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Research Article

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Research Status of Life Cycle Safety Risk Identification of Utility Tunnel

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Abstract: China is now emerging as a smart city, and the utility tunnel is also part of the smart city construction, which will be the focus of attention for a long time to come. In order to ensure the safety of the utility tunnel, it is necessary to carry out safety risk identification and hidden danger investigation and management. The purpose of this paper is to sort out the current research status of the full life cycle risk identification of integrated utility tunnel in domestic and abroad, and through the analysis and summary of relevant literature, it is concluded that the risk identification of integrated utility tunnel is in a flourishing stage of development, but most of the research is static single line, lacking holistic perspective and dynamic assessment.

Keywords: Utility tunnel, full life cycle, security risks

1. Introduction

Utility Tunnel is a structure built in the underground space of urban roads, which can accommodate various pipelines including common municipal transportation pipelines and power cables [1]. It is the main municipal transportation infrastructure to realize urban functions, and it is also an important resource transportation system for modern cities. Risk identification refers to the use of various methods to systematically and continuously understand the various risks faced and analyze the potential causes of risk accidents before the occurrence of risk accidents.

Although the construction of the utility tunnel has improved the utilization rate of underground space and greatly enhanced the ground space, the urban utility tunnel, as a complex entity, integrates a variety of pipeline facilities. Its main components include the tunnel structure itself, internal pipelines, ancillary structures, signage, monitoring facilities, etc., as well as many external factors such as the external road structure, environmental factors, and human factors. The system composition is large and complex, with potential safety risks and hidden dangers, and safety accidents can have a significant impact [2]. There are a wide variety of underground pipelines with strong concealment. In addition, some underground pipelines in cities have been built for a long time and are generally aging. Moreover, the previous pipeline materials were of poor quality and the technology was backward, so there is a possibility of pipeline leakage, rupture, or even explosion [3]. Once an accident occurs during the operation and maintenance period, it is very likely to trigger a chain reaction, affecting the safe operation of the entire utility tunnel and even seriously affecting the normal life of urban residents.

Therefore, in order to improve the safety of the utility tunnel, it is necessary to identify its safety risks, effectively realize functions such as risk classification and hidden danger investigation in the utility tunnel and prevent the occurrence of accidents.

2. Background

The continuously growing urban population and the huge consumption of urban resources pose challenges to the urban system. An urban system integrating comprehensiveness, convenience, high-efficiency, and safety is the inevitable choice and the only way for urbanization development. Against this backdrop, urban utility tunnels have developed rapidly.

In 1833, the world's first underground utility tunnel was born in Paris, France. The tunnel housed pipelines such as water supply pipes, communication pipelines, compressed-air pipelines, traffic signal cables, and drainage channels. Subsequently, London, UK, began to construct utility tunnels in 1861, which accommodated municipal pipelines such as water supply, communication, electricity, gas, and sewage. Hamburg, Germany, started to build utility tunnels in 1893. By the 20th century, countries such as the United States, Spain, Russia, Japan, and Hungary also began to construct urban underground utility tunnels.

In 1958, during the renovation of Tiananmen Square in Beijing, an underground utility tunnel with a length of approximately 1 km was laid. The Zhangyang Road Utility Tunnel in Pudong, Shanghai, completed in 1994, has a total length of 11.125 km and is known as the "No.1 Trench in China". It houses four types of pipelines, namely water supply, power, communication, and gas pipelines, and is equipped with relatively complete safety facilities and a central computer management system. However, during the actual operation of the Zhangyang Road Utility Tunnel, due to safety concerns, the laid gas pipelines were not actually put into use. Subsequently, many cities in China successively launched the construction of utility tunnels[4]. In August 2015, the State Council issued the Guiding Opinions on Promoting the Construction of Urban Underground Utility Tunnels[5], requiring each city to formulate special plans, improve standards and specifications, demarcate construction areas, clarify implementation entities, specify requirements for pipeline entry, increase government investment, and improve financing support, so as to comprehensively promote the construction of underground utility tunnels.

It has become a widespread consensus at home and abroad that the rational development and utilization of underground space should be achieved. Integrating the planning and construction of utility tunnels in the comprehensive development of urban underground space has emerged as an obvious trend. Although utility tunnels have numerous advantages, their construction in China is still not mature, and currently, they still face many problems. The underground pipeline system is intricate and complex. Urban underground pipeline accidents caused by various reasons are increasing day by day. These accidents may trigger ground subsidence, leading to damage to pipelines such as water supply, drainage, gas, heating, and power supply, and even causing damage to ground buildings, which is extremely likely to result in losses of life and property. Research on the safety guarantee of urban utility tunnels urgently needs to be improved. It is of great significance for the construction of utility tunnels in China to face up to the gap in utility tunnel construction compared with developed countries or regions, promptly identify and reasonably address the risks existing in the construction of utility tunnels.

3. Research Status

The International Tunnel Association [6] wrote Guidelines for Tunneling Risk Management in 2004, which provides detailed reference standards and methods for risk management of tunnel engineering. In 2013, J. Curiel-Esparza [7] proposed an expert system that combines the color-coding method, the Delphi method, and the Analytic Hierarchy Process. This system analyzes the criticality and threat of utility tunnels to support the planning of urban underground facility safety policies. In the article, utility tunnels are defined as underground structures containing one or more utility facilities, which allow for the installation, maintenance, and removal of systems without the need for street cutting or excavation. These underground facilities consist of tunnels where all necessary utility services for large urban areas are gathered together. Canto-Perello, J; Curiel-Esparza, J. [8] explored the risk assessment regarding personnel entry into utility tunnels, taking it as a fundamental design and operation parameter, and analyzed the potential hazards of each utility facility. The accessibility and maintainability of the power distribution system are key factors in choosing underground tunnels over other utility distribution methods. However, utility tunnels exhibit synergistic effects, making them highly complex and difficult to manage. In the design, factors endangering personal safety and health must be minimized. Although the risks in the design and operation and maintenance of utility tunnels are high, for urban areas, utility tunnels may be one of the most sustainable urban underground facilities. Therefore, the safety of utility tunnels should be highly emphasized.

With the frequent occurrence of accidents in recent years, China has attached increasing importance to safety. Coupled with a deeper understanding and emphasis on the construction of urban utility tunnels, at the national level, codes such as the Code for Comprehensive Planning of Urban Engineering Pipelines [9] and the Technical Code for Urban Utility Tunnel Engineering [10] have been successively issued. Additionally, local regulations such as the Guidelines for the Construction of Urban Utility Tunnels in Fujian Province (Trial) [11], and the Technical Regulations for the Construction of Urban Underground Pipeline Utility Tunnels in Chongqing [12] have been introduced. These regulations provide reference suggestions for the construction of utility tunnels from aspects such as systems, laws and regulations, technology, and economy.

Based on the Kent method, Zhu [1] conducted a study on the classification of safety risks and influencing factors of the urban utility tunnel system, established an accident identification system for utility tunnels. Combining modern emergency management methods and using the event evolution model, on the basis of identifying the safety risks of urban utility tunnels, Zhu analyzed the basic accidents of urban utility tunnels, the evolution paths and laws among accidents, and constructed an evolution mechanism diagram. Moreover, Zhu constructed the basic fault tree model of urban utility tunnels, as well as the evaluation systems for safety status and safety impact consequences, thus promoting the research on the safety guarantee of utility tunnels. Yang [2] took the overall utility tunnel system as the object for safety risk identification of utility tunnels. The fault tree analysis method was adopted to conduct a comprehensive analysis of safety accidents in urban utility tunnels. The study mainly focused on various risk sources that pose potential safety hazards and risks to the system. According to the characteristics of these risk sources, they were classified and sorted, and a clear hierarchical structure of the safety risk classification system was established. This approach can effectively identify the risks of utility tunnel safety accidents. Yang [13] aimed to fully analyze various risk factors involved in the construction process of utility tunnels and explore a more scientific, reasonable, effective method suitable for the risk assessment of utility tunnels in China. The study determined the risk levels at each stage of the utility tunnel's full life cycle and the comprehensive risk level of the project and accordingly put forward avoidance measures and suggestions for the potential major risks at each stage. Based on the theories of risk management and the full-life cycle, Zhao [14] determined 43 full-life-cycle risk factors through literature analysis, field research, and expert interviews. A questionnaire survey was conducted to investigate the probability of risk occurrence and the degree of harm. Then, using the principal component analysis method, the main risks faced in the construction of utility tunnels were determined, the causes of the main risks were analyzed, and corresponding countermeasures and measures were proposed in response to the causes of the risks. Liu[15] combined with the safety accident cases that occurred during the construction of the utility tunnel in Shijiazhuang. Based on Heinrich's Law, they comprehensively analyzed potential safety hazards and accident causes, identified the reasons for construction safety problems, and proposed corresponding solutions, providing theoretical guidance for construction safety.

To sum up, the research on the safety of utility tunnels has a wide coverage and a clear hierarchical structure, basically covering the safety design and management throughout the entire process of utility tunnel construction. Meanwhile, it delves into the characteristics of various disasters that utility tunnels may face and corresponding prevention and control measures, which can also provide certain theoretical support for the safety management of utility tunnels.

3. Conclusion

(1) Currently, at home and abroad, most of the research on risk identification of utility tunnels focuses on single - factor or general - overview guidance research with a single pipeline as the object, and there is a lack of special research from an overall perspective and specifically for safety assurance.

(2) At present, the risks of most underground utility tunnels are estimated and analyzed from a static perspective, and the analysis results are one-sided. To better grasp the risks of utility tunnels and achieve intrinsic safety, a dynamic risk assessment framework needs to be proposed.

(3) To prevent the occurrence of utility tunnel accidents, it is necessary to conduct strict safety inspections and safety evaluations of urban underground utility tunnels, formulate multiple sets of emergency response plans, provide strong safety technical support, and continuously improve the supervision ability.

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