode in concourse fire**

Location of fire source	Exhausters in concourse		Exhausters in platform		Exhausters above tracks	
	Scenario	Outlet number	Scenario	Outlet number	Scenario	Outlet number
concourse	Smoke exhaust	52	Wind supple-ment	34 at south end	—	—

3.1.2 Test results

In case of concourse fire, the main content of the test is the wind speed of the smoke outlet in the concourse. During the test, the wind speed of 5 different locations for each smoke outlet among 52 outlets was measured. After filtering and data processing, the average wind speed of the smoke outlets in concourse was 3.7m/s.

The dimension of smoke outlets in the concourse was 500mm × 500mm with deflection grilles. Its designed wind capacity was 5262m^3/h. the average wind speed measured in the test was 3.7m/s, which was equivalent to the wind capacity of 3330m^3/h (55.5 m^3/min)-about 63% of the value of the design value. According to the actual construction area of the concourse (1710m^2), the actual amount of smoke exhaust is calculated as (55.5m^3/min × 52) / 1710 m^2 = 1.69 m^3/m^2 min.

Test results showed that the smoke ventilation/smoke exhaust system designed for the concourse couldn't meet the design requirements. The duct's pressure loss and the fan performance were tested. Only to find that when the concourse's ventilation/smoke exhaust system was switched to the fire mode, serious leakage occurred at valves and ducts, and the exhaust amount couldn't meet the design requirements.

After the adjustment and improvement of the system, another test was carried out. The average wind speed of the concourse's smoke outlet increased to 4.04m/s; the air flow of a single smoke outlet is $3636 m^3/h$ ($60.6\ m^3/min$), which was about 70% of the value of the design. As a result, the smoke exhaust capacity of the concourse measured in the test was $(60.6m^3/min \times 52) / 1710\ m^2 = 1.84\ m^3/m^2$ min, which still couldn't meet the design requirements.

3.1.3 Hot smoke test in case of concourse fire

In case of concourse fire, the hot smoke test was carried out. Figure 3 showed the smoke movement in the concourse during the hot smoke test.

According to the observation, the visibility in the concourse was less than 2m when the fire developed to its medium-term, which meant that the ventilation/smoke exhaust system behaved badly in fire. By improving the ventilation/smoke exhaust system, the smoke exhaust capacity was improved obviously, and the visibility reached to 5m. However, smoke at entrance/exit 1 gathered and settled due to the incompletion of the entrance/exit, which led to poor air circulation.

***Figure.3.* smoke movement in concourse during hot smoke test**
(fire source at the center of the concourse)

3.2 Platform fire

3.2.1 ventilation / smoke exhaust system operation mode of the station

In case of platform fire, the ventilation / smoke exhaust system of the platform and the hot smoke exhauster at top of the tracks adopted smoke exhaust mode. The smoke in the platform was exhausted through the smoke tower to the ground. Fresh air entered the platform through the entrances/exits, concourse, and mouths between the concourse and platform. The smoke control method of the platform is shown in Table 3:

Table 3 **Smoke control in platform fire**

Location of fire source	Exhausters at concourse		Exhausters at platform		Exhausters above tracks	
	Scenario	Outlet number	Scenario	Outlet number	Scenario	Outlet number
platform	—	—	Smoke exhaust	66	Smoke exhaust	108

3.2.2 Test results

In case of platform fires, the wind speed of the smoke exhaust outlets at the top of the platform and tracks was measured. The average wind speed of the smoke exhaust outlets above platform was 3.8m/s, the average wind speed of the smoke exhaust outlets above tracks was 1.65m/s.

500mm × 500mm double layer smoke exhaust outlets, with an designed air capacity of 5454.5m^3/h, were used at the top of the platform. The average wind speed measured in the test was 3.8m/s, which was equivalent to the wind capacity of 3556.8m^3/h (59.3 m^3/min)-about 65% of the value of the design. According to the actual construction area of the platform ($1097m^2$), the actual amount of smoke exhaust of the smoke exhauster at the top of the platform was calculated as ($59.3m^3/min×66)/1097\ m^2=3.56\ m^3/m^2·min$.

500mm × 1000mm smoke exhaust outlets were used at the top of the tracks. The average wind speed measured in the test was 1.65m/s, which was equivalent to the wind capacity of $2970m^3/h$（$49.5\ m^3/min$）. The actual amount of smoke exhaust of the smoke exhauster at the top of the tracks was calculated as ($49.5m^3/min×108)/1097m^2=4.87\ m^3/m^2·min$.

In case of platform fire, downward wind speed was tested at different locations of the two stairs and two escalators. According to test results, the actual downward wind speed of stairs was between 0.82 m/s ~ 1.15 m/s.

3.2.3 Cold and hot smoke test in case of platform fire

In case of platform fire, cold smoke test was carried out at the centre of the platform, platform stairs, and the tunnel near the platform respectively. Figure 4 shows the smoke movement observed at the escalator when cold smoke released at the centre of the platform. Figure 5 shows the smoke movement observed at the stairs when cold smoke released at the stairs.

Fig.4. **status at the mouth of the escalator under platform cold smoke test（cold smoke source was in the center of platform）**

Fig.5. **status at the mouth of the escalator under platform cold smoke test**
（cold smoke source was in the mouth of escalator）

According to the observation, regardless of locations of the smoke source, under the effect of the downward airflow at the stair and escalator mouths and the around retaining walls, smoke was not found spreading to the concourse from the stair and escalator mouths.

In case of platform fire, hot smoke test was carried out with the smoke source at the centre of the platform. Under the joint action of the downward airflow (0.82m/s ~ 1.15m/s) and the retaining wall at the mouths of the stairs and the escalators, no smoke spread from the platform to the concourse when hot smoke released at the maximum heat release rate of 0.5 ~ 0.7MW.

Through the cold and hot smoke tests, we can see that although the measured downward air flow speed at the stair mouths can not meet 1.5m/s, which is stipulated in the national standard "Code for Design of Metro" (GB50157-2003)[4], the existing design achieves the desired results. The evacuation of passengers has been secured and the objectives of stopping the spread of smoke to the concourse through the mouths of the stairs and the escalators have been achieved.

Figure 6 and Figure 7 shows the smoke flow of the platform under the hot smoke test condition. We can see from them that the effect of the smoke-proof divisions divided by the retaining walls is not satisfactory. The entire platform has become one division. The reason for this phenomenon is that the retaining walls were not built above the tracks at the side of the platform, but only built along the centre of the platform.

Fig.6. **hot smoke test: south end of platform**

（the hot smoke source was at the center of the platform）

Fig.7. **hot smoke test: north end of platform**

（the hot smoke source was at the center of the platform）

4 CONCLUSION

Through the systematic full-scale fire test, the newly built subway is able to meet basic requirement for safe evacuation of people in case of a fire. But there are still some problems that need to be further improved. For example, the closeness of the switching valve and ducts of the ventilation / exhaust system should be further dealt with, and the capacity of the smoke exhaust system should be improved; entrance 1 of the station should be constructed timely and be improved to ensure smooth flow of the air and avoid settlement and gathering of smoke; the smoke exhaust effect of the concourse and the smoke-proof division of the platform need to be improved, is necessary to build smoke retaining wall above the tracks near platform. In addition, it has been found from the test that in the existing “code for Design of Metro", the value given for the smoke exhaust volume of platform is low while the downward wind speed at stair mouth is high. We suggest that those requirements should be adjusted.

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