

Green Tunnel Construction Technology and Application

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Abstract. With the dramatic growth of urban tunnels in recent years, energy saving and environmental protection have received intensive attention in tunnel construction and operation. As reference to the concept of green buildings, this paper proposes the concept of green tunnels. Combining with the key issues of tunnel design, construction, operation and maintenance, the major aspects of green tunnels including prefabricated construction, noise control, ventilation & lighting energy saving, and digital intelligent maintenance are discussed and the future development of green tunnels is outlined with the economic and social benefits as indicators.

1. Introduction

Recent decades have seen a dramatic increasing pace of urban tunnel construction driven by the increasing traffic demands and advancement of tunnelling techniques. The construction and operation of the urban tunnels consume a large amount of energy and generate a significant amount of pollutants. Recently, the new energy-saving and environmental protection technologies, such as energy-saving LED lighting, sectional ventilation at the top of long tunnels, and acoustic noise reduction technology are tentatively used in tunnel construction and operation.

With the global energy shortage and the deterioration of the living environment, the concept of energy saving, environmental protection and green has become a global consensus. Ministry of Construction in China issued the “Green Building Evaluation Standard (GB/T50378)”^[1] in 2006, proposed the concept of green building, and conducted a series of technical research and engineering applications. Implementing the concept of green tunnel, systematically researching green tunnel technology, improving the service level of urban tunnels, reducing the energy consumption of tunnel construction and operation, and achieving energy conservation and environmental protection are the urgent tasks and development targets of current tunnel construction.

2. Concept of Green Building Development

In the 1960s, Paul Soller, an American Italian architect, merged the words Ecology and Architecture into “Arcology” and proposed the concept of “ecological architecture”, known as “green building”^[2]. In 2001, Tsinghua University published “China Ecological Residential Technology Evaluation Manual”,



first completely defined the green building system in China. The national standard “GB/T50378”^[1] defines the “green building” as: during the entire life-cycle of buildings, resources (energy, land, water and materials) should be saved, the environment needs to be protected while pollution ought to be reduced to the maximum extent. It can be conceptually defined as “four savings and one environmental protection”. It provides people with healthy, applicable and efficient use of space and buildings which are in harmony with nature. The European green building market is at the highest standard in the world, but the fastest growth of green building is in Asia. In February 2016, the China central government proposed a new eight-character guideline for building evaluation: application, economy, green, and beauty. It directly put “green” into policy. The development of green buildings includes prefabricated construction and standardization, intelligentization and technicalization of operation and maintenance.

3. Concept of Green Tunnel Development

The tunnel construction requires to minimize the traffic evacuation, groundwater loss, ground deformation, and impact of surrounding buildings. It is essential to exercise green tunnel construction to maintain the safety and comfort of the vehicles and people in tunnels, to minimize impact on surrounding environment, and to save energy and protect environment. “Green tunnel” refers to an underground structure that harmoniously coexists with nature and the city. It provides people with an unobstructed, efficient, convenient, and comfortable travel environment. During the entire life-cycle of green tunnels, it effectively saves resources, protects the environment, and reduces pollution. Its development includes five major aspects: 1) prefabricated construction technology of green tunnel; 2) noise control technology of green tunnel; 3) lighting energy saving technology of green tunnel; 4) ventilation technology of green tunnel; and 5) digital intelligent maintenance technology of green tunnel.

4. Green Tunnel Construction Technology & Applications

4.1 Prefabricated construction technology

At present, the prefabricated construction technology has been widely used in bridges, industrial, civil buildings, etc. With the continuous expansion of the construction scale of the tunnel as well as the increasing construction requirements, prefabrication construction is used in underground engineering more and more widely.

The prefabricated tunnel construction technology brings out significant social, economic and quality benefits. In terms of social benefits, factory production of prefabricated components greatly reduced the amount of field works, thereby reducing dust and noise pollution. While reducing the adverse impact on the daily lives of the adjacent residents, it also minimizes the environmental pollution. Prefabricated construction improves the working environment and construction safety. In addition, prefabricated components can effectively save materials and reduce the construction wastes^[3]. In terms of economic benefits, the prefabricated construction technology increases the standard of construction mechanization and construction speed, reduces labour and construction costs. In terms of quality and efficiency, prefabrication construction is not limited by season and weather conditions, and the wading operation is permitted. The unified and standardized production method of the factory enables the components to be strictly controlled in terms of curing conditions, production accuracy, material selection and ratio, and the product quality is more assured.

The prefabricated tunnel linings are mainly used in integrated pipe galleries, subway stations and mine tunnels. The underground utility pipelines of the Shanghai World Expo are mainly integrated corridors. The section of the pipeline corridor with a length of 451m in the Xihuan Road is prefabricated by the factory and assembled on site. It is the first prefabricated integrated trench construction in China. In addition, corrugated steel pipe culverts can be used to replaces the conventional reinforced concrete underground pipe gallery. After the steel materials are treated with effective waterproof, anti-corrosion and anti-rust treatment, the service life of the integrated pipe gallery can be greatly extended.

4.2 Noise control technology

The tunnel is a semi-enclosed space and the noise is difficult to dissipate. It emitted repeatedly and superimposed by the wall surface which generate a larger noise value. It seriously affects the traffic environment and safety. In addition, the tunnel entrance will have a “horn effect”, which will affect traffic near the tunnel entrance and lives of residents. From the few cases of existing tunnel noise control, there are limited noise control measures that can be taken after the completion of the tunnel, which greatly affect the passage of the tunnel. Therefore, with the development of urban tunnels, the study of noise control issues in the design phase is of great significance.

In road traffic, noise control is mainly conducted through sound insulation, sound absorption, and the use of low-noise road surfaces. Among them, sound insulation is one of the most important methods currently used. Currently, various kinds of sound barriers are used in urban viaducts (some sound barriers also have sound-absorbing function). Shanghai Xinjian Road Tunnel also adopts a fully-enclosed soundproof shed (As shown in Figure 1). According to the principle of sound insulation, the effect of a fully-enclosed soundproof shed is far better than that of a normal sound barrier, but its cost including the later maintenance costs are relatively high.

Sound-absorbing materials (structures) have always been popular in tunnel noise management. The Nanjing Gulou tunnel uses metal perforated plates within 164.04ft of tunnel opening, and the perforated aluminium plates are used for the sidewall of the open section, achieving a good noise reduction effect. Some new types of sound-absorbing materials gradually put into utilization in recent years, such as sound-absorbing enamel steel panels and sound-absorbing sandstone panels (shown in Figure 2). The large-pore asphalt concrete was used in the renovation project of Beijing Jinsong Road, which was reduced by an average of 4dB compared with ordinary asphalt pavements by experts. Considering that the road surface environment in the tunnel differs from normal roads, for instance the change in temperature and humidity is small, which is beneficial to the maintenance of the road surface, the research and application of low-noise roads in tunnels will have a broader perspective.



Figure 1. Soundproof Shed at Xinjian Road Tunnel Entrance



Figure 2. A sound absorbing sandstone plate used in a tunnel

4.3 Lighting energy saving technology

In order to effectively reduce tunnel lighting energy consumption, lighting energy-saving technologies, including lighting sources, energy-saving controls, light reduction at the entrance, and lighting arrangement have been proposed or applied at different stages from the early period of design to the later period of operation. For the features of urban tunnels, the following describes two energy-saving methods or measures with better energy-saving effects.

The construction of urban tunnels mostly adopts open-cut methods. They are distributed under the city roads with shallow depth, which provides favourable conditions for the installation of light guide pipes. The Puxi ramp of the Changjiang Road Tunnel uses light pipe instead of enhanced lighting fixtures to realize strengthening the lighting at tunnel entrance and exit. Its design uses 20.87in light pipe, prism diffuser at the entrance of the tunnel and dream diffuser at the exit, a total of 45 sets, providing natural light for 10 hours per day. According to the economic analysis of replacing LED lighting solutions, a total of 60 sets of 220W LED can be replaced, which saved about 48,200kWh per year and the static payback period was about 3.6 years.

The type of light-reducing facility of the Nanjing Yangtze River Tunnel is the light-reduced grating with a length of 147.64ft. The most unfavourable brightness of the tunnel portal is 2500cd/m², the brightness at the starting position of the shading shed is about 1000cd/m², and the brightness value at the connection with the main hole is 50cd/m². The 360.89ft long light-reduced gratings are used at the Hong Kong-Zhuhai-Macao Bridge undersea tunnel. The most unfavourable sky luminance is 6500cd/m² measured by the physical model test. The light intensity at the starting position of the shade shelter is about 3250cd/m², and the brightness value at the connection position with the main hole is 85cd/m². Shading sheds can achieve ideal shading effects.

4.4 Environmental-protecting ventilation technology

Unlike road tunnels, there are more ramps connecting the urban tunnel with the main tunnel, the surrounding of the main tunnel or ramp is a residential or commercial area, and there are standard limits for pollutant discharge. Therefore, environmental-protecting ventilation technologies are particularly important for urban tunnels.

Since ramps in urban tunnels are numerous, the distribution of air flow inside the tunnel is complicated. The underground transportation system of the Nanjing Green Austrian Axis is one of the most complex transportation hub systems in China. The ventilation scheme for underground transportation is shown in Figure 3. The airflow field in a multi-channel tunnel is affected by the natural wind outside the tunnel, the traffic volume, the number of ramps, etc. However, the ramps entering and exiting the main tunnel are capable of being fully utilized as the natural tunnel air supply and exhaust ducts, which can greatly reduce the energy consumption of tunnel ventilation operations.

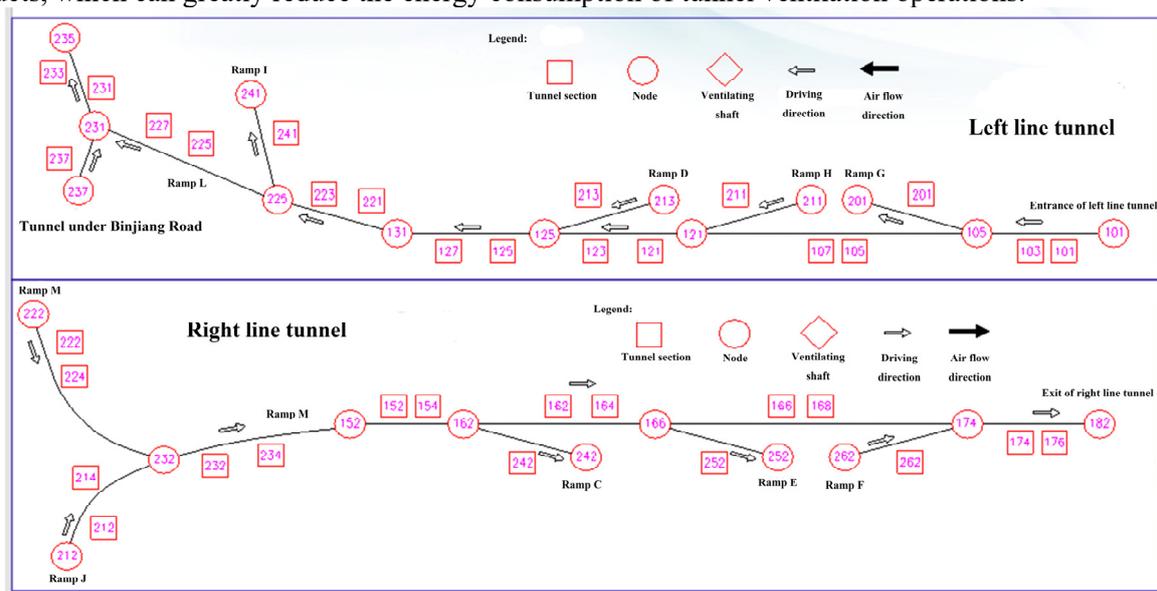


Figure 3. Design of underground traffic operation ventilation

The key to ensure the normal operation of the tunnel is appropriate ventilation program, which is proposed in combination with the actual situation of the tunnel. Common ventilation methods in tunnels include longitudinal full-jet ventilation, inclined vertical well section vertical ventilation, semi (full) horizontal ventilation, and vertical shaft-type natural ventilation. The longitudinal full-jet ventilation method installs a jet fan in the main tunnel to exhaust the polluted gas through the tunnel entrance. The ventilation method is simple in technology, low in energy consumption, and easy to operate and maintain. For tunnels with special geographic location and surrounding environment (such as through river tunnels), it is suitable to adopt method of vertical well section & smoke focusing vertical ventilation. A dedicated exhaust duct and smoke exhaust hole are provided to prevent the accident of flue gas from spreading in the tunnel. Urban tunnels with shallow depths are more suitable for setting up natural

ventilation holes. This ventilation scheme has no energy consumption and does not require operation and maintenance. It is the ventilation method for future urban tunnel construction promotion.

With the increasing of the length of urban tunnel construction and the improvement of environmental protection requirements, the new technology should be utilized. The electrostatic dust removal technology is required when it is no conditions to get high ventilation in tunnel, so that polluted gas can be discharged after being purified in the tunnel. This technology can effectively reduce the discharge of pollutants from tunnels and improve the tunnel opening environment. However, the cost of post-transportation nutrition is high. Its technical composition is shown in Figure 4.

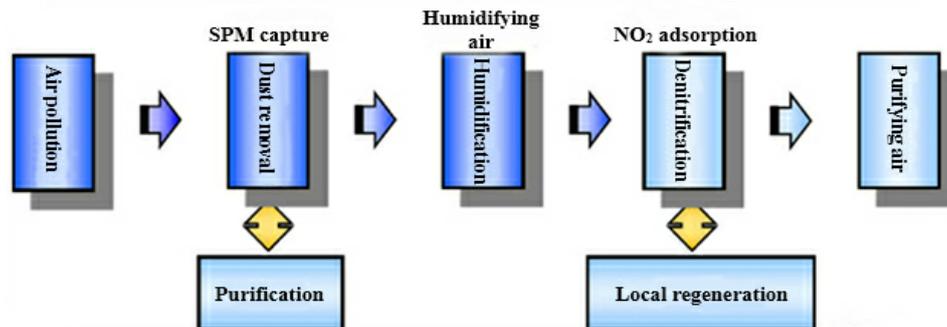


Figure 4. Composition of electrostatic dust removal technology

4.5 Digital intelligent maintenance technology

The tunnel intelligent maintenance technology uses a new generation of information technology to construct a life cycle intelligent maintenance technology platform for tunnels. Information technology utilizes advantages of information collection, information dissemination, information analysis, and information display to combine cloud computing technology, big data technology, and Internet of things and internet technology. The cycle intelligent management technology platform can effectively improve the operation safety of the tunnel, reduce the operating cost of the tunnel, and extend the service period of the tunnel, which has significant economic and social benefits^[4].

The establishment of an intelligent tunnel management and maintenance platform based on BIM visualization, a significant amount of information can be integrated into the platform, such as the equipment location, operating status, functions, and equipment information of the drainage, fire-fighting, power distribution, lighting, monitoring, and ventilation systems in the tunnel. Through 3D visualization, emergency command capabilities such as tunnel traffic accidents and fire accidents can be improved, and personnel casualties or property losses can be reduced.

Through the intelligent tunnel management and maintenance platform, it can fully understand the running status of the equipment and accurately locate the faulty equipment. Using big data technology to evaluate the status of tunnel equipment, the corresponding relationship between various monitoring parameters and health status of the equipment is obtained. Through analysis of the distribution rules, the tunnel maintenance management operation and maintenance effect evaluation mechanism is proposed. Collecting, collating and analyzing the environmental indicators of the tunnel at different time periods and different traffic flow conditions, the location of the tunnel accident prone, the traffic flow at different time periods and the direction of traffic flow during peak hours through the platform, traffic mitigation and control measures during the peak hours can be proposed, which maximize increasing the tunnel capacity and reducing the accident rate.

4.6 Tunnel geothermal utilization technology

GSHP (Ground Source Heat Pump) utilizes the features that rock medium temperature is relatively stable with respect to atmospheric changes to achieve the purpose of heating or cooling by extracting energy in rock and soil medium. Ground source energy belongs to clean and renewable energy, which is of high-efficiency, energy-saving and environmental protection. It can effectively alleviate the current

situation of energy shortage in our country and meet the national policy of building a conservation-minded society.

The GSHP uses the Carnot cycle principle of thermodynamics to extract energy from nature through deep-buried piping systems around buildings. The system is based on rock and soil, groundwater or surface water as a low-temperature heat source, and is composed of a water source heat pump unit, a geothermal energy exchange system, and an in-building system [5], as shown in Figure 5. According to the different forms of geothermal energy exchange systems, the ground source heat pump system is divided into bury-piped, groundwater, and surface water ground source heat pump system. According to available data [6], there are more than 2,000 projects with ground source heat pump systems in China each year, and the construction area is nearly 80 million m². It is estimated that by 2020, the area of ground source heat pumps for heating and cooling will reach 200 million m², 400 million m² by 2030, and 1 billion m² by 2050.

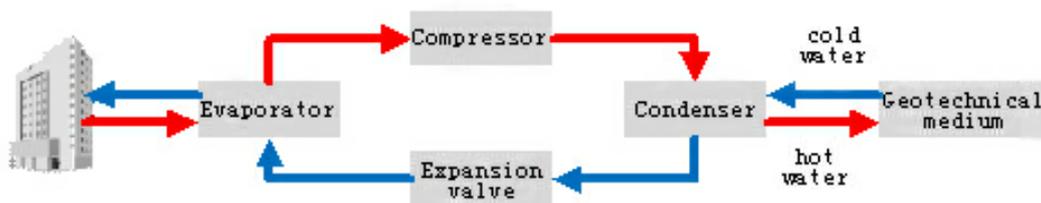


Figure 5. Schematic diagram of ground source heat pump system

In the world for the first time application of the technology in the tunnel is Austria, where related experiments about the LT24 interval (open-cut method), the LT22 interval (the new Austrian method) of Lainzer tunnel, part of the stations and intervals in Vienna metro line 2 were conducted and have achieved initial results [7]. In UK, the heat pump system is used to reduce the temperature of the train carriage and improve passenger comfort [7]. Ampofo [8] analyzed the groundwater heat pump system (shown in Figure 11) at the Victoria tube station in the UK and found that the heat pump system is superior to the air conditioning system in terms of cooling efficiency, operating cost, and low carbon environmental protection. The application of ground source heat pump in China's subways and tunnels is still at an exploratory stage. Many domestic scholars have analyzed the heat pump applications in subway stations in different regions such as Shanghai and Chengdu [9-11].

5. Conclusions

With the ever-increasing level of urbanization and increasingly severe resources and environmental situations, the higher demands on the construction and operation of tunnels need to be proposed. Starting from "green building", this paper puts forward the concept of "green tunnel" through the understanding of its connotation and the deep analysis of its development concept, and combining the actual demand and development of the tunnel. Focusing on the key issues of tunnel design, construction, operation and maintenance, the technical development level of green tunnels is analysed from the prefabricated construction, noise control, environmental-protecting ventilation, lighting energy conservation, digital intelligent maintenance, etc. Combining with the feature elements, the development direction of the green tunnel is further proposed, which provides a useful reference for the initial construction of the basic framework of the green tunnel.

Acknowledgments

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