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Review Article

# Application of Glass Fiber Reinforced Polymer Composite (GFRPC) Escape Pipeline in Tunnel

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**Abstract:** During the tunnel construction process, unfavorable geological conditions are often encountered. Geological disasters such as collapse, roof fall, water inrush, gas explosion, etc. occur frequently, causing different degrees of property damage and casualties to the construction of the tunnel, seriously affecting harmony during construction. The domestic emergency hedging is mainly the use of 8-10mm steel coils, but the steel is heavy and not suitable for the frequent movement of tunnels. This paper introduces the new Glass Fiber Reinforced Polymer Composite (GFRPC) escape pipeline used in Chongqing Jiuyongyi Jinyunshan Tunnel, and compares the traditional steel coil parameters to provide reference for subsequent tunnel hedging measures.

**Keywords:** Tunnel glass fiber reinforced polymer composite escape pipe, Light and safety

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## 1 Background introduction

### 1.1 Tunnel accident analysis

With the rapid construction of China's highway network and railway, the tunnel has increasingly shown the superiority of crossing the mountain. In recent years, China's road tunnel construction has achieved gratifying results and significant progress in both quality and quantity. The security problems that followed have gradually emerged. Tunnel construction is different from other production forms, taking into account construction engineering and mine production, and has its own unique safety production characteristics. According to statistics, there were 33 tunnel construction accidents in China from 2009 to 2013, resulting in 161 direct deaths. The specific statistics are as follows:

#### 1.1.1 Number of tunnel accidents

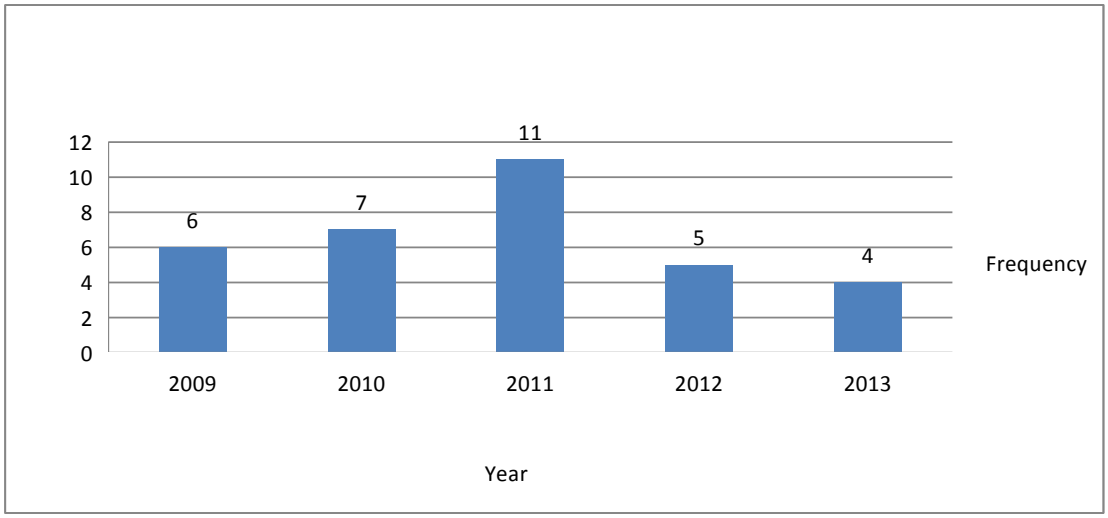


**Figure 1.** Statistics of the number of tunnel construction accidents in China from 2009 to 2013

### 1.1.2 Number of deaths from tunnel accidents

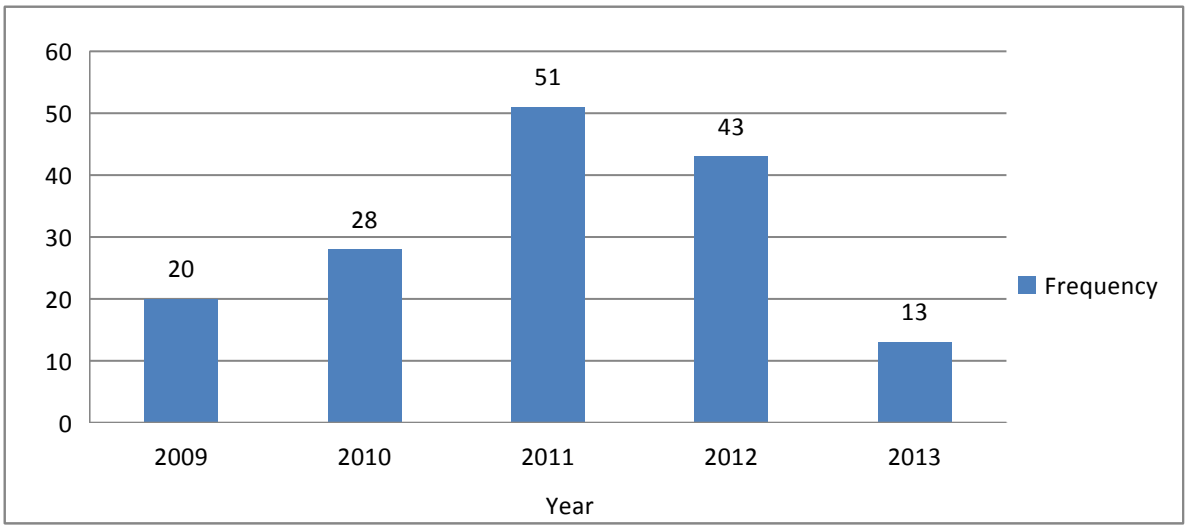


**Figure 2.** Statistics of deaths from tunnel construction accidents in China from 2009 to 2013

### 1.1.3 Types of accidents and the number of occurrences and deaths

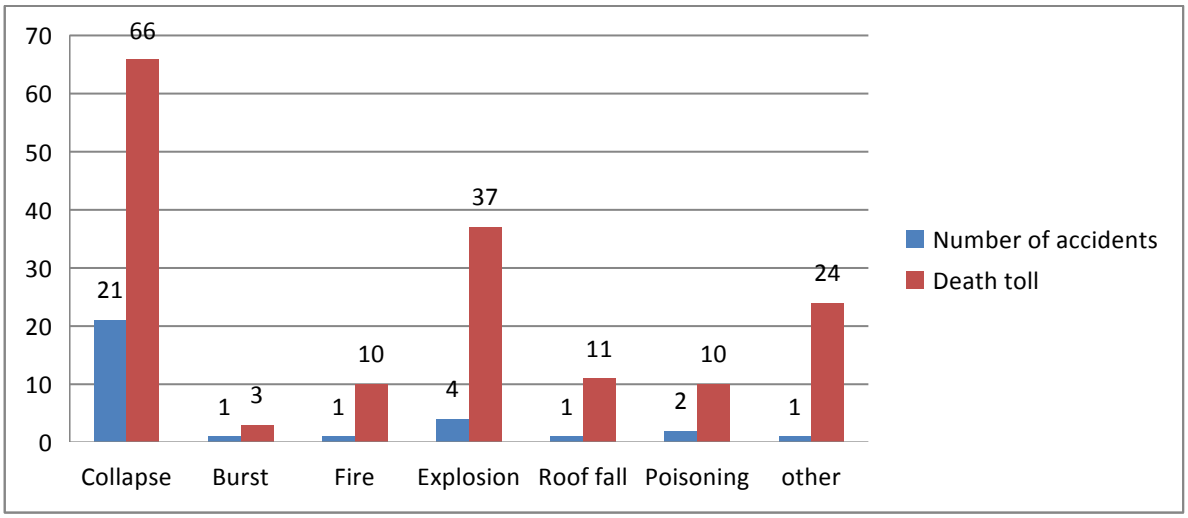


**Figure 3.** Statistics of types and occurrences of tunnel construction accidents and deaths in 2009-2013

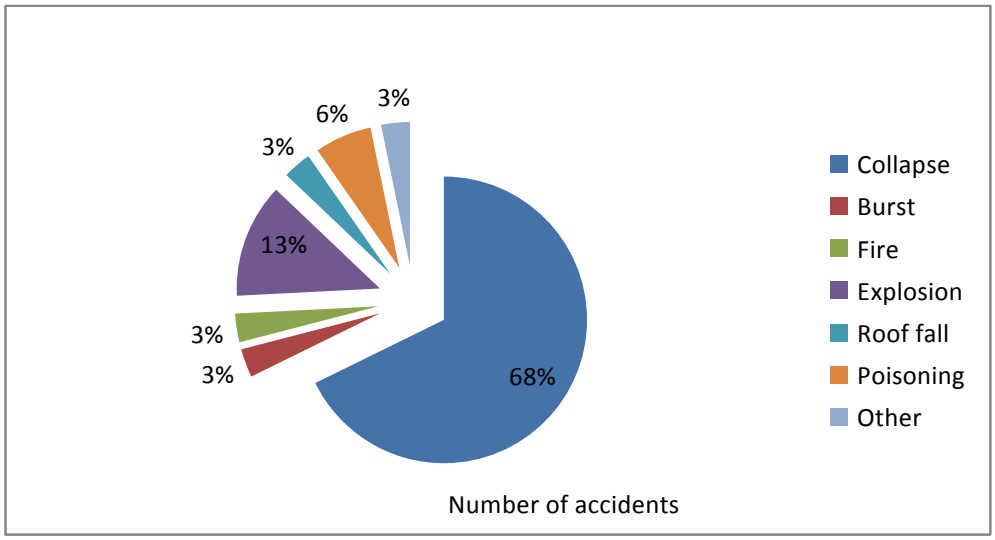


**Figure 4.** Tunnel construction accidents as a percentage of total accidents in 2009-2013

It can be seen from Figure 4 that the main types of collapse and explosion accidents account for the total number of accidents, which is the focus of accident prevention, and collapse accidents are the top priority and the first important point in the tunnel construction process. The collapse accident is easily affected by the topography, geology, hydrology, climate and other conditions. The tunnel project has the characteristics of complicated and variable geology, small working space, many unpredictable factors, and various dangerous and harmful factors intertwined. Construction risks are extremely high, and industrial accidents are not uncommon.

It can be seen from Figure 5 that the types of accidents in the tunnel construction process in 2009-2013 accounted for the percentage of total accidents. Accidents accounted for 64% due to collapse, explosion accidents accounted for 12%, roof fall accidents accounted for 9%, poisoning suffocation accidents accounted for 6%, bursts, fires, and other accidents each accounted for 3%. Therefore, it is the first priority to prevent tunnel damage by focusing on preventing and reducing the losses caused by collapse accidents.

### 1.2 Project overview

#### 1.2.1 Tunnel features

The mileage starting and ending of the Jinyunshan Tunnel is K0+000-K6+120. The Jinyunshan Tunnel is located at the end of the contract section and is a full-line controlled project. The tunnel traverses the Jinyun Mountain Range, with complex geology, rocky and karst water, fault fracture zone, coal or goaf, paste rock swelling and corrosive. Among them, the V-type surrounding rock is 939 meters, accounting for 38.7% of the whole tunnel; the IV-type surrounding rock is 972.5 meters, accounting for 40.15% of the whole tunnel; the III-type surrounding rock is 516 meters, accounting for 21.2% of the entire tunnel. 2.4% of the longitudinal slope must be reversed and drained; one-way three-lane large section and the emergency parking belt have an excavation width of more than 20 meters. The construction is difficult and the risk of collapse is high.

#### 1.2.2 Facility requirements

The State Administration of Work Safety, the State-owned Assets Supervision and Administration Commission of the State Council of the Ministry of Transport, and the State Railway Administration have issued the provisions of the "Nine Regulations on Tunnel Construction Safety": It is necessary to set up escape routes in accordance with regulations, and it is strictly forbidden to carry out construction work without safety facilities in place. At present, the technical solutions for solving the problem of emergency escape and avoidance of tunnel falling rock and landslide accidents at home and abroad mainly focus on laying large diameter circular pipes in the longitudinal direction of the tunnel as the escape route for construction workers. When an accident occurs, the construction personnel pass the round escape pipe. Under the impact of the falling rock and the landslide when the tunnel collapse accident occurs, the force is characterized by short duration, high strength, difficult to predict the load form and space-time distribution, and the material. And the mechanical properties of the structure under impact dynamics are difficult to describe accurately. In addition, the installation and use of the project site also provides multiple performance and functional requirements for the pipeline, such as light weight, high strength, high ring stiffness, good impact toughness, thermal insulation and corrosion resistance, quick installation, convenient disassembly, reusability and low cost. In order to meet the above requirements, our department has selected a glass fiber reinforced polymer composite (GFRPC) material as a tunnel escape pipe through various schemes.

## 2 Pipe characteristics

Glass fiber reinforced polymer is a composite plastic based on glass fiber reinforced unsaturated polyester, epoxy resin and phenolic resin. As a composite material, it is used as a tunnel escape pipe. It has the characteristics of light weight, high strength, easy installation, heat insulation and fire resistance, insulation and corrosion resistance, energy absorption and impact resistance, and cost-effective. It is suitable for tunnel use.

### 2.1 Pipe size and structure

Glass fiber reinforced plastic is a composite plastic based on glass fiber reinforced unsaturated polyester, epoxy resin and phenolic resin. As a kind of composite material, it is used as a tunnel escape pipe. It has the characteristics of light weight, high strength, easy installation, heat insulation and fire resistance, insulation and corrosion resistance, energy absorption and impact resistance, and high cost performance.

According to Alvin R. Tilley, a well-known American expert in anthropometry, the results of anthropometric research show that when crawling and moving, the crawling height is 800mm and the crawling length is 1520mm when comfortable. Alvin • R. Tilley pointed out that the circular pipe is set to a smaller diameter of 800 mm when the entrance and exit of the circular opening at the bottom of the whole body is crawling through.

The inner diameter of the round pipe is 800mm and

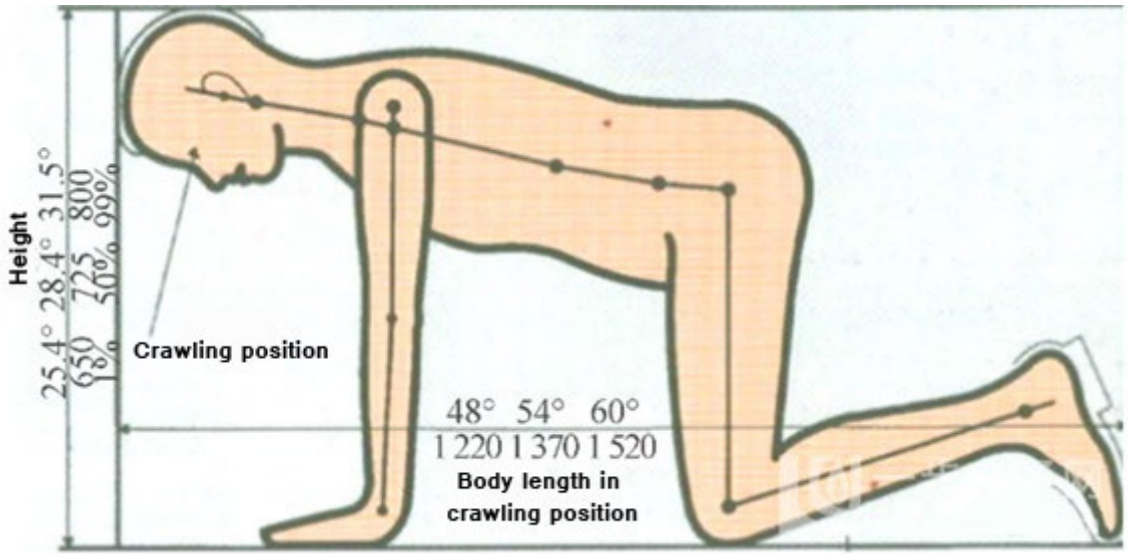


**Figure 5.** Ergonomics during crawling

the wall thickness is 35mm. In order to facilitate the construction of the upper and lower sections of the tunnel, a 40° elbow is used for connection, which is convenient for adapting to the terrain.

**Figure 6.** Pipe diameter


**Figure 7.** Elbow

## 2.2 Ring stiffness

It has good pressure resistance and is not easy to be deformed. When collapse occurs during tunnel construction, the escape pipe can withstand pressure and resist environmental damage to ensure the safety of personnel in the pipeline. Tested Glass fiber reinforced polymer composite(GFRPC) pipe ring stiffness: >27 kN/m2 (according to GB/T 9647-2003), meeting the stiffness requirements.

## 2.3 Impact performance

When the tunnel collapses, when the external force is impacted, the escape tube instantaneously deforms, absorbs a large amount of impact energy, and then quickly restores its original shape. That is to say, the escape pipeline needs to meet the evacuation requirements of the evacuation pipeline, and provides an extremely safe guarantee and reliable guarantee for the emergency rescue of the highway tunnel

**Figure 8.** Ring stiffness test

construction. Through the simulation, 300 kg of falling rock can fall freely and hit the pipeline at a distance of 7 meters. After the test, the minimum static space after the impact of the pipeline exceeds 550cm, which can fully meet the needs of tunnel construction personnel to escape in a low posture.

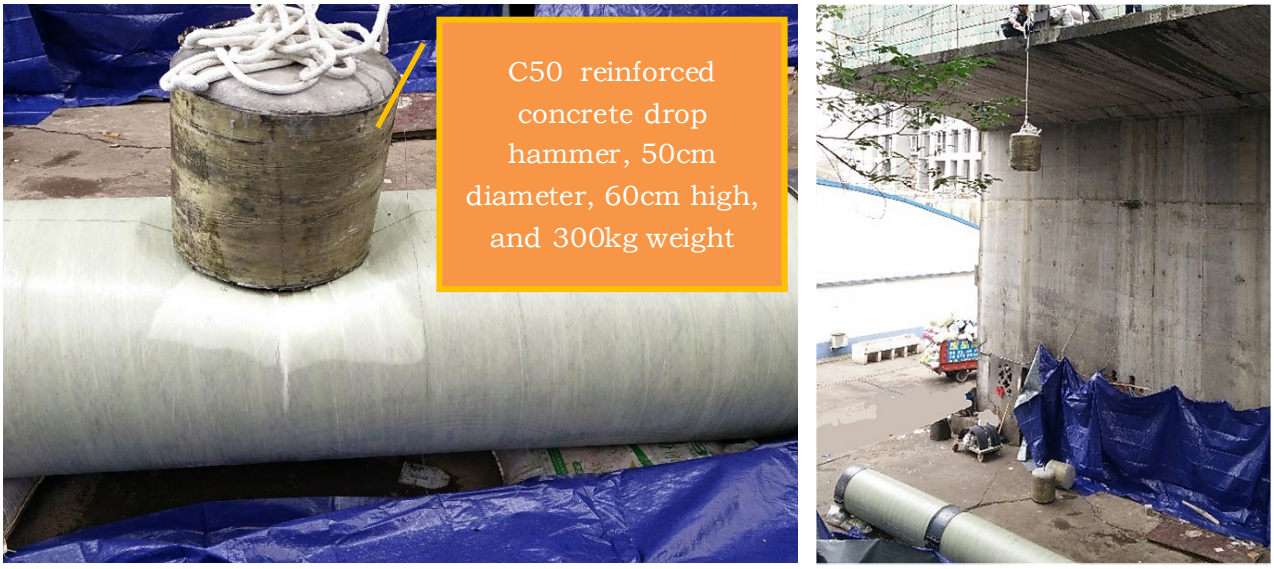


**Figure 9.** Simulated impact test

### 2.4 Heat insulation, fire resistance, insulation

Glass fiber reinforced plastic is a kind of material with slow heat transfer, good insulation and good transient high temperature resistance. In fact, the measured thermal conductivity is 0.2 watts per meter (W. m). Less than one-hundredth of a percent of the common steel pipe wall thermal conductivity of 45 watts per meter (W. m), can provide good insulation protection for escape personnel in the heat caused by fire or explosion. In addition, good insulation prevents the pipeline from being charged and threatening the safety of personnel due to line damage.

### 2.5 Easy to install

#### 2.5.1 Material is light

The escape pipeline adopts a new composite material of FRP surface layer and lightweight particle sandwich layer. The inner diameter of the pipeline is 0.8 meters, and the standard section of the finished product is 3 meters long and weighs about 250 kilograms. The corresponding length of steel pipe with a wall thickness of 10 mm weighs about 630 kg, which is less than one-half of the latter.

It is installed in groups of 4 people. It can be installed

without any mechanical cooperation in the narrow tunnel, which is convenient, flexible and fast.

**Figure 10.** 4 group installation

### 2.5.2 Convenient connection

Adjacent pipe ends are connected by sockets, and the basket screw clasp is cleverly used to ensure that it will not loosen under the effect of lateral impact. The pipeline is equipped with a special elbow, which is easy to install when the tunnel is layered and excavated.

**Figure 11.** Basket screw buckle

The round pipe cushion is a sandbag placed flat, and the cushion layer is 250 mm thick and 800 mm wide. The thin-walled pipe used for the tunnel escape pipe is freely placed on the leveling cushion. When subjected to the rockfall impact load, the bottom of the round pipe is mainly restrained by the vertical and lateral friction of the cushion.

## 2.6 Cost-effective

Glass fiber reinforced polymer has strong resistance to the atmosphere, water and acid, alkali, salt and multiple oils and solvents. It has excellent anti-oxidation and durability, and can be reused many times. Its service life theory can reach up to 50 years.

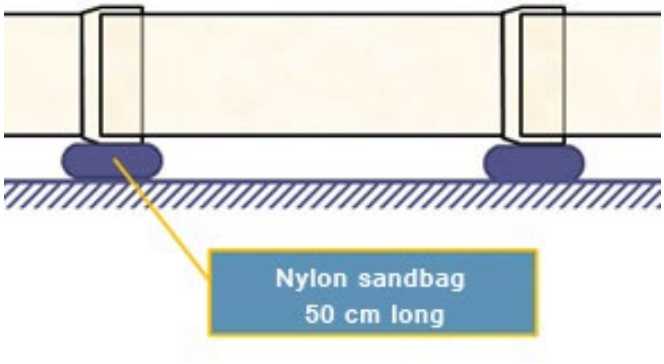


**Figure 12.** Schematic diagram of sandbags

**Figure 13.** Effect of tunnel use

## 2.7 Performance comparison

### 2.7.1 Main parameters of glass fiber reinforced plastic tunnel escape pipeline

**Table 1.** Main technical parameters of escape pipeline

| Category | Item | Indicator | Unit | Remarks |
|---|---|---|---|---|
| Appearance and weight | 1. The connection structure type | Socket pipe | | |
| | 2. Color | (Beige) white | | |
| | 3. The standard section length of the finished product | 3 | m | With the length of the plug |
| | 4. Inner diameter | 0.8 | m | |
| | 5. Line quality | 85 | kg/m | Pipe section, without socket |
| | 6. Standard section quality | 255 | kg | With plug quality |
| | 7. Socket length | 0.3 | m | |
| | 8. Elbow corner | 40 | degree | The elbow and the standard section are connected by socket |
| Static performance | 9. Ring stiffness | 27 | kN/m2 | According to GB/T 9647-2003 |
| Dynamic performance | 10. The maximum static subsidence at the top of the pipe after being impacted by the falling rock | 0.25 | m | 300kg rockfall 7m high free fall impact on the heart, The falling rock is still and stays at the top of the pipe and is not measured. |
| | 11. The minimum static space height in the pipe after the pipe body is impacted by the falling rock | 0.55 | m | |
| Physical properties | 12. Thermal conductivity of the pipe wall | 0.2 | W/(m•K) | According to GB/T 10294-2008. In contrast, 1% carbon steel has a thermal conductivity of 45 W/(m•K). |
| Warning sign | 13. Yellow reflective tape | The body surface is long and sticky. | | Prevent other work processes on the site / mechanical damage to the pipe structure, stick to the eye-catching height of the pipe body |
| On-site installation labor demand | 14. Individual work team staffing | 4 | people | The work team refers to the combination of personnel who can independently complete the pipeline handling, placement and connection in place. |

### 2.7.2 Comparison with traditional steel pipe performance

At present, tunnel construction is generally carried out with 1cm thick steel coils. This paper compares the traditional steel coils with glass fiber reinforced

polymer escape pipelines for the main performance of escape pipelines.

**Table 2.** Performance comparison table between GFRPC and steel escape pipelines

| GFRPC pipe advantages and features | Indicator item | Index comparison | |
|---|---|---|---|
| | | GFRPC type escape pipeline | Steel pipe |
| Lightweight and strong, easy to install | 1. Material | Glass fiber reinforced resin + particle sandwich | Carbon steel |
| | 2. The length of the finished standard section | 3 m | — |
| | 3. The quality of the finished line | 85 kg/m | 210 kg/m |
| | 4. The connection structure | Plug + flower basket screw buckle, easy to install and disassemble | Welding |
| | 5. Installation work team staffing | 4 people | 1 excavator + 4 people |
| Good elasto - plasticity, energy absorption and impact | 6. Ring stiffness | ≥25 kN/m2 | ≥25 kN/m2 |
| | 7. The minimum static space height inside the pipe after the pipe body is impacted by 300kg rockfall | ≥0.55 m | — |
| Insulated and fireproof, well-protected | 8. Pipe wall thermal conductivity | ≤0.2 W/(m·K) | ≥45 W/(m·K) |
| Insulation performance | 9. Resistance | Insulation | 9.78 ×10-8 (Ω m) |
| Controllable cost and high cost performance ratio | 10. Corrosion resistance, durability, reuse | It has strong resistance to the atmosphere, water and acid, alkali, salt and various oils and solvents. It can be reused many times without anti-corrosion coating and curing. | Vulnerable to the atmosphere, water and acid, salt corrosion, easy to rust, anti-corrosion coating and post-conservation, difficult to reuse |

## 3 Conclusion

The Glass Fiber Reinforced polymer composite (GFRPC) material is used as the escape pipeline of the Jinyunshan tunnel. The biggest feature is that it is easy to install. It only takes 4 people to complete the work done by the previous excavator and several people. The movement ensures the escapable pipeline to the maximum extent. This is very rare in the case where the working face of the tunnel is limited and the disturbance of each process is large. Compared with the traditional steel coil, the advantages are obvious and it has been recognized by many parties. At present, the pipeline of the material is still undergoing further research and development improvement. It is expected that the improved product can increase the positioning and visual function of the intelligent personnel, facilitate the understanding of the personnel in the pipeline, and further reduce the weight of the pipeline. Through the use of the Glass Fiber Reinforced polymer composite (GFRPC) escape pipeline in the Jinyunshan tunnel, this paper fully understands the characteristics and performance indicators of the material, and provides reference for the selection of new escape pipelines in the tunnel.

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