SAFETY AND RISK ASSESSMENT SYSTEMS FOR UNDERGROUND SPACE FACILITIES IN SHANGHAI

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ABSTRACT

Shanghai has now become the city with the largest scale of underground space construction in China. More than 10 million people commute every day through underground architectures, such as subways, underground garages, tunnels, underground transportation hubs, and underground commercial complexes. However, underground space also has its weaknesses regarding disaster prevention because of its internal environment characteristics, such as possibility of closures, restricted access, difficulty of rescue, and ease of spread of disasters. According to the investigation in Japan and other countries from 1970 to 2000, the causes of accidents in underground spaces mainly include equipment failure, fire, improper use of the facilities, flood caused by heavy rain, air condition deterioration, construction accident, structural damage, and human crime. Fire constituted 30.5% of these causes, air condition deterioration constituted 19.5%, construction accident constituted 16.1%, and flood constituted 4%. The number of these accidents in underground space facilities is increasing every year, thereby threatening the safety of underground space.

The authors study Shanghai and devise a safety and risk assessment system for underground space facilities based on the analysis of the causes of accidents in the underground space. The technical method of the assessment system comprises five key links, including the identification of risks; the formulation of a safety factors index, a safety evaluation criteria, an evaluation weight system; and the implementation of a comprehensive evaluation. The assessment system has also been applied to more than 100 cases of underground space safety evaluations in Shanghai, during which the applicability of the system is further verified and improved. This paper explains and discusses the main technical route of the assessment system and the main contents of each key link.

1. THE CHARACTERISTICS OF UNDERGROUND SPACE DISASTERS AND ACCIDENT STATISTICS

1.1 Characteristics of underground space disaster

(1)Strong closure and disaster destructiveness aggravation. People are easy to lose their sense of direction in underground space. When a disaster occurs, the level of psychological panic and action confusion is more serious than that in the buildings on the ground; secondly, when the malfunction of mechanical ventilation system happens, it's very difficult to rely on natural ventilation as a remedy. What's worse, it's very difficult to control and exclude the smoke in underground space and it is unfavorable for the internal personnel evacuation and the entrance of external rescue staff.

(2)Entrance being restricted, being difficult to evacuate. There is a vertical upward process in the evacuation and refuge from underground space to the open space of the ground, the process needs more physical power than downward, so it affects the speed of the evacuation. At the same time, the evacuation route from the bottom to the top is consistent to the natural flow of the internal smoke and heat, also causes great difficulties to personnel evacuation.

(3)Difficult to implement the rescue. Many rescue equipment can't be in place in time when underground space disaster happens. In addition, the bar-mat reinforcement and the surrounding soil or rock in the underground structures have a shielding effect on the electromagnetic wave, it also hinders the use of wireless communications, it will affect the communication work of the prevention of the internal disaster center and delay the implementation of the rescue.

(4)Great possibility of the expansion and spread of disasters. For basements attached to the buildings in the ground, as being connected with the buildings in the ground, the possibility of the expansion and spreading of the internal hazards to the ground is large, which causes great threat on the upper buildings.

1.2 The statistics of underground space accidents

Relatively speaking, the time of underground space development in China is short and we lack foundational research data of the types of underground space disasters and the vulnerability of underground engineering disasters, our research group learned from some research results of underground disasters in Japan, at the same time we made a statistical analysis of great underground space accidents in shanghai since 2000 and made a summary of the type characteristics and location characteristics of underground space accident.

(1)Statistics and analysis of the types and frequency of disasters in underground space

According to the statistics of various kinds of the calamity and accidents in the domestic and foreign underground space in the period 1970-1990 by the 720 research group in Japan, and the statistics of great underground space accidents in Shanghai since 2000 made by our research group, the underground space usage safety accidents mainly include: fire disaster, flood accident, explosion, poisoning (deterioration of air quality), terrorist attacks (fire accident, explosion, hazmat, etc.), traffic accident, damage to the structure, public facilities failure, crime and so on. Among them, disasters caused by fire are the most, which account for about 1/3, when there is a fire, the condition of smoking elimination and cooling is very poor, temperatures increase rapidly, the toxic smoke produced by fire can make people suffocated, and it can reduce visibility, resulting in personnel evacuation difficulty, making fire-fighting difficult and causing great damage. It is the underground space disaster which can't be neglected mostly.

Other major disasters in underground space include: equipment failure, fire, improper use of the facilities, flood caused by heavy rain, air condition deterioration, construction accident, structural damage, and human crime. Fire constituted 30.5% of these causes, air condition deterioration constituted 19.5%, construction accident constituted 16.1%, and flood constituted 4%.

(2)Statistical analysis of the location of underground space disasters

According to the statistical analysis, the numbers of disasters in places which have many personnel activities are large such as the underground public, public facilities, such as underground street, subway station, accounting for about 50% of accidents. When disasters occur, the vulnerability of the personnel intensive underground facilities is relatively large, it should become the focus prevention and management of underground space disasters.

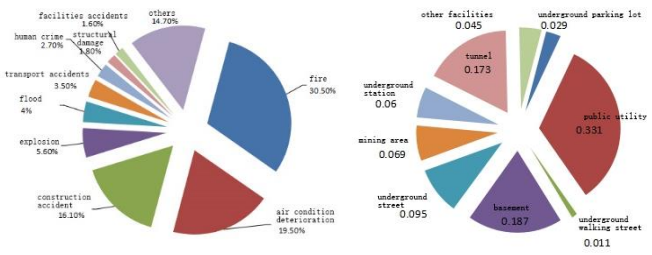

Fig.1 Statistics of the kind of disaster and occurred places

2. IDENTIFICATION OF RISKS OF UNDERGROUND SPACE DISASTERS

According to the analysis of major accidents in Shanghai underground space, as well as the safety hazard of underground space in the operational period by our research group, we classify the risk of underground space disasters into various types:

(1)Identification of risks of fire

Contains: Delaying alarm; difficulty in locating the spot, which delays the primary fire- fighting action; accessibility of fire brigade to the fire spot; water shortage near the fire source; blockage of information transmission; wrong guidance to refugees, which detain them in fire scene; unable to startup manual sprinkle facilities; failure of spare power supply; malfunctions of fire extinguishing equipment in air duct and funnel; unable to startup composite fire extinguishing equipment which caused by effect of thermal current; safety area for refugees because of smoke evacuation system's malfunction; closure of fire resisting shutter and smoke bypass; early falling of fire resisting which causes chaos in crowd; survivors' scrambling for escape which hampers the connection of water source of fire extinguishers; no fire insulation between 1st and 2nd basements, which is against curbing fire at source and organizing fire- fighting action; and too many wood-texture materials.

(2)Identification of risks of explosion hazard risk

Contains: Leaking of the inflammable gas; not perceiving the diffusion of inflammable gas after the initial explosion; not smelling the inflammable gas in basement when it diffuses along the air duct; second-explosion which usually causes heavy casualties to fire fighters; malfunction of the gas emergency shutdown valve; unable to close the upper valve because of the thermal radiation; retarding reaction due to lacking knowledge of the orientation of the building; delaying alarm and obstacle of firefighter's arrival caused by traffic jam.

(3)Identification of risks of the wind direction of hypoxia and harmful gases

Contains : Lagged feeling; alarm and rescue delaying; not turning on the fire resisting shutter; running the spare generator which consumes too much oxygen; stopping air conditioner after the door closed; not knowing how to deal with the emergency because of management system's retarding reaction.

(4)Identification of risks of flood

Contains: Water's immersion into underground space because of rainstorm or no block between adjacent construction spots after flood; breaking water main due to not knowing its position in rescue process; unable to turn on outer door of the basement to drain off water because of air pressure difference.

(5)Identification of risks of the electrical hazards

Contains: Time lag of the accident cause's investigation; unable to make preparation for replacing spare equipment; chaos caused by overlong switch time between normal illumination and emergency illumination.

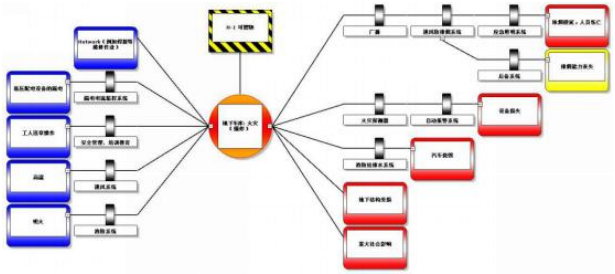

Fig.2 Underground garage fire risk identification butterfly knot method analysis

3. SAFETY ASSESSMENT SYSTEM FOR THE USE OF UNDERGROUND SPACE

3.1 Establishment of assessment index system

Based on the risk identification of underground space disasters, further optimize the extraction and classification of risk factors, and form the underground space safety assessment index system.

The safety assessment system of underground facilities should consist of multiple factors and indexes. Safety management, operating facility and equipment system and operating environment are the three first-level indexes which directly reflect the security quality. The second-level indexes and third-level indexes are determined by the first-level indexes.

(1)Sub item of safety management evaluation index system. The index includes four second -level indexes, ten third-level indexes. Shown as Table 1.

Table1 Sub item of safety management evaluation index system

First-level indexes	Second-level indexes	Third-level indexes	Main evaluation content
Safety management	Safety institution	Safety management and personnel	Safety management organization
			Full-time or part-time personnel safety management
			Safety management personnel qualification
		Safety production responsibility system	Principal Responsible Person
			Implement safety management personnel
			File management of safety production responsibility system
	Safety regulation	Safety management objective	Safety production control index
			Safety production target of all levels
		Investment in safe operation	Safety investment guarantee system
			Implementation of security investment
			Security reward and punishment system
		Safety operation procedures	Safety operation regulation formulation and Implementation
		Safety inspection system	Safety inspection system
			Security check file management
		Accident hidden trouble management	Hidden accident investigation
			Accident hidden trouble management
			Accident hidden danger monitoring
			Accident hidden file management
		Security information exchange	Information exchange mechanism
			Customer feedback
			Staff opinion processing
	Emergency rescue system	——	Emergency rescue organization
			Emergency plan formulation
			Emergency plan management
			Emergency rescue equipment and rescue personnel
			Equipment and maintenance
			Emergency training and training plan
	Safety training	——	Safety training and education system
			Safety training for special operators
			Safety training and education for temporary workers

(2)Sub item of safety management evaluation index system. All kinds of underground space and facilities shall be equipped with power supply, lighting, drainage, ventilation, fire protection, alarm, monitoring and infrastructure and equipment, the index includes five second -level indexes and 26 third- level index. Shown as Table 2

Table2 Sub item of operating facility and equipment evaluation index system

First-level indexes	Second-level indexes	Third-level indexes	Main evaluation content
Operating facility and equipment system	Fire prevention system	fire automatic alarm system (FAS) and linkage control	fire detector
			Manual alarm button
			Fire accident broadcast
			Fire alarm controller
			Fire communication
			Fire linkage function
		sprinkler system	Spray pump
			Pressure stabilizing system (air pressure water supply device
			alarm valve
			Water flow indicator
			Nozzle
			Pump adapter
			System linkage test
		Gas fire extinguishing system	——
		Indoor fire hydrant system	——
		Fire extinguisher configuration and management	——
	Power supply system	the power supply	——
		the buck substation	Voltage reducing transformer substation equipment
			Safety protection equipment for transformer substation
			Operation and maintenance
		relay protection	Setting requirements
			Performance status of relay protection device
			Operation and maintenance
		emergency power supply system	Self-owned generating set generator
			UPS
		electrical line	Electrical line protection
			Operation and maintenance
	mechanical and electrical equipment	the elevator and the automatic sidewalk	Elevator equipment
			Safety protection mark
			Management and maintenance
			Repair parts
		flood prevention system	System equipment for flood prevention door
			Safety protection mark
			Management and maintenance
			Repair parts
		water supply and drainage equipment	water supply system
			drainage system
			collecting basin
			Management and maintenance
			Repair parts
		ventilation and air conditioning equipment	Air conditioner
			ventilated
			smoke extraction
			Management and maintenance
			Repair parts
	communication system	communication system	Communication system technology
			Transmission system
			Official telephone system
			Private telephone system
			Wireless communication system
			Image information system
			Broadcasting system
			Communication power supply
			Grounding of communication system
		maintenance system	Management and maintenance
			Repair parts
	Environment and equipment monitoring and control system	BAS/EMC system	system function
			System response capability
		safety protection identification	——
		maintenance system	Management and maintenance
			Repairing and fitting

(3)Sub item of the environment safety evaluation index system. The index includes three second-level indexes like the operation environment, the building structure, the external environment and seven third- level

indexes. Shown as Table 3

Table3 Sub item of operating environment evaluation index system

First-level indexes	Second-level indexes	Third-level indexes	Main evaluation content
Operating environment	operation environment	Operating environment	Basic Requirements
			Exclusion criteria
		Evacuation environment	Induced mark
			emergency lighting
			Emergency evacuation sign
	building structure	Architectural and structural defects	Architectural and structural defects
		Exit and channel design	Stairs and passages
			Entrance and Exit
			Countermeasure and measure
		Fire protection of building structures and ancillary facilities	Structural fire resistance and fire protection
			Fire zone and separation measures
	external environment	Natural disaster prevention	Flood prevention
			Lighting prevention
			Ive and snow prevention
			Earthquake prevention
			Wind disasters prevention
		Security guard	Security organization setting and responsibilities
			Safety emergency handling
			Protection zone

3.2 Establishment of assessment criteria system

The establishment of assessment criteria system strictly conform to the current laws, regulations and technical standards. It is valued in order to ensure safe operation of the project, the guarantee of safety and health of workers in the labor process, and also to ensure the safety of users and customers.

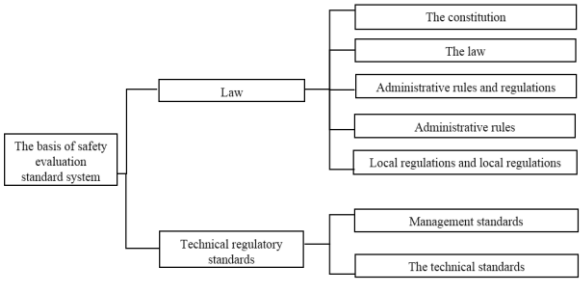

Fig.3 The basis of evaluation standard system

3.3 Establishment of assessment weight system

By using expert consultation method combined with AHP analytic hierarchy process, the comprehensive weight of each index is determined. Shown as Table 4.

Table4 Safety assessment weight order

	Level indicators	The secondary indicators	The weight
Underground space facilities use safety evaluation	The safety management (0.3403)	Security agencies and personnel	0.0543
		The safety rules and system	0.1269
		Emergency rescue system	0.0697
		Safety education and training	0.0894
	Operating facilities (0.5426)	Fire protection system	0.1740
		Power supply system	0.1167
		Mechanical and electrical equipment	0.0955
		Communication system	0.0782
		Environment and equipment monitoring and control system	0.0782
	Environmental safety (0.1171)	Operating environment	0.0471
		Building structure	0.0385
		The external environment	0.0315

4. CASE ANALYSIS

In order to verify and improve the "safety assessment system of underground space", the group chose underground commercial complex in 2012 for the pilot evaluation. The determined location was Shanghai people's Square "Dmall Shopping Center project". Evaluation results are as follow:

Table5 Safe assessment of Dmall Shopping Center

First-level indexes	Second-level indexes	Second-level indexes weight	Second-level indexes score	First-level indexes standard score	First-level indexes score
Safety management	A、Security agencies and personnel evaluation	0.0542	81.00	34.02	32.61
	B、Safety education and training evaluation	0.1269	97.00		
	C、Evaluation of emergency rescue system	0.0697	100.00		
	D、The safety rules and system evaluation	0.0894	100.00		
Operating facility and equipment system	E、Fire protection system evaluation	0.1740	74.19	54.26	42.81
	F、The power supply and lighting system evaluation	0.1167	96.52		
	G、Mechanical and electrical equipment evaluation	0.0955	70.00		
	H、Communication system evaluation	0.0782	92.86		
	I、Environment and equipment monitoring system evaluation	0.0782	60		
Operating environment	J、Evaluation of operating environment	0.0470	100.00	11.7	11.41
	K、Civil engineering structure evaluation	0.0385	94.32		
	L、The natural environment evaluation	0.0315	97.83		
Total score	86.83				
level	Level 2 - basic security				

According to the statistical analysis, the total score for the use of safe of the project was 86.83, safety level was two and basically secure. The level of fire protection equipment was three and didn't have the flood waterlogging and environmental monitoring facilities.

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5. EPILOGUE AND SUGGESTION

In this paper, a preliminary safety assessment index system for underground facilities is established on the basis of the investigation about the accidents occurred in underground facilities. It provides basis for further exploring the assessment system and has certain rationality.

At the same time, the following issues still need to be further studied:

(1)The establishment of underground space disaster database to provides the basis for quantitative assessment;

(2)The establishment of underground space disaster early warning system to make the management persons can find the accidents early, which the control measures can be made as soon as possible.

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