Analysis and Control of Fire Safety Risks in the Connected Areas between Subway Underground Stations and Surrounding Underground Spaces

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Abstract: This paper reviews the characteristics, advantages, disadvantages, and fire safety risk features of the five types of connections between subway underground stations and surrounding underground spaces; for the connected areas between subway underground stations and surrounding underground spaces, based on existing standard specifications, the paper proposes key points for fire safety risk identification; analyzes the fire safety risk characteristics from five aspects: fire hazard sources, fire propagation pathways, evacuation conditions, fire-fighting facilities configuration, and fire safety management, and puts forward effective risk control measures and suggestions. The results of this paper can provide technical support and reference for improving the fire safety level of the connected areas between subway underground stations and surrounding underground spaces.

1. Introduction

With the acceleration of urbanization, as an efficient, environmentally friendly, and energy-saving public transportation method, the subway is increasingly favored by people[1]. At the same time, to improve the utilization and functionality of underground space, subway underground stations often form connected areas with surrounding commercial, cultural, entertainment, and other underground spaces, forming complex underground building groups. However, such connected areas also bring fire safety risks, such as fire spread, smoke diffusion, and difficulties in evacuation. Once a fire occurs, it may cause a large number of casualties and property losses, and even trigger social panic and unstable factors[2]. Therefore, conducting a fire safety risk analysis and control of the connected areas between subway underground stations and surrounding underground spaces is a necessary measure to ensure the safety of urban transportation operations and people's lives and property.

This paper aims to explore the connection methods between subway underground stations and surrounding underground spaces, fire prevention design, analyze fire safety risk characteristics and influencing factors, and propose effective risk control measures and suggestions, providing scientific decision-making basis and technical support for relevant departments and units. This paper has important theoretical significance and practical value. It can not only improve the fire safety level of the connected areas between subway underground stations and surrounding underground spaces, reduce the possibility and consequences of fire accidents, but also provide reference and lessons for fire safety risk analysis and control of other similar underground building groups.

2. Connection Methods and Characteristics between Subway Underground Stations and Surrounding Underground Spaces

According to the Shanghai Construction Standard "Code for Design of Connections between Underground Rail Transit Stations and Adjacent Underground Spaces" (DG/TJ 08-2169-2015), the

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connection methods between underground stations and surrounding underground spaces can be categorized based on their spatial relationships into: passage connection, shared wall connection, vertical connection, sunken plaza connection, and integrated connection[3]. As shown in Figure 1. The characteristics, advantages and disadvantages, as well as potential fire safety risks of these five connection methods are shown in Table 1[4][5]

Table 1: Connection Methods between Subway Underground Stations and Surrounding Underground Spaces

Connection Method	Features	Advantages	Disadvantages	Fire Safety Risks
Passage Connection	Underground stations and surrounding underground spaces are connected through an underground passage at the horizontal level due to a certain distance between them.	Effective utilization of underground space, expansion and attractiveness of underground commercial activities, and convenience for passenger transfer and access.	The length of the passage may be restricted, potentially causing congestion.	High risk of fire spread, requiring sufficient fire separation, smoke control measures, and reasonable evacuation routes and equipment.
Shared Wall Connection	Underground stations and surrounding underground spaces share underground walls, and connection is achieved through doorways in the shared walls.	Saves underground space, reduces construction costs and duration, and maintains the independence and security of underground spaces.	Has certain impacts on the structural stability of the station.	Openings or doors and windows in the walls may become pathways for fire spread, requiring strict fire doors and windows, and regular inspection and maintenance.
Vertical Connection	Underground stations and surrounding underground spaces have a vertical relationship, and connection is achieved through vertical transportation (elevators, escalators, stairs).	Saves underground space, simplifies structure and construction, and reduces the possibility of fire spread.	Increases the height of vertical space, posing challenges to structural design.	Shafts or stairs may become chimney effects during a fire, accelerating fire expansion and smoke rise, requiring effective separation and smoke control measures, and ensuring sufficient safety exits in the shafts or stairs.
Sunken Plaza Connection	There is a sunken plaza between the underground station and the surrounding underground space, and connection is achieved through the sunken plaza.	Increases natural lighting and ventilation of underground spaces, improves comfort and aesthetics, and adds vitality and popularity to underground spaces.	Occupies ground space, impacting urban planning.	May produce large amounts of smoke and heat during a fire, affecting the safety of people in the plaza and rescue operations, requiring appropriate smoke exhaust systems and fire-fighting facilities.
Integrated Connection	Underground stations and surrounding underground spaces are organically connected, forming a whole, and achieving connection in multiple directions, horizontally and vertically.	Maximizes the use of underground space, creating a multi-functional and multi-level comprehensive space, and improves passenger travel efficiency and comfort.	Increases the complexity of management. Consideration of fire safety and evacuation issues is required, and design must accommodate different uses and safety needs of the subway station and surrounding spaces.	Fire may involve multiple areas and levels during a fire, requiring a complex and comprehensive fire protection system and management system, and the development of detailed and flexible emergency plans.

(a)Passage Connection (b)Shared Wall Connection (c)Vertical Connection

(c)Sunken Plaza Connection (d)Integrated Connection

Figure 1: Subway Underground Station Connection Methods with Surrounding Underground Spaces

3. Fire Safety Risk Analysis of the Connected Areas between Subway Underground Stations and Surrounding Underground Spaces

The fire safety risk analysis of the connected areas between subway underground stations and surrounding underground spaces is one of the essential components of subway operation management. The connectivity between underground stations and adjacent underground spaces may lead to the spread of fires, the proliferation of smoke, and difficulties in evacuation, posing a severe threat to fire safety. Therefore, it is necessary to systematically identify the fire safety risks in these connected areas, analyze their risk characteristics, and propose corresponding risk control measures to ensure the fire safety of the connected areas between subway underground stations and surrounding underground spaces.

3.1. Fire Safety Risk Identification

Current standards and specifications provide detailed requirements for the fire safety of the connected areas between subway underground stations and surrounding underground spaces[4][5][6]. This paper organizes these regulations and distills key points for fire safety risk identification, as shown in Table 2.

Table 2: Key Points for Fire Safety Risk Identification in the Connected Areas between Subway Underground Stations and Surrounding Underground Spaces

Building Category	Fire Safety Risk Identification Focus	Code Requirements	Reference Specifications	Implementation Date
General Provisions for Connection	For projects newly built or renovated after 2018, buildings connected to	Article 4.1.6: Commercial and other non-subway function areas located on the same level as the station hall public area should be separated from the station hall public area by firewalls. They	"Subway Fire Protection Design Standard" (GB51298-2018)	December 1, 2018

Areas between Subway Underground Stations and Surrounding Underground Spaces	subway underground stations should not be directly connected to the subway.	should be connected through sunken plazas or connecting passages instead of direct connections.		
	The connection project between the overhead building and the station should be subjected to fire separation.	Article 8.2.7: The connection project between the overhead building and the station should use firewalls with a fire resistance rating of 3.00 hours, and floor slabs with a fire resistance rating not lower than 2.00 hours for fire separation. When openings are necessary, they should be equipped with fire shutters with a fire resistance rating not lower than 3.00 hours or Grade A fire doors.	Design Standard for Upper Cover of Urban Rail Transit(DG/TJ 08-2263-2018)	September 1, 2018
	At the connection, two fire shutters are required and should be controlled by the subway station and the connecting unit respectively.	Article 8.2.3: When the connection project uses fire shutters for separation between the surrounding underground space and the underground station, the fire separation measures should be set on both sides of the management section and controlled independently.	"Code for Design of Connections between Underground Rail Transit Stations and Adjacent Underground Spaces" (DG/TJ08-2169-2015)	November 1, 2015
	The safe evacuation of the underground station and the surrounding underground space should be set up independently. No safety exit signs should be set above the connection, and it should not be used as a safety exit.	Article 8.3.1: The safe evacuation of the underground station and the surrounding underground space should be set up independently. The fire safety evacuation of the connection project should be included in the overall design of the managing party. When the connection project is managed by a third party, the evacuation facilities should be set up independently.	"Code for Design of Connections between Underground Rail Transit Stations and Adjacent Underground Spaces" (DG/TJ08-2169-2015)	November 1, 2015
	Evacuation signs and emergency lighting should be set up in the connection project.	Article 8.4.3: Evacuation signs should be set up in the connection project. The standard for emergency lighting in the connection passage should not be lower than that of the underground station (emergency lighting should be powered by a dedicated circuit from the emergency power supply, the minimum horizontal illuminance on the ground should not be less than 3.0lx, the continuous power supply time should not be less than 60 minutes, and the switch time from normal lighting to emergency lighting should not exceed 5 seconds).	"Code for Design of Connections between Underground Rail Transit Stations and Adjacent Underground Spaces" (DG/TJ08-2169-2015)	November 1, 2015
	The fire control room of the surrounding underground space and the fire control room of the underground station should have intercom fire telephones.	Article 8.4.5: The fire control room of the surrounding underground space and the fire control room of the underground station should have intercom fire telephones.	"Code for Design of Connections between Underground Rail Transit Stations and Adjacent Underground Spaces" (DG/TJ08-2169-2015)	November 1, 2015
Sunken Plaza Connection	N/A	Article 8.2.1: When using sunken plazas for connection, the following requirements should be met: 1. The short side of the sunken plaza should not be less than 13m, and the area should not be less than 169m^2 . 2. For sunken plazas with sunshades, the sunshades should not be fully enclosed, and the openings around should be evenly distributed. The area of the openings should not be less than 25% of the ground area of the open space outdoors, and the height of the sunshades above the roof surface should not be	"Code for Design of Connections between Underground Rail Transit Stations and Adjacent Underground Spaces" (DG/TJ08-2169-2015)	November 1, 2015

		less than 1m; when using rainproof louvers around, the height above the roof surface should not be less than 1.6m, and the ventilation and smoke exhaust area should be calculated based on the effective area of the louvers.		
Passage Connection	The connecting passage should have two fire shutters controlled by the subway and the adjacent building respectively, with a fire resistance rating of not less than 3 hours.	Article 4.1.6: The length of the connecting passage should not be less than 10m, and the width should not exceed 8m. The connecting passage should have two fire shutters controlled by the subway and commercial and other non-subway function areas respectively, with a fire resistance rating of not less than 3.00h.	"Subway Fire Protection Design Standard" (GB51298-2018)	December 1, 2018
	The connection project should have fire alarm systems, automatic sprinkler systems, indoor fire hydrant systems, smoke control systems, and other fire-fighting facilities.	Article 8.4.1: The connection project should have fire alarm systems, automatic sprinkler systems, indoor fire hydrant systems, smoke control systems, and other fire-fighting facilities.	"Code for Design of Connections between Underground Rail Transit Stations and Adjacent Underground Spaces" (DG/TJ08-2169-2015)	November 1, 2015
Shared Wall Connection	1. Two fire shutters should be set at the connection, controlled by the subway station and the connecting unit respectively. 2. The fire shutters and fire doors should have a fire resistance rating of not less than 3 hours. 3. The width of each fire shutter should not exceed 8m, and there should be a firewall with a width of not less than 24m between adjacent fire shutters. 4. Commercial decoration, advertising, etc., should not extend into the station area. 5. Fire shutters and the surrounding area of the connection must be properly fire-stopped, with no holes left.	Article 8.2.2: When using shared wall connections, the following requirements should be met: 1. The connection project and the surrounding underground space and the underground station should be separated by firewalls with a fire resistance rating of 3.00h, floors with a fire resistance rating of not less than 1.50h, fire shutters with a fire resistance rating of not less than 3.00h, or Grade A fire doors. 2. When using fire shutters for separation, the width of each fire shutter on each side of the station's external wall should not exceed 8m, and there should be a firewall with a width of not less than 24m between adjacent fire shutters.	"Code for Design of Connections between Underground Rail Transit Stations and Adjacent Underground Spaces" (DG/TJ08-2169-2015)	November 1, 2015
Vertical Connection and Integrated Connection	Vertical transportation facilities such as stairs, escalators, and vertical elevators used for connection should be located outside the main structure of the station.	Article 8.2.2: Vertical transportation facilities such as stairs, escalators, and vertical elevators used for connection should be located outside the main structure of the station.	"Code for Design of Connections between Underground Rail Transit Stations and Adjacent Underground Spaces" (DG/TJ08-2169-2015)	November 1, 2015

3.2. Fire Safety Risk Characteristics

The fire safety risk characteristics of the connected areas between subway underground stations

and surrounding underground spaces mainly include the following aspects:

(1) Structural complexity of the connected area. The connected area typically encompasses multiple underground spaces with different functions, such as commercial, parking, services, etc. These spaces are interconnected through various connection methods like stairs, elevators, and passages, which increase the difficulty and risk of fire spread and evacuation.

(2) High population density in the connected area. As the hub of the subway underground station and the surrounding underground spaces, the connected area is a place for people to enter, exit, and transfer. Therefore, high population density may occur under normal operations and emergency situations. People coming from different directions and destinations may have inconsistent emergency response capabilities and evacuation awareness, increasing the severity and scope of fire accidents.

(3) Poor environmental conditions in the connected area. Due to the underground location, the connected area is limited by natural lighting and ventilation conditions, which can easily lead to poor air quality, high temperature and humidity, and smoke accumulation. These phenomena not only affect people's comfort and sense of safety but also reduce the ability to detect and control fire accidents, increasing the spread speed and harmfulness of fire accidents.

(4) Low management level in the connected area. Involving multiple underground spaces with different functions and ownership, the connected area often lacks unified and effective management mechanisms and measures, such as the maintenance, inspection, and use of fire-fighting facilities, as well as personnel training, drills, and guidance. These management deficiencies lead to insufficient prevention and response capabilities for fire accidents, increasing the probability and degree of loss from fire accidents.

3.3. Fire Safety Risk Analysis

Based on the above fire safety risk characteristics, this paper analyzes the fire safety risks in the connected areas between subway underground stations and surrounding underground spaces from the aspects of fire hazard sources, fire propagation pathways, evacuation conditions, fire-fighting facilities configuration, and fire safety management:

(1) Analysis of fire hazard sources. Fire hazard sources mainly include electrical equipment, lighting equipment, ventilation equipment, cable lines, and flammable items, which may malfunction, short circuit, overheat, or rub during use, causing fires[2]. In addition, poor behaviors of passengers and staff, such as smoking, using open flames, and carrying dangerous goods, can also lead to fires[12].

(2) Analysis of fire propagation pathways. Fire propagation pathways mainly include connected doorways, stairwells, elevator shafts, exhaust shafts, and pipe shafts, which may become channels for the spread of smoke and flames during a fire, affecting the safety of other areas. Therefore, fire separation facilities, such as fire doors, fire shutters, and firewalls, should be installed in these pathways and regularly inspected and maintained.

(3) Analysis of evacuation conditions. Evacuation conditions mainly include evacuation sign indicators, width of evacuation passages, number of evacuation exits, and evacuation distances, which directly affect the escape efficiency and safety of passengers and staff during a fire[7][8]. Therefore, these conditions should comply with relevant specifications and be optimized and adjusted according to actual situations.

(4) Analysis of fire-fighting facilities configuration. Fire-fighting facilities mainly include automatic alarm systems, automatic sprinkler systems, portable fire extinguishers, emergency lighting systems, and public address systems, which play an important role during a fire, enabling timely detection and control of the fire, and guiding and assisting in the evacuation of personnel[1][9]. Therefore, these facilities should be configured according to specification requirements and maintained in good working condition.

Analysis of fire safety management. To ensure the fire safety of the connected area, a series of management measures need to be taken, including the formulation and implementation of fire safety regulations, strengthening of fire safety education and training, regular fire inspections and drills,

equipping and maintaining fire-fighting facilities and equipment, and establishing and improving fire emergency plans and organizational mechanisms. These management measures require coordination and cooperation from all parties, such as subway operators, business managers, public security departments, fire departments, etc., to form an effective fire safety protection system.

4. Fire Safety Risk Control Strategies for the Connected Areas between Subway Stations and Adjacent Buildings

Fire safety risk control in the connected areas between subway underground stations and surrounding underground spaces is an essential aspect of urban rail transit design. Due to the confined spaces, dense populations, and rapid fire spread characteristics of these connected areas, a fire incident could severely impact human safety and urban operations. Therefore, fire safety risk control should be approached from the following aspects:

(1) Strictly control the number, location, and scale of the connected areas to avoid excessive or large openings that may affect the station's fire compartmentation and evacuation efficiency. Connections should be situated near station entrances and exits for quick passenger evacuation and equipped with isolation facilities such as fire doors or fire shutters to prevent fire spread[10][11].

(2) Enhance the fire protection design and facility configuration in the connected areas to improve their inherent fire resistance and firefighting capabilities. The connected areas should be constructed with non-combustible or fire-resistant materials and equipped with adequate fire hydrants, firefighting equipment, smoke detectors, automatic sprinkler systems, emergency lighting, and signage, all integrated with the station's fire alarm and monitoring systems[1][9].

(3) Strengthen fire safety management and inspections in the connected areas to regulate internal fire and electricity use and item placement, eliminating various fire hazards. Regular fire patrols and drills should be conducted, and fire education and training for merchants and staff should be intensified to raise fire safety awareness and emergency response capabilities.

(4) Enhance fire safety coordination and linkage in the connected areas by establishing effective information communication and emergency response mechanisms to achieve fire safety integration between the station and surrounding underground spaces. The connected areas should maintain close contact and cooperation with the station, promptly reporting and handling fire incidents, organizing evacuation and rescue actions according to the emergency plan, and cooperating with firefighting department operations[12].

5. Conclusion

This paper takes the connected areas between subway underground stations and surrounding underground spaces as the research subject, analyzes their fire safety risk characteristics, and proposes effective risk control measures and suggestions. The main conclusions of this paper are:

(1) It reviews the characteristics, advantages, disadvantages, and fire safety risk features of the five connection methods between subway underground stations and surrounding underground spaces, providing a foundation for subsequent fire protection design and risk analysis.

(2) For the connected areas between subway underground stations and surrounding underground spaces, it identifies key points for fire safety risk based on existing standard specifications, offering technical guidance for ensuring fire safety in the connected areas.

(3) Analyzes the fire safety risk characteristics of the connected areas from five aspects: fire hazard sources, fire propagation pathways, evacuation conditions, fire-fighting facilities configuration, and fire safety management, and proposes effective targeted risk control measures and suggestions, providing feasible solutions for reducing fire risks and minimizing fire losses in the connected areas.

(4) The findings can provide technical support and reference for improving fire safety levels in the connected areas between subway underground stations and surrounding underground spaces and can also offer insights and inspiration for fire safety research in other similar engineering projects.

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