Explosion-proof, Anti-corrosion Intelligent Tunnel Fire Protection System

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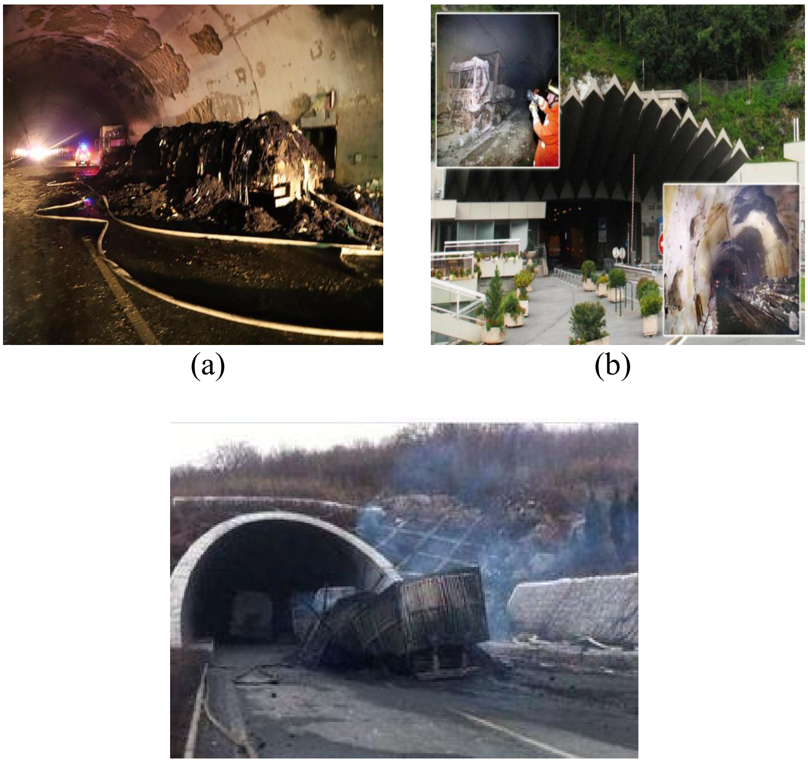
Abstract: With the development of technology and transportation industry, long tunnels have become commonplace in the construction of highways and railways. At present, the fire-fighting measures for the long tunnel still remain in the use of hand-held chemical fire extinguishers and erected fixed-line water pipes for firefighting. Rescue and escape conditions are both large and insufficient. In view of the shortcomings of traditional tunnel structural components such as poor fire resistance, old fire extinguishing methods, poor escape conditions and rescue difficulties, this paper proposes a long tunnel fire protection system that intelligently monitors fire sources and extinguishes fires. The system uses the refractory ceramic mixture as the inner arc plate material of the tunnel, adopts the linear moving fire source detection system and takes into consideration the tunnel smoke extraction, and can improve the internal air environment of the tunnel while achieving the intelligent fire protection effect. It also provides sufficient time for personnel to escape and rescue. The proposed system aims to provide a theoretical reference for the construction of future tunnels.

1. Introduction

With the economic development and increased investment in national infrastructure, the transportation industry has made considerable progress. In the construction of roads or railways, there are many tunnels with large engineering volume and long mileage. On the one hand, the long tunnel improves the road linearity, on the other hand, the engineering quantity is reduced, and the construction cost is reduced. However, due to the long tunnel itself, there are major problems in the escape and fire fighting in the event of fire. The main performances are as follows:① It is difficult to enter the tunnel;② The fire-fighting facilities are damaged by fire, or the trapped people will not use the fire-fighting equipment;③ A large amount of harmful smoke generated during the fire seriously threatens the safety of the trapped person. Whether in China or abroad, the occurrence of long tunnel fires poses a serious threat to human life and property, as shown in Figure 1.



(a) (b) (c)

Figure 1: Tunnel damage caused by fire: a. Wenzhou Ring Expressway Jiangbeiling Tunnel; b. British Channel Tunnel Fire; c. Shanxi Jinji Highway Tunnel Fire.

When a fire occurs, there are huge limitations and dangers in human rescue. Therefore, the intelligent fire protection of the tunnel and the assistance of escape are extremely important. Intelligent tunnels were proposed by Han[1] in 2000. Since then, with the development of various industries, intelligent tunnel systems have begun to diversify[2-11], but mainly focused on traffic monitoring and decision analysis. Automated firefighting for tunnels remains a general concept, or there are many restrictions on the use of automated fire protection systems. Based on the shortcomings of traditional tunnel structural components such as poor fire resistance, old fire extinguishing methods, poor escape conditions and rescue difficulties, this paper proposes a long-distance tunnel fire protection system that intelligently monitors fire sources and extinguishes fires. The system uses the refractory ceramic mixture as the inner arc plate material of the tunnel, adopts the linear moving fire source detection system and takes into consideration the tunnel smoke extraction, and can improve the internal air environment of the tunnel while achieving the intelligent fire protection effect.

2. Intelligent Tunnel Structure

2.1. Oxygen Supply Pipeline

Oxygen delivery pipes are erected on both sides of the inspection road. The conveying pipe is arranged at the bottom of the tunnel, and the pipe radius is 1~2cm as needed. When the fire occurs, the trapped person is provided with the necessary oxygen, which reduces the possibility of smoke poisoning of the trapped person and is conducive to escape. When the personnel escapes, the supply air supply line stops working.

2.2. Exhaust Gas Extraction Pipe

At the center of the top of the tunnel, an exhaust gas evacuation pipe is provided to be connected to the fan shaft outside the hole. When a fire occurs, the supply air volume is less than the exhaust gas discharge amount. The working power of the smoke pumping pipe is selected according to the tunnel length and the actual situation of the tunnel. When the visibility is less than 30m, the system starts to work and pumping. When the visibility is greater than 30m, the smoking and smoking equipment stops working.

2.3. Linear Motion Monitoring Devicee

Located in the center of the top of the tunnel and fixed on a linear track. The monitoring part uses plated ceramic insulation and uses weak electricity as the working power source. The unit consists of a mobile monitor, a mobile temperature detector and a mobile smoke detector. The mobile monitor is on duty and can transmit real-time internal conditions to the tunnel to the control center. The temperature detector has a warning value of 50°. The smoke detector warning value is 30m.

2.4. Fire Protection Components

The inner arc plate of the tunnel is a hollow structure and is laid on the outer wall of the tunnel. The laying method can be a hooking method or an epoxy bonding. The outer arc plate spout adopts plum-shaped linear induction. The outer wall structure can be customized according to the shape of the load-bearing structure. Small holes are arranged on the outer wall, and the small holes are arranged in a plum blossom shape. There is a certain air pressure in the outer wall, and the air pressure is not more than 4.0 MPa. The inner and outer arc plates of the tunnel are connected to the main water pipe, and the excuses are nested.

The system uses 24-hour omnidirectional dynamic monitoring and full-process dynamic tube loss compensation. It will not end because the tunnel fire is extinguished.

3. Inner Arc Plate Material Selection

The selection of the arc plate in the tunnel, according to the conditions and requirements, needs to be compared according to the actual environmental conditions, from the aspects of practicability, economy and protection.

In a specific chemical industry, in a dangerous underground structure, the inner arc plate should use a full ceramic structure. For example, in the passage of chemical fuels for specific production and transportation, as well as specific underground storage warehouses.

In the civil air defense project, in order to resist the explosive force of the bomb, elements such as alumina, zirconia, alumina, nickel, asbestos are added during the production of the ceramic inner arc plate. This will increase the structural strength and mitigate the harmful effects such as shock waves.

The selection of materials is primarily determined for general vehicle and cargo combustion.The hollow inner arc plate substrate can be selected from PPR type, PVC type, hydrocarbon type, resin type and plastic high temperature resistant base material. Hollow inner arc plate, located outside the structural layer. The surface of the fire-fighting surface is coated with ceramic insulation. The thickness of the plated layer is determined according to the fire prevention rating.

Materials with a refractory temperature greater than 1000 ° C are called high temperature resistant insulation materials. Depending on the fire activity of the material and the stability at high temperatures, relatively inert materials are used. The physical and chemical changes of the material under the influence of temperature are minimized. Material selection should use natural elemental structure as much as possible, avoiding the use of chemically synthesized materials. For example, ceramics and asbestos, the choice of materials is as follows:

① Soft Material

A ceramic fiber material having a relatively low thermal conductivity is a soft material. Nano-type microporous materials are one of the currently known materials with better thermal insulation properties, and their thermal conductivity is lower than that of air.

The nano-scale silica material has a void formed therein of less than 60 nm, which is smaller than the space required for thermal movement of air molecules. Air does not produce heat transfer in the interstices of nanoscale silica materials.

Nano-microporous insulation material, belonging to aerogel insulation material, WDS insulation material, has been widely used in aircraft black box and steelmaking, chemical and other activities.

② Hard Mineral Materials

Alumina, zirconia, bauxite, clay, asbestos, ceramics, which are hard materials with higher strength. However, hard materials cannot be used in large-scale masonry in tunnel fire prevention projects due to the influence of building boundaries. Under ambient conditions, hard mineral materials can only be combined at high temperatures. Mainly to form high-density special materials for heat insulation, explosion resistance and corrosion resistance. According to actual needs, an appropriate amount of mineral elements are added to the matrix material to achieve the required thermal insulation properties of the hollow inner arc plate.

On the surface of the existing structure, an epoxy resin adhesive is applied and adhered as an interface to form an effective rigid connection. It can be externally hooked, and the external hook can carry no less than 5 times the quality of the inner arc plate. In the inner arc plate member, the attached portion is placed with a concave symmetrical body, and the mounting type is adjusted as a plug-in type.

4. Parameter Calculation When Fire Occurs

4.1. Ventilation Calculation in the event of Fire

①Air supplye

$$Q_s = \frac{1}{2} A \times L \times h + q_e + q_o \qquad (1)$$

Qs is the airflow required for oxygen escape, and the unit is m^3/min. A is the contour area inside the tunnel. h is the escape time of personnel. q_e is the air volume in the air supply duct. q_o is the loss of air volume in the air supply duct. According to the total amount of wind required, the storage capacity of the air supply outside the tunnel, the air compressor and the air storage tank are reversed, and the power model of the air supply equipment is determined.

②Exhaust air volume

$$Q_p = 2\left(A \times L \times h + q_g\right) + Q_s \qquad (2)$$

Qp is the amount of smoking, the unit is m^3/min. A is the contour area inside the tunnel. h is the time of exhausting smoke. q_g is the amount of exhaust gas in the exhaust pipe.

According to the amount of smoke exhausted, the pumping capacity of the smoking machine at the top of the hole is reversed to determine the power model of the pumping equipment.The safety factor for extracting exhaust fumes is 2, which guarantees Qs=2Qp. After the power is selected, in order to ensure the safety of the equipment, the basic power surplus factor is designed to be 1.5. For example, in a long tunnel, the inclined well and shaft structure can be used to carry out check calculation design, increase the smoke exhausting point, and improve the ability to exhaust exhaust gas.

4.2. Water Pressure Calculation

Because the fire position is random, it can be fired outside the hole and moved into the hole.

Any part, after entering the hole, the ignition point stops at a certain point and cannot move outside the hole. Need to consider the most unfavorable state.Because the tunnel is assembled by hollow inner pressure arc plates, a water carrying connector with a pressurized state is formed. The normal reserve pressure is not more than 4Mpa. If there is a fire source, the tube damage pressure after intervention, the need to make up the difference, the water source outside the hole is continuously provided, and the water quantity is replenished in time.

Simulate the tube pressure difference, and the ignition point is considered to be 3 times the length.The tube loss pressure difference range is changed in the interval where σ0 is $0 \rightarrow \sigma_{max}$=4Mpa. The initial formation of incremental decreasing trend, with the occurrence of pressure difference, continuous dynamic pressure, forming an increasing trend, in the process of the formation of the balance, the pressure difference is basically balanced.

The water source interface of the hole is a three-point line or multi-point line interface. The main consideration is to form the ability to increase the differential pressure in a short time.

The length of the fire point is such that the material is not leaked, and when the explosion does not occur, the basic vehicle body is burned, and the length of the vehicle body is considered to be L=20 m. The fire safety factor is 3L=60m.

$$Q_{sl} = \sum P_s = V \times h \times A \times n \times 3L \qquad (3)$$

V is the jet water velocity. h is the jet time. A is the diameter of the spout water column. n is the number of ceramic or plated high-pressure nozzles.

5. Conclusions

The intelligent tunnel proposed in this paper has a continuous process of improvement and development from theory to practical application. After that, we will continue to research and explore the tunnel system, and strive to improve the system and contribute to the underground structure and fire protection.

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