Safety Problems During Tunnel Excavation in China

Professor Pierpaolo Oreste

Academy Petroleum and mining engineering

Name Wang Xupeng s250670

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Abstract

In these years, tunnel projects have been raising significantly in quantity and quality with the increasing of city constructions and expressways.Meanwhile, people are paying more attention on safety problems in tunnel constructions. This article has adapted some countries' tunnel experiences and discusses the main safety problems in tunnel, how to monitor these problems, summarizes the principles and what measurements can be used for different categories problems with some relevant cases. Analyses these information and experience, so that it will have essential impacts on guiding the risks identification and safety management.

The article mainly concentrates on these parts:

1. This paper analyzes the typical tunnel construction safety cases with main risk sources, the conditions of risk factors and the mechanism of the tunnel risks to provide basis for assessment.
2. To gain the conclusion of risk grades, the paper combines the geological factors, constructions , other factors , the analysis of the risk factors occurrence and the field survey with the standard query countermeasures.In the end, the paper brings forward the warning system of tunnel construction based on the mechanical tunnel risks.
3. The paper consists of risk identification, risk assessment, risk countermeasures, analyzing each probability of risks.Then, assess the acceptable risk range.
4. Through the special tunnel safety risk assessment, it will identify the key risks , reduce the probabilities in tunnel construction based on the analysis, provide for the construction units risk managements and guides. We can receive the feedback of risk analysis to verify the reliability of the field management.
5. In order to test the tunnel safety, set up the tunnel safety evaluation system, it needs to integrate the collection of plenty of construction site safety management information and the practical tunnel construction dynamic risk analysis model.

Keywords: tunnel subway, construction safety, risk analysis, safety assessment, site administrator,early-warning system

1. Introduction

1.1 Background

China is a country located in a mountainous zone, and the area of mountains and plateaus accounts up about 70% of the total land area. Since 1979 the reform and opening up, under the economic strategy of stimulating domestic demand, with the development of the global economy, the development of China’s transportation industry is getting faster and faster, and the tunnel engineering accounts for an increasing proportion of the entire transportation network, and the more and more complicated geological conditions for crossing, make the construction of road tunnel projects more and more difficult.

Compared with other projects, the special terrain and geological conditions and construction environment of the road tunnel project are uncertain factors that make the tunnel construction process huge risks. In addition, in recent years, the scale of the project has become larger and larger, but because the research on the construction technology and safety management related to the tunnel project is still relatively backward, and the unscientific understanding of the risk of the tunnel project, the unreasonable control before the risk, and the In place of risk management and unprofessional construction teams, tunnel engineering safety accidents occur frequently, and the consequences are very serious and worrying.

Limited by China's national conditions, construction factors account for a significant proportion of the entire road tunnel construction risk. "Many", "chaotic" and "low" are the characteristics of most construction sites in China. "Many" means that there are many construction units. The construction of road tunnels is difficult and dangerous, which requires the construction unit to have sufficient response capabilities when faced with risk accidents. However, the technical level of China's tunnel construction team is very unbalanced, and many units cannot correctly understand the risks, and their risk awareness is very weak. "Chaotic" refers to chaos on site management. According to my survey, many construction units lack safety management awareness, and management personnel cannot effectively control the construction process and construction quality, leading to risk accidents. "Low" refers to a low level of knowledge. The construction unit lacks the necessary training for the construction personnel, and many construction companies and personnel do not have enough understanding of the principles of the

New Austrian Method, so the phenomenon of irregular construction is very common. Because the construction of tunnel engineering requires a lot of money, and the impact on the local environment is generally long-term and unpredictable; the complexity of the working environment of tunnel engineering results in a longer construction period than other projects; tunnel construction in China mostly uses drilling and blasting methods, which affects the building The requirements for materials are also high; tunnel construction involves a large number of related types of workers, and the consequences and negative effects of various risks cannot be eliminated for a while. It can be seen that the implementation of tunnel construction safety risks and on-site management is extremely necessary and urgent. In order to ensure the safety of tunnel construction, reduce tunnel construction safety accidents, control the consequences and losses of accidents, increase the construction team's awareness of tunnel construction risks, and protect people's lives and property safety, risk assessment and site management have become tunnel construction and rational use A subject worthy of research on huge construction funds.

The ultimate goal of risk assessment research is to serve the construction site, and the basis of construction site safety management is risk assessment. The management personnel of the construction party shall control the risks as much as possible on how to identify the risks, how to evaluate the risks, and how to manage the risks to minimize the risk loss. Therefore, it can be said that risk assessment is of great significance to all relevant units of the engineering project.

1.2 Construction risk assessment is helpful to reduce accidents

Because the tunnel is restricted by the side walls of the tunnel, the air in the tunnel is poor, the lighting conditions are limited, the air visibility is very low, and the noise during construction is particularly loud. Therefore, once an accident occurs during operation in a long and narrow tunnel, it is difficult to disperse workers in time.

Complex geological conditions may cause various dangers in underground construction; incomplete geological data before construction increases the danger and uncertainty of survey and construction, and it is likely that the tunnel may collapse during construction due to the inability of relevant departments to provide accurate information A series of problems, such as large deformation, rock burst, water gushing, etc. once these situations occur, it may cause risks and even casualties.

Because the excavation of the tunnel destroys the integrity of the existing rock mass and breaks the balance of the entire surrounding rock, it has certain impacts on the original buildings. For tunnels, the excavation of the tunnel destroys the original vegetation. The impact on the ecological environment is also difficult to determine in a short time.

Due to the specific construction environment of tunnel engineering, the construction period of tunnel engineering is longer than that of general engineering. Tunnel construction can take as little as one year, as long as several years, or even more than ten years. Therefore, the construction environment is very uncertain; this makes the supply of raw materials and construction equipment change with fluctuations in prices. Thereby it has a great impact on the entire project cost, and the economic risk is greater.

1.3 Researches on tunnel risks

Einstein · H · H mainly does related research on the characteristics of the risk analysis of tunnel construction and the concepts to be followed.[1]-[3] Reilly · J· J proposed that the risks of tunnel construction can be divided into four categories according to the consequences: personnel injuries and deaths; cost increase;construction period errors; four risks that cannot meet the requirements.[4] R· Stuzk, L· Olsson, and U· Uohansson applied the risk analysis technology to the Stockholm Ring Road Tunnel and some regular conclusions were obtained.[5] B· Nilsen conducts a relatively in-depth study on the risks of sub-sea tunnels in areas with complex underlying conditions.[6] Heinz Duddeck discussed how to conduct risk assessment for tunnels that cross the strait and tunnels that cross the Alps.[7] what’s more, Hisashi Sato and others have counted a large number of tunnel engineering risks and classified them in Japan.[8] Reilly· J and J· Brown are responsible for the risk management and cost control of infrastructure projects such as tunnel engineering related research.[9]

The application research of risk analysis in tunnel engineering has only developed in recent years in China due to the short construction time of tunnel engineering mainly. However, with the development of economy, more and more researches on tunnel safety have been conducted. Professor Ding Shizhao of Tongji University has conducted a certain research on the risks in underground engineering construction [10]. Chen Long of Tongji University systematically explained the research framework and implementation methods of tunnel engineering risk analysis, and discussed basic issues such as the mechanism of tunnel risk [11]. Jia Sasa conducted a comprehensive study on the construction risks of road tunnels and perfected the construction risk management system of road tunnels [12]. Jia Jianqing took the Fangdoushan deep tunnel excavation project as the background to study the time-dependent reliability and risk management of the tunnel and underground space engineering support [13]. Teng Hongjun studied the safety risks of surface buildings due to tunnel construction and proposed corresponding control measures [14]. According to the construction characteristics of weak surrounding rock formations, and combined with various risk response methods, Li Feng proposed the response to various risk factors measures, and formulated emergency plans for some of the main risks in the strong weathering layer [15]. Chen Zhong made a detailed study on the risk management of subway shield tunnel construction based on the successful experience of shield tunnel construction in the first phase of Chengdu Metro Line 1 project [16]. Combining the specific characteristics of the shield tunneling tunnel engineering technology and project management, Li Jian systematically studied the risk management methods during the construction of the tunnel engineering, and constructed the basic framework of project site management [17]. Chen Jiejin has conducted a comprehensive and systematic in-depth study on the theory of risk integrated dynamic management in the whole process of urban tunnel engineering, comprehensive risk assessment methods and risk management information systems [18]. Chen Jun studied the characteristics of underground engineering,also analyzed the typical accidents of underground engineering, proposed how to construct a dynamic risk management system for underground engineering, and conducted research on risk estimation and evaluation [19]. Relying on the project "Research on Safety Control Technology for Passenger Dedicated Line Tunnel Construction" initiated by the Shanghai Railway Administration, Li Jingjing used questionnaire survey methods to identify 63 important safety risk factors in the construction of tunnel engineering projects, and established a corresponding risk evaluation index system [20]. In conjunction with the Chongqing Natural Science Foundation project "Research on Safety Risk Assessment and Safety Management System of road Mountain Tunnel Construction", Feng Lu did a detailed study on the early warning system of tunnel safety risk accidents.[21]

To sum up, they have conducted systematic research in the aspects of tunnel construction risk management, environmental protection, and operation accident control, which provided a more complete direction for later tunnel construction risk analysis, but they also focused on the establishment of concepts and qualitative research. There are often few quantitative studies,and not many current studies on how to further achieve the combination of technical and economic indicators, combined with risk warning, and especially combined with on-site management. In general, the current risk research on tunnel engineering is still not perfect, basically at the stage of qualitative analysis or semi-quantitative analysis, and a lot of work is still needed.

1.4 Research approach

Based on the project, the paper conducts safety risk research on road tunnels. First of all, according to the construction characteristics of road tunnels, we searched relevant documents, collected a large number of tunnel construction risk accident examples, and statistically analyzed the risk mechanism. Identify the risk factors of tunnel construction in combination with relevant regulations, and study the causes and consequences of the risks. After understanding the risk factors, bring forward the governance countermeasures for the risk factors, and give the risk acceptance criteria after governance. On this basis, provide construction units with road tunnel construction safety management countermeasures.

2. Analysis and Identification of Safety Factors in Tunnel Construction

2.1Identification Method of Risk-causing Factors

Expert investigation method is a method that analyzes the research object directly or through simple calculations based on the survey results, the knowledge and experience of experts, and makes predictions based on its own characteristics and laws. When there is a lack of information and historical data, the expert survey method can better obtain a more realistic evaluation. Here is the figure that shows the investigation flow.

Figure 2.1 expert investigation method flow of consultation

Set up the leading group

↓

clear the forecast goals

↓

Select experts to participate

↓

Compile the questionnaire

2.2Determination of Influencing Factors of Tunnel Risk

Comprehensively consider the identification and analysis of road tunnel construction risk factors, determine the road tunnel construction risk factors, in order to establish the best treatment plan for the road tunnel construction risks. Determining the risk factors is a very important part of the tunnel risk assessment and management.

This paper is based on *Safe Production Law of the People's Republic of China* [22]and other related laws and has been wide collected range of papers published in the industry , and expert investigation and identification methods have been used to establish an index evaluation system for safety risk influencing factors of construction road tunnels.This system is determined according to the risk events of the tunnel, which is mainly divided into five categories: collapse, gas, water gushing and mud outburst, large deformation, and rock burst.

2.2.1 Collapse Causing Factors

Tunnel collapse refers to a geological disaster phenomenon in which part or the whole rock falls under the action of gravity after the excavation of the tunnel vault or waist. The cause of the collapse in the industry is generally believed to be that after the tunnel was excavated, the integrity of the original surrounding rock was artificially broken, the original mechanical equilibrium system was broken, and a "wall rock cavity" was formed, and the surrounding rock stress redistributed As a result, stress is generated in the surrounding rock, and the surrounding rock stress and the ultimate bearing capacity of the surrounding rock are reacted. There are three action forms:

①The stress of the surrounding rock of the tunnel is less than the bearing capacity of the surrounding rock. The tunnel has a certain safety reserve, and the surrounding rock is safe status.

②The stress of the surrounding rock of the tunnel is equal to the bearing capacity of the surrounding rock. The tunnel is in a sub-safe state, any one is not conducive to a small stable movement of the surrounding rock of the tunnel may break the balance and cause a collapse.

③The stress of the surrounding rock of the tunnel is greater than the bearing capacity of the surrounding rock .Then,tunnel collapse.

The collapse process is roughly as follows: excavation → surrounding rock plastic deformation → excessive deformation of the support → partial failure of the support → failure of the support and surrounding rock → collapse. Tunnel collapse may occur during tunnel excavation, after excavation, after construction and support, and even after lining.

In addition to being related to the initial stress of the rock mass, the occurrence of collapse risk mainly depends on the lithology, occurrence, structure and other factors of the surrounding rock; however, man-made operation errors during construction will also lead to tunnel collapse. There are some statistic information about tunnel collapse in recent years in appendix 1.Under normal circumstances, tunnel collapse is related to construction conditions and design methods, and more importantly, it is restricted by hydrogeological conditions. In the comprehensive construction management of various factors, through expert investigation methods, we generally divide the risk of tunnel collapse into six types of secondary risk factors:bad terrain geological factors, groundwater factors, design factors, excavation factors, construction factors, and monitoring factors.

①bad terrain geological factors.

Generally speaking, the engineering geological conditions of tunnels are complex. The tunnel passes through the fractured zone, passes through sections with thin stratum coverage, passes through surface water sources such as ponds, reservoirs, trenches, gullies, etc. and is eroded and dissolved by groundwater for a long time. It is very prone to collapse after excavation in the case of solid bodies, swelling soil layers, shallow buried sections, quicksand layers, and severely biased sections. Therefore, various unexpected bad geological phenomena have a huge impact on tunnel construction.

② groundwater factors

Water is one of the important reasons for the collapse. The softening, soaking, erosion and dissolution of groundwater aggravate the instability and collapse of the rock mass. Rock masses with alternating hard and soft layers or with weak layers, under the action of groundwater, greatly reduce the strength of the weak surface, and thus collapse.

③ design factors

The construction personnel did not have enough understanding of the New Austrian Method and ignored the deformation laws of the surrounding rock. Improper design schemes, construction methods and measures caused sudden deformation of the surrounding rock and led to landslides.

As we all know, the surrounding rock of a tunnel is the most important information for tunnel design, and the unclear condition of the surrounding rock will make the design support strength less than the required. In the process of tunnel excavation, if the actual geological conditions are found to be inconsistent with the design, if they cannot be modified in time, after the initial construction, the provided stress and the ultimate stress of the surrounding rock are not sufficient to resist the gravity stress of the surrounding rock, which will lead to The rock has anomalous phenomena such as relaxation and collapse.

④ excavation factors

The excavation method is also an important factor leading to tunnel collapse. Since the tunnel construction is in a hidden space, the requirements for demolition methods are stricter. If the charge is too large, it will disturb the rock formation and cause collapse. When the excavation distance is less than the width of the tunnel excavation, due to the "space-time effect" of the lining and the excavation surface support, the ultimate stress of the surrounding rock is sufficient to resist its own weight stress and will not collapse. At present, the construction unit blindly insists on the construction period and blindly accelerates the excavation speed, but the primary lining, the second lining and the invert do not keep up in time, resulting in a collapse.

⑤construction factors

The requirements for construction support quality and support timing are strict. Because support can provide an effective constraint on the surrounding rock, the disturbance to the surrounding rock should be minimized during the construction process. The time-space effect is also an important factor affecting the collapse of tunnel construction. The bolting and shotcrete support structure can become a moment-free structure only when it is closely integrated with the excavated rock mass, and can effectively prevent the surrounding rock from falling. However, if the construction team cut corners and cut materials, the support quality is unqualified, or if the blasting is not controlled during the construction process, serious over-excavation occurs, and even some construction units do not meet the design requirements of the sprayed concrete strength thickness, and privately reduce the length of the anchor rod. The support resistance is less than the sliding force of the surrounding rock, or the surrounding rock is not tightly bonded, so that the non-bending moment structure generates a bending moment, which leads to a collapse accident.

⑥monitoring factors

Monitoring and measurement occupies a pivotal position in construction. The occurrence of collapse is generally precursory, and monitoring and measurement can detect abnormalities in real time. However, in actual construction, the monitoring measurement data is often ignored, or the monitoring process is not standardized, the measurement is not performed in accordance with the regulations and the results are analyzed or the information feedback is not timely, resulting in decision errors, ineffective measures, and collapse

2.2.2 Gas hazard factors

The soil is a three-phase body, and the pores in the soil contain water and gas. In the early stage of coal accumulation and coal formation in ancient plants, cellulose and organic matter were decomposed by anaerobic bacteria. In a high temperature and high pressure environment, while coal was formed, gas continued to be generated in the pores of the soil due to physical and chemical effects. Gas is colorless, tasteless, odorless, combustible and explosive gas. In the process of the earth's evolution, plants and other organic matter chemically decompose to generate gas under high temperature and oxygen deficiency. Its main component is $CH4$, which is extremely flammable but not self-igniting. Gas exists in a free state and an adsorbed state in coal or surrounding rocks. There are three types of common gas tunnel accidents, namely gas burning, gas suffocation, and gas explosion, among which gas explosion is the most harmful. Three basic conditions must be met for a gas explosion accident:

1. The concentration of gas is up 5%~16%;
2. There is an ignition source with a temperature of 650～750℃;
3. The concentration of Oxygen is higher than 12%.

In the process of tunnel excavation, gas explosion accidents will occur when these three conditions exist. If the gas concentration is too high, the accident will bring huge losses to the safety of life and property. The presence of gas in the tunnel reduces the concentration of oxygen and can cause people to suffocate due to hypoxia. It has strong diffusivity and can diffuse quickly in the entire tunnel, and is most likely to accumulate in the tunnel vault, collapsed cavity or ventilated corner.

There are many factors that cause gas risk events in road tunnels. Comprehensive gas tunnel construction evaluation factors and man-made factors in the construction are proposed. The gas disaster risk factors in tunnel construction are divided into basic four categories: geological factors, human factors, construction management factors and monitoring measurement factors.

① geological factors

Geological factors mainly refer to the strata saturated with coal seams. It can be seen from the conditions of the gas explosion that the gas-filled coal seam or geological structure contains more than 12% oxygen in the air, and there is a qualified detonating fire source, the tunnel explosion will occur. Therefore, geological factors mainly refer to the gas contained in the stratum. Under normal circumstances, the gas pressure system in the formation is in a balanced state, but because the tunnel excavation breaks this balance, the cracks in the coal and rock formations increase rapidly, and the adsorbed gas is released in a large amount in an instant, and the gas will flow in a large amount in the form of airflow. Into the tunnel space, the gas ejected can fill the tunnel, causing suffocation, causing the gas to burn or explode, and once the gas burns or explodes, it will cause huge losses.

② human factors

In gas risk accidents, some accidents can be completely avoided. The discovery of such accidents is mainly caused by man-made fire sources. According to reliable information, many front-line construction workers did not know enough about gas risks, did not understand the conditions of gas explosion accidents, and the negligence of management personnel eventually led to accidents. For example: some workers use open flames in the tunnel (such as smoking in the tunnel). Therefore, in gas risk accidents, managers with gas tunnel construction experience and tunnels with proper gas prevention measures can generally reduce accidents.

③construction management factors

The management of gas tunnels is critical to preventing gas accidents. It can also be obtained through the case that most of the gas explosions on the construction site are caused by electric sparks that provide the possibility of gas explosion. Therefore, the management of the construction site, especially the control of open flames, is very important.

④monitoring measurement factors

The monitoring here refers to the monitoring of the gas tunnel. General monitoring items of gas tunnels are mainly monitoring gas pressure and absolute gas emission. These two items are one of the keys to prevent gas tunnel risk accidents. However, the monitoring technology for gas tunnels in tunnel monitoring is not yet mature, and the staff does not pay enough attention to its monitoring. Moreover, the risk of a gas tunnel is generally unlikely to penetrate the entire tunnel, and it is likely to exist only in a small section, and this small section is also likely to be a section that was not checked by the previous geological survey. Therefore, monitoring of gas has become very necessary.

2.2.3Water gushing and mud outburst factors

Due to the three-phase nature of the surrounding rock and soil, the hydrodynamic conditions and surrounding rock mechanics are always in equilibrium. However, the tunnel excavation process will definitely disrupt its balance, exposing part of the underground water channel, so that the groundwater flows into the tunnel space through the water channel formed by the soil. When the gushing water is accompanied by a large amount of mud, the mud will burst. It happened. Whether the tunnel water and mud outburst occurs, the following three conditions need to be met:

1. Energy storage conditions of water-bearing surrounding rock;
2. Ground hydrodynamic conditions and energy release conditions of water-bearing surrounding rock;
3. Stability of water-bearing surrounding rock.

In the process of tunnel excavation, water gushing and mud outburst accidents may occur when these three conditions are met. There are many factors that cause the risk of water gushing in the tunnel.Tunnel water and mud outburst are not only related to construction conditions and the characteristics of the tunnel itself, but also mainly restricted by hydrogeological conditions, which are controlled by topographic and geomorphic conditions, stratum lithology and geological structure.The main factors of the gushing water and projecting mud soil construction risk are:

1. Geological factors

Judging from the structural characteristics of the surrounding rock of the tunnel, the surrounding rock condition is not the main factor in the tunnel water gushing and mud outburst risk, but the main factor is the development of various fracture zones. When it develops, the tunnel is prone to large-scale water gushing. Some scholars pointed out that the tunnel water inflow is more serious in the vicinity of large fault zones and regional faults, especially near extensional faults.

2. topographic and geomorphic conditions

The accident of water gushing and mud outburst in the tunnel is closely related to the terrain and topography conditions of the tunnel passing area. Generally speaking, tunnels that pass through surface water sources such as ponds, reservoirs, trenches, gullies, etc. are more likely to see water gushing and mud outburst accidents.

3. stratum lithology

The water inflow of the tunnel is also closely related to the lithology of the formation. Some scholars have found through the investigation of tunnel water inflows larger than 10,000m^3/d at home and abroad that large-scale water-gushing tunnels are generally built in soluble rock masses such as limestone and dolomite. In this type of soluble rock type surrounding rock, the tunnel water inflow is large and the water volume is high. The specific water inflow is generally 0.35～3.47m^3/(min·km), and the specific water inflow of plutonic rocks is generally 1208～1694m^3(min·km). Argillaceous rock and sandstone type surrounding rock, the tunnel water inflow is relatively small, but when it is affected by the fault zone, it also tends to have a large water inflow.

4. climate factors

Normally, The risk of water gushing during construction in the rainy season is far greater than in the dry season. Because of the sufficient rainwater supply on the ground, the water content of the surrounding rock surrounding the tunnel increased, leading to accidents.

5. Tunnel length and depth

Some scholars believe that the greater the length of the tunnel, the more opportunities for access to ground hydrogeology, and the wider the range of groundwater replenishment, the greater the amount of water gushing when an accident occurs. However, it should be pointed out that due to the large differences in the geological conditions of different tunnels, the relationship between the length of the tunnel and the risk of water and mud outburst is not very obvious. That is, the risk factor of water gushing and mud outburst of the tunnel mainly depends on the topography, stratum lithology and Features of geological structure. At the same time, when the depth of tunnel is deeper, the groundwater replenishment is more sufficient, and the total and specific water inflow of the tunnel both increase with the thickness of the overlying rock mass.

2.2.4 Large Deformation Factors

Among all kinds of geological disasters, the large deformation of tunnel surrounding rock is a kind of important geological disaster that is easy to cause construction difficulties, destroy construction equipment, delay construction period, and increase engineering cost. For the large deformation risk of surrounding rock, due to the difficulty of research, a relatively definite definition has not yet been formed. Yu Yu believes that large deformation means that the deformation of the surrounding rock exceeds the reserved deformation of the initial support of the tunnel[23]. It is also believed that the essence of large deformation is that when the surrounding rock is dislocated or fractured due to shear deformation caused by the shear stress of the rock mass, the rock mass cannot withstand its shear deformation and produces a squeezing deformation into the tunnel space. Therefore, in engineering practice, the large deformation of surrounding rock has not been included in the design code. However, scholars agree that large deformation is a phenomenon that occurs in soft rock.Through the expert survey method, we generally analyze from two aspects: geological conditions and supporting conditions.

1. geological condition

The investigation found that large deformation risks generally occur in deep weak surrounding rocks with higher ground stress, which means surrounding rocks with saturated compressive ultimate strength less than 30Mpa. That means, in the hard surrounding rock, the surrounding rock has strong mechanical properties, and the strength of the surrounding rock can withstand the shear deformation from the stress redistribution of the surrounding rock itself after excavation, or it can resist the shear of the surrounding rock together with the lining. Destructive force, at this time, the surrounding rock generally does not appear large deformation. Some minerals in the surrounding rock of the tunnel react with water to expand, which is also one of the important reasons for the large deformation of the tunnel.

2. Supporting condition

Under normal circumstances, when the tunnel supporting structure cannot provide sufficient supporting force and the deformation of the weak surrounding rock cannot be effectively restrained, the surrounding rock begins to deform. It can be seen that as long as the correct supporting structure is adopted, the supporting quality is protected, and the timely supporting is carried out, the occurrence of large deformation can be controlled scientifically to a large extent. On the contrary, unreasonable support measures, unscientific construction methods, and substandard support quality may cause large deformation risks of surrounding rocks even under good geological conditions. Therefore, when the support rigidity is too small, the support is not timely, and the construction method is not scientific, the support may not provide sufficient support force, and the surrounding rock deformation cannot be controlled in time, resulting in large deformation disasters.

2.2.5 Rock Bust Risk-causing Factors

During the construction and excavation of underground engineering, the elastic deformation energy accumulated in the rock mass is released suddenly and violently, causing the rock to burst and eject the rock mass, which is called rock burst. The academic debate on the definition of rock burst focuses on whether the rupture of an um-powered ejection phenomenon can be called a rock burst. Rock burst does not necessarily cause the ejection of rocks, but it will inevitably cause sudden damage to the excavation face. For engineering, it is like rock burst does not necessarily cause rock ejection, but it can also cause sudden damage to the excavation face. So we are more concerned about the damage caused by rock bursts. Rock burst is the result of the combined effects of various factors such as the strength of the surrounding rock mass, the occurrence of the rock formation, the stress state of the surrounding rock, the deformation characteristics, the structural environment of the rock mass, the intensity of superficial regeneration, the layout of underground engineering and the construction technology. Sufficient elastic strain energy stored in the rock and stress concentration points that causing damage are the two main conditions for the occurrence of rock burst risk in tunnel construction.

The main factors of rock burst risk are divided into four categories:

1. Rock structure factors

It can be found in a large number of engineering examples that most rock bursts occur in marble, porphyritic marble, gneiss and other rock masses with complete brittleness In the rock mass. The common mechanical feature of these rock masses is that the rock fractures sharply after reaching the peak strength, which can be expressed by the brittleness of the rock. The brittleness index of a rock is the ratio of the total deformation before the peak strength of the rock to the permanent deformation, and the larger the ratio, the higher the brittleness. The complete rock mass preserves the conditions of elastic strain energy. Therefore, a large amount of elastic strain energy can be accumulated, so that when the rock is broken, the required dissipation energy is relatively less, so that the broken rock block can obtain enough kinetic energy for ejection, which is conducive to the occurrence of rock burst.

2. Depth of tunnel

Rock bursts generally occur in tunnels with larger buried depths, because the greater the buried depth, the greater the ground stress. However, some studies have shown that for underground caverns close to the slopes of mountain slopes or river valleys, they cannot be mistaken for rock bursts due to their shallow depth.

3. Groundwater factors

Generally speaking, the rock mass where a rock burst occurs is very dry, with very little lithological water content. Because the water in the rock will cause two kinds of changes to the rock: First, the water has the ability to soften the rock. Water and certain cation-containing solutions can reduce the surface energy between rock particles, thereby reducing the degree of rock fracture. Secondly, the bedding, joints, and fissures in the water-bearing rock are obviously better than those in the dry rock. The number of bedding, joints, and cracks are much better, and the porosity of the rock is higher. Therefore, there is generally no risk of rock burst when there is abundant groundwater.

4. Human excavation factors

In the construction of underground engineering in high ground stress areas, after manual excavation, the initial stress balance state of the surrounding rock mass is disturbed. After redistributed the stress, local stress concentration of the surrounding rock is formed. When the stress concentration reaches a certain level, it will be released. , It is possible to form a rock burst. The stress conditions of surrounding rock constitute the external cause of rock burst disasters. One of the most important conditions for rock burst disasters is the local stress concentration in the surrounding rock mass. Through analysis, it is found that the stress concentration around the circular cavity is not large, while the stress concentration around the non-circular cavity varies, especially in some parts (the corner points of the non-circular cavity). It is quite high and a rock burst may occur. Blasting is also an important external cause of rock bursts. The huge elastic wave generated by blasting spreads rapidly, causing the rock mass in a critical state to be disturbed and causing sudden instability and destruction, resulting in the occurrence of rock burst.

2.3 Prevention Countermeasures of Tunnel Construction Risks

2.3.1 Collapse Risk Prevention

In the process of tunnel excavation, the collapse is mainly affected by geological factors and design factors. Here is the specific table.

Table 2.1 tunnel collapse risks and prevention

	Causing factors	Countermeasures
Geological survey	Data collection, conventional geological method, advanced geological forecast.	Seriously investigate the unfavorable geological and hydrogeological conditions, and do well in advance geological forecasting.
Pr-construction preparation	Training situation, emergency plan situation, personnel management, implementation team, mechanical equipment level, construction quality, inspection, supervision situation.	Formulate sound labor operating procedures. On-site construction personnel shall conduct pre-job training, implement certificated induction, and use protective equipment reasonably.
Excavation condition	Excavation methods, circular footage, blasting equipment inspection and implementation, groundwater treatment, blasting methods, tunnel over-excavation, and section changes.	Properly enter the tunnel, excavate according to the design requirements, choose a reliable excavation method, and pay attention to the geological conditions at any time.
Support and lining situation	Support stiffness, advanced support, stratum reinforcement and improvement, support	Support must be in place in time, support quality and rigidity must meet the design

	timing, support method, support quality, closed loop cycle.	requirements, and support methods must be correct.
Construction preparation	Construction geological survey, construction related laws and regulations investigation, design document verification, construction organization design.	Prepare targeted and operable construction organization design and special construction plan.
Monitoring measurement	Face stability, measurement equipment and layout, measurement frequency, regulatory requirements, monitoring items, monitoring measurement system, information feedback and processing.	The survey people shall conduct timely geological surveys in strict accordance with relevant regulations, and do a good job in information feedback processing analysis.

2.3.2 Gas risks and prevention

Due to the nature of gas, the construction safety of gas tunnels is mainly reflected in the three basic factors that control gas explosions. It should also be noted that the previous monitoring and measurement information of gas is very important. Generally speaking, as long as the presence of gas is detected, it should start at 15 meters before and after passing through the gas layer, and the tunnel should be constructed as a gas tunnel.

Table 2.2 gas risks and prevention

	Causing factors	Countermeasures
Preparation for construction	Training situation, emergency plan situation, personnel management, implementation team, mechanical equipment level, construction quality, inspection, supervision situation	Formulate sound labor operating procedures. On-site construction personnel shall conduct pre-job training, implement certificated induction, and use protective equipment reasonably.
Excavation condition	Excavation method, circular footage, gas pr-drainage, groundwater treatment, blasting method	Choose reliable excavation methods, strictly control blasting, and pay attention to groundwater conditions at all times
Supporting and lining situation	Isolation measures, air-tight concrete, supporting timing, construction joints, settlement joint treatment, supporting methods and quality	Support must be in place in time, support quality and rigidity must meet the design requirements, and support methods must be correct. Take isolation measures.
Monitoring	Face stability, measurement equipment and layout, measurement frequency, regulatory requirements,	The survey personnel shall conduct timely geological surveys in strict accordance with relevant regulations, and

	monitoring items, monitoring and measurement systems, information feedback and processing, gas (concentration and pressure) monitoring.	do a good job in information feedback processing analysis.
Uncovering coal and preventing outbursts	Data collection, conventional geological law, advanced geological forecast, vibration or remote blasting, gas pressure relief and discharge.	Extensively collect geological conditions, make advance geological forecasts, and do a good job in gas pressure relief and discharge in gas-filled areas.
Fire source controlling	Fire inspection, welding and other dangerous operations	Work strictly in accordance with rules and regulations.
Ventilation	Ventilation system, ventilation equipment, ventilation quality	Check the ventilation equipment regularly.
Protection	Mechanical equipment protection, personnel protection	Strengthen the safety training of construction personnel
Electrical equipment and work machinery	Cable selection, electrical and protection conditions, wind power lockout	Operate strictly in accordance with machinery safety operation rules and regulations.

2.3.3Water gushing and mud outburst risks prevention

Tunnel water and mud outburst are the most common geological disasters in tunnel construction. Tunnel water gushing and mud outburst seriously endanger the safety of tunnel construction and affect the construction progress. If the risk of water gushing and mud outburst cannot be handled well during the tunnel construction process, it will not only seriously affect the construction safety during the construction period of the tunnel, but also cause serious problems. Casualties and economic losses will also affect the normal use of the tunnel during the operation period. Therefore, strengthening the research on the prevention of water and mud outburst in tunnels and effectively formulating the countermeasures for water and mud outburst are of great significance to ensure the safety of tunnel construction and operation. The occurrence of water gushing and mud bursting accidents is often not sudden. Limited by the special environment of the tunnel, a small amount of water gushing accident accompanied the entire construction process of the tunnel. Limited by the requirements of the route, the risk of water gushing and mud outburst is unavoidable in many cases, but relevant measures can be taken to minimize the impact of the risk on the entire construction and reduce the risk to an acceptable level.

Table 2.3 tunnel water gushing and mud outburst

	Causing factors	Countermeasures
Before construction	Training situation, emergency plan situation, personnel management, implementation team, mechanical equipment level, construction quality, inspection, supervision situation	Formulate sound labor operating procedures. On-site construction personnel shall conduct pre-job training, implement certificated induction, and use protective equipment reasonably.
Excavation condition	Excavation method, circular footage, gas pr-drainage, groundwater treatment, blasting method	Choose reliable excavation methods, strictly control blasting, and pay attention to groundwater conditions at all times
Supporting and lining	Isolation measures, air-tight	Support must be in place in

condition	concrete, supporting timing, construction joints, settlement joint treatment, supporting methods and quality	time, support quality and rigidity must meet the design requirements, and support methods must be correct. Take isolation measures.
Preparation for construction	Construction geological survey, construction related laws and regulations investigation, design document verification, construction organization design	Prepare targeted and operable construction organization design and special construction plan.
Monitoring	Face stability, measurement equipment and layout, measurement frequency, regulatory requirements, monitoring items, monitoring and measurement systems, information feedback and processing, gas (concentration and pressure) monitoring.	The survey personnel shall conduct timely geological surveys in strict accordance with relevant regulations, and do a good job in information feedback processing analysis.
Protection	Mechanical equipment protection, personnel protection	Strengthen the safety training of construction personnel

2.3.4 Large deformation risks prevention

As a serious geological disaster phenomenon, large deformation of underground surrounding rock has a serious impact on tunnel construction. However, due to the lack of research on the theory of large deformation, there is no unified definition and criteria for judging the risk of large deformation. However, according to a large number of research data statistics: no matter what kind of surrounding rock, as long as it is excavated, it will produce a certain amount of deformation. These deformations are allowed within a certain range in the design code, but when the actual deformation is large and exceeds the reserved deformation, then we can consider that the tunnel has a large deformation.

Table 2.4 large deformation risks prevention

	Causing factors	Countermeasures
Geological survey	Data collection, conventional geological method, advanced geological forecast.	Seriously investigate the unfavorable geological and hydrogeological conditions, and do well in advance geological forecasting.
Before construction	Training situation, emergency plan situation, personnel management, implementation team, mechanical equipment level, construction quality, inspection, supervision situation	Formulate sound labor operating procedures. On-site construction personnel shall conduct pre-job training, implement certificated induction, and use protective equipment reasonably.
Excavation condition	Excavation method, circular footage, gas pr-drainage, groundwater treatment, blasting method	Choose reliable excavation methods, strictly control blasting, and pay attention to groundwater conditions at all

		times
Supporting and lining condition	Isolation measures, air-tight concrete, supporting timing, construction joints, settlement joint treatment, supporting methods and quality	Support must be in place in time, support quality and rigidity must meet the design requirements, and support methods must be correct. Take isolation measures.
Preparation for construction	Construction geological survey, construction related laws and regulations investigation, design document verification, construction organization design	Prepare targeted and operable construction organization design and special construction plan.
Monitoring	Face stability, measurement equipment and layout, measurement frequency, regulatory requirements, monitoring items, monitoring and measurement systems, information feedback and processing, gas (concentration and pressure) monitoring.	The survey personnel shall conduct timely geological surveys in strict accordance with relevant regulations, and do a good job in information feedback processing analysis.
Protection	Mechanical equipment protection, personnel protection	Strengthen the safety training of construction personnel

2.3.5 Rock burst risks prevention

In China, the prevention of rock burst has not yet formed an effective mechanism. Under the conditions of high ground stress, if the surrounding rock has a tendency to rock burst, the safe construction of the tunnel under this condition has always attracted attention.

Table 2.5 rock burst risks prevention

	Causing factors	Countermeasures
Before construction	Training situation, emergency plan situation, personnel management, implementation team, mechanical equipment level, construction quality, inspection, supervision situation	Formulate sound labor operating procedures. On-site construction personnel shall conduct pre-job training, implement certificated induction, and use protective equipment reasonably.
Excavation condition	Excavation method, circular footage, gas pr-drainage, groundwater treatment, blasting method	Choose reliable excavation methods, strictly control blasting, and pay attention to groundwater conditions at all times
Supporting and lining condition	Isolation measures, air-tight concrete, supporting timing, construction joints, settlement joint treatment, supporting methods and quality	Support must be in place in time, support quality and rigidity must meet the design requirements, and support methods must be correct. Take isolation measures.
Preparation for construction	Construction geological survey, construction related laws and regulations investigation, design document verification, construction organization	Prepare targeted and operable construction organization design and special construction plan.

	design	
Protection	Mechanical equipment protection, personnel protection	Strengthen the safety training of construction personnel

2.4 Summary

Through the collection of existing data, combined with on-site investigations, the use of expert investigation methods for road tunnel construction safety.

Through the analysis and identification of all risk factors, the tunnel construction safety risk factor evaluation index was established, and based on the existing risk countermeasures and risk acceptance criteria, combined with the characteristics of our tunnel construction, from the mechanism of construction safety accidents. Drew the tunnel construction risk early warning system model.

Based on some cases analysis, the expert investigation method is adopted to determine the influence index of tunnel construction risk factors. It is preliminarily obtained that the factors affecting the safety of tunnel construction are: collapse, gas, water and mud, large deformation, and rock burst risks. Through the study of these factors, the risk influencing factor index of tunnel construction was determined. The preventive measures after the tunnel construction safety risk occurred were summarized: through the study of the tunnel construction safety risk of collapse, gas risk, water inrush and mud inrush risk, and large deformation risk , The hazard factors of rock burst risk, and a corresponding preventive countermeasure system has been established.

3. Tunnel Construction Risk Early Warning System and Risk Acceptance Criteria

3.1Tunnel construction risk early warning system

Early warning is a kind of advance information warning or warning of disaster or dangerous state. The tunnel construction risk early warning system refers to the prediction of sudden or long-term tunnel construction emergency or long-term warnings through real-time engineering information analysis and evaluation under sub-safe or unsafe conditions during tunnel construction. The tunnel construction risk early warning system is one of the effective ways to prevent safety accidents.

This paper is based on "*Safety Law of the People's Republic of China*", "*Guidelines for Safety Risk Assessment of Tunnel Construction*", "*Code for Construction of Tunnels*" and other laws and regulations.

3.1.1The early warning system of tunnel construction collapse

As people pay more and more attention to the safety construction of tunnels, collapse accidents have been reduced a lot. However, tunnel collapse accidents are not uncommon. The reasons are not only geological unavoidable factors, but also tunnel collapses caused by improper construction. But the tunnel collapse is not accidental.

Table 3.1 the index of tunnel collapse risk

Index	After excavation, the face falls off
	Sinking vault
	Change of arch foot level clearance

3.1.2The early warning system of gas

Because the gas is colorless and odorless, it is difficult to detect gas risks without clear geological survey data and strict gas monitoring. But of the three conditions for the occurrence of gas risk, we can control the occurrence of the entire risk accident as long as we control one of them. In the case of certain geological conditions, the gas content generally does not change much; and under normal ventilation conditions, the oxygen content in the air in the tunnel is unlikely to change rapidly in a short time, so these two conditions are difficult to control in emergencies. But the control of the fire source can be done artificially.

Table 3.2 the index of tunnel gas risk

Index	Gas measurement data
	Geological survey
	Monitor measurement data

3.1.3The early warning system of water bushing and rock burst

During the construction of the tunnel, large-scale water and mud inrush accidents occurred when the tunnel encountered unfavorable geological conditions such as underground rivers, and confined water. Generally, water and mud and sand were used as carriers to quickly protrude. This is one of the most serious geological disasters in tunnel construction. It is not easy to occur under general geological conditions, but due to its strong concealment and unpredictability, it is very easy to cause serious economic losses and even casualties. Therefore, special attention should be paid to the construction of weak and broken surrounding rock tunnels with groundwater. When encountering mud bursts, water gushing, or special dangers that cannot guarantee safety, the person in charge of the site should immediately organize personnel and construction machinery to evacuate to a safe location, stop construction and wait for treatment. In the construction of tunnels with developed groundwater and weak and broken surrounding rocks, effective advance geological detection and forecasting measures should be taken to predict the geological conditions of the surrounding rocks in advance, and predict whether there is a possibility of mud outburst and water bushing based on the measured geological conditions to prevent disaster accidents happened.

Table 3.3 the index of tunnel water bushing and mud outburst

Index	Constructing during rainy season
	The development of groundwater
	Surrounding rock
	The face development of krast rock
	Rock fault

3.1.4The early warning system of big deformation

The large deformation of the surrounding rock is a slow deformation process, so the prediction study should be carried out step by step with different prediction methods according to the conditions of the surrounding rock at different stages. For the prediction of the excavated section, after the excavation of the surrounding rock, the geological analysis and prediction should be carried out first based on the geological conditions exposed by the excavation. After the initial support, analyze and forecast based on the monitoring and measurement data. The forecasting method differs depending on its forecast range. The method of predicting the excavated section should be based on monitoring and measurement. Advance prediction should be based on geological analysis, combined with numerical simulation and other means for comprehensive analysis and judgment.

Table 3.4 the index of tunnel big deformation

Index	Geological information
	Rock fault
	Characteristics of groundwater
	Displacement of surrounding rock

	Rock face change
	Rock face fissure
	Abnormality of stress test

3.1.5The early warning system of rock burst

Rock burst is the process of sudden release of strain energy in a rock mass. As a condition for rock burst formation, one is to have an energy source, that is, a higher initial ground stress; the other is a rock mass that can effectively accumulate strain energy. In addition, external conditions that cause stress differentiation and strain energy release are also required, such as excavation.

Table 3.5 the index of tunnel rock burst risk

Index	Core cake cracking
	Abnormality of stress-strain curvy
	Abnormality of rock mechanics test

3.2 Basic criteria for accepting safety risks in tunnel construction

The risks associated with the tunnel construction process are concealed, complicated and uncertain. Tunnel construction safety risk management also involves multiple directions such as structure, elector-mechanical, transportation, and management. The factors affecting risk are complex, and once a risk occurs, it will inevitably be accompanied by economic losses and casualties. This will have a great negative impact on society.

In tunnel construction safety risk management, after identifying risks, the core question of risk management is: how to deal with risks? What is the risk factor after treatment? Is it safe? How safe is enough? Risk acceptance criteria can answer these core questions. When conducting tunnel construction safety risk management, how to evaluate the safety level of the tunnel after risk treatment, determine whether the risk treatment is at an acceptable level, and whether control measures still need to be taken after risk treatment, all need to follow the risk acceptance criteria. Because of the gap between the various industries, the risk acceptance criteria of each industry are also very different. At present, there is no clear system on the acceptance criteria of tunnel construction safety risks, and the research on the acceptance criteria of tunnel construction safety risks is still in the early stage.

This paper bases on some guidance like "*Guidelines for Safety Risk Assessment of Tunnel Construction*", divides risk acceptance criteria into two categories: probability acceptance criteria and consequence acceptance criteria, and related research has been done on them.

3.2.1Acceptance criteria for probability of occurrence of safety risks in tunnel construction

The probability of occurrence of safety risks in tunnel construction refers to the risk coefficient of safety accidents during the construction process.Because the research on tunnel risk is still in the initial stage, and because of the complexity of tunnel engineering conditions, the risk coefficient is generally changed.

When the probability value is difficult to obtain, frequency can be used instead of probability; the center value represents the logarithmic average of the given interval.

Table 3.6 the probability standard and acceptance criteria

Range	Logarithmic average value	Description	Probability level	Acceptance criteria
>0.3	1	Very likely	5	Unacceptable
0.03~0.3	0.1	likely	4	Unexpected
0.003~0.03	0.01	Occasionally	3	Unexpected
0.0003~0.003	0.001	Unlikely	2	Acceptable
<0.0003	0.0001	Very unlikely	1	Ignorable

3.2.2 Acceptance criteria for risk consequence of tunnel construction

Safety risk consequences refer to the impact of the consequences on the construction of the tunnel during the construction process and after a safety accident occurs. This thesis divides the consequences into 2 aspects: personal injury with death and economic loss.

① economic loss.

Economic loss refers to the sum of various costs incurred by the project after the occurrence of a risk accident, including direct costs and various costs required for accident handling.

Table 3.7 economic loss level standard

Description of consequence	Disaster	Very seriously	Seriously	Large	Slight
Consequence level	5	4	3	2	1
Economic loss(rmb)	>10million	3~10million	1~3million	0.3~1million	<0.3million

Acceptance standard	Unacceptable	Unacceptable	Unexpected	Acceptable	Ignorable

② personal injury and death .

Casualties refer to the casualties that occur during the construction activities, and are classified according to the type and severity of casualties.

Table 3.8 the level standard of casualties consequence

Description of consequence	Disaster	Very seriously	Seriously	Large	Slight
Consequence level	5	4	3	2	1
Numbers of casualty	F>9	2<F<9 or SI>10	1<F<2 or 2<SI<9	SI=1 or 1<MI<11	MI=1
Acceptance standard	Unacceptable	Unacceptable	Unexpected	Acceptable	Ignorable

PS. F means number of death; SI means number of serious injures; MI means number of minor injures.

3.3 Tunnel construction safety risk level

According to the probability and consequence level of construction, the risk level is divided into four levels: extremely high, high, medium and low.

Table 3.9 the standards of risk grading

Probability \ Consequence		Slight	Large	Seriously	Very seriously	Disaster
		1	2	3	4	5
Very likely	5	High	High	Extremely high	Extremely high	Extremely high
Likely	4	Medium	High	High	Extremely high	Extremely high
Occasionally	3	Medium	Medium	High	High	Extremely high
Unlikely	2	Low	Medium	Medium	High	High
Very unlikely	1	Low	Low	Medium	Medium	High

3.4Acceptance criteria for risks in tunnel construction

In view of the characteristics of tunnel construction safety risks, comprehensively combining the contents of this chapter, the risk acceptance criteria should be comprehensively evaluated and analyzed from the two aspects of the consequences of accidents and the probability of accidents to form the tunnel construction safety risk acceptance criteria.

Table 3.10 acceptance criteria

Risk level	Acceptance standards	Treatment
Low	Ignorable	This type of risk is relatively small, and no risk treatment measures and monitoring are required.
Medium	Acceptable	This type of risk is medium, no risk measures are required, but monitoring is needed.
High	Unexpected	These risks are relatively large, and risk treatment measures must be taken to reduce and strengthen monitoring, and the cost of reducing the risk is not higher than the loss after the risk occurs.
Extremely high	Unacceptable	This type of risk is the biggest and must be taken seriously and avoided, otherwise the risk must be reduced to an undesired level at least.

3.5 Summary

Based on the characteristics of the tunnel construction safety risk assessment, combined with the analysis of the factors affecting the tunnel construction safety risk, a corresponding early warning system is proposed for the tunnel risk factors, and its risk acceptance criteria are studied. The main content is as follows: through the study of the signs of the tunnel construction risk factors, the early warning system of the tunnel construction safety risk factors are studied. The acceptance criteria for the road tunnel construction safety risk are established from the two aspects of the probability of construction safety accidents and the loss of the consequences of the accident standards.

4.Risk Assessment of the Wanhui Tunnel

Tunnel site security risk management is the guarantee of tunnel security. Through the analysis of various safety management accidents on site during the tunnel construction process, the essential characteristics, background and development rules of safety accident phenomena are explored, and a tunnel safety early warning system is constructed. By formulating a scientific and complete on-site management system, the possibility of risks can be reduced and accidents can be prevented.

4.1Overview of the wan-hui Tunnel

The design start mileage of the tunnel in this section is GDK33+022.303, and the end mileage is GDK33+835.447[25]. After passing through Xincheng Road and Gongye East Road in turn, enter the urban area. The section crosses Xincheng Road and Gongye East Road vertically, and the rest is basically along the south of Yingbin Road. Walk under the side green belt. There are DK33+650 construction shafts in this range, and the large mileage is terminated with DK33+951 shield starting shafts. The site is a landform of denuded hills and valley bottoms between hills, the terrain is slightly undulating, and the elevation varies between 18.30~23.50m. The underground pipelines within the tunnel crossing range are dense and diverse. According to pipeline data and on-site exploration, the main underground pipelines in the field include cables, communication cables, water supply and drainage pipes, gas pipes, etc. with varying depths. The tunnel mainly traverses plain fill, silty clay, and fully weathered mixed gneiss. According to the tunnel section, buried depth and geological conditions, this section of the tunnel is designed and constructed using the shallow burying method and the shotcrete method.

4.1.1Topography

The site in the section of GDK33+022.303~GDK33+835.447 is a valley between denuded hills and hills. The terrain is slightly undulating, and the ground elevation varies from 18.30 to 23.50m. The valleys are mostly vegetable plots with developed vegetation.

4.1.2Stratum lithology and geological structure

(1) Fourth Holocene Artificial Accumulation Layer(Q4ml)

①Plain fill: brown-gray, brown-yellow, slightly wet, loose to slightly dense, mainly composed of cohesive soil, sand, etc. containing a small amount of gravel, with a layer thickness of 0.90~12.00m, distributed in layers on the surface where artificial activities are frequent. Each drill hole is exposed, and the bottom elevation is 9.79~21.45m.

(2) Alluvial strata(Q4al)

②Silty clay: brown-yellow, brown-red, soft plastic, local hard plastic, uneven soil, containing a small amount of sand, layer thickness 2.20~2.90m, only exposed in BD1Z-2300, BD1Z-2301, BD1Z-2302 drill holes . The elevation of the top of the layer is 9.79~11.19m, and the elevation of the bottom of the layer is 7.59~8.29m.

③Mucky silty clay: dark gray, flowing plastic, smelly, uneven soil, containing organic matter, with a lot of sand in some parts, layer thickness 1.20~3.70m, only in BD1Z-BDG1, BD1Z-BDG2, BD1Z-BDG3, BD1Z -Drill holes BDG4, BD1Z-S1315, BD1Z-S1401 and BD1Z-S1402 have been revealed. The elevation of the top of the layer is 13.52-20.80m, and the elevation of the bottom of the layer is 11.22-19.50m.

④Silt: gray-black, slightly dense, saturated, poorly graded, with a small amount of clay, layer thickness 1.00~2.00m, only exposed in BD1Z-BDG2 and BD1Z-BDG4 boreholes, layer top elevation 14.13~19.50m, The bottom elevation is 13.13~17.50m.

(3) Residual layer (Qel)

⑤Silty clay: mainly yellow-brown, black-red, partially gray-white, hard plastic, layer thickness 1.40-19.90m, the layer is exposed in each drill hole, the top elevation of the layer is 7.59-21.45m, and the bottom elevation of the layer is -3.47 ~14.70m.

(4) Mixed gneiss(Pzl)

⑥Fully weathered mixed gneiss: mainly brownish-yellow, the rock mass is soil-like, except for quartz, all kinds of minerals have been weathered and altered, the thickness of the layer is 4.60~21.50m, and it is exposed in each drill hole, the top elevation of the layer -.3.47~14.70m, bottom elevation of -18.25~7.26m.

⑦Strongly weathered mixed gneiss: blue-gray, the core is fragmented, block, locally flat to short columnar, metamorphic structure, gneissic structure, cracks developed, and the rock mass is relatively broken. The layer thickness is 1.10~8.40m, most of the drill holes are exposed, the top elevation of the layer is -18.25~7.26m, and the bottom of the layer is -22.65~3.26m.

⑧Weakly weathered mixed gneiss: blue-gray, metamorphic structure, gneiss-like structure, the rock mass is mostly short-column to long-column, partially fragmented, with well-developed joints and fissures, layer thickness 1.90-25.00m, most of the boreholes It is revealed that the elevation of the layer top is -22.65~3.26m, and the buried depth of the layer top is 20.0~44.40m.

The tunnel body is full-to-weakly weathered mixed gneiss, which is fully weathered into sandy soil, strong weathered into blocks, and weakly weathered is relatively complete. Full-to-strongly weathered mixed gneiss has uneven weathering, loose structure, and low strength. It has poor resistance to external damage and poor stability.

Table 4.1 the stress of layers

Layers from the above	Stress (k Pa)	Grade
①	0	
②	120	2
④	80	2
⑤	200	2
⑥	250	3
⑦	500	4
⑧	1000	5

4.1.2 Hydrogeology

The buried depth of groundwater level during the survey period is 1.30~9.0m. According to the test results of water samples, groundwater is non-corrosive to concrete structures and non-corrosive to steel bars in reinforced concrete structures.

4.2Tunnel risk assessment

Through the above analysis, calculation, comprehensive analysis and evaluation, there is a possibility of collapse, water gushing and mud bursting, deformation and rock burst.

Table 4.2 risk level

Risks	Probability	Consequence	Risk level
Collapse	5	4	High
Water gushing and mud bursting	3	2	Medium
Deformation	4	3	High
Rock burst	4	3	Medium

4.3 Hazards during tunnel excavation

Table 4.3 hazards and corresponding measures

Hazards	Possible damage	Measures
Lifting equipment production and installation	Weak welding, improper on-site command, falling from height	Regular inspections, prompt corrections when problems are found, and strengthening on-site management
Foundation pit support is not strong	The collapsed machinery or personnel were buried, the pieces fell and the people were injured.	Strengthen on-site management, formulate safety protection measures and put them in place, and regularly check whether there are cracks and cracks in the on-site support

The upper and lower channels are not well protected	Falling from height	Strengthen education and training, enhance safety awareness of all personnel, implement on-site protective measures
Vertical transportation	Falling from a height due to improper command, injuring people, broken wire rope, failure of hoisting equipment	Strengthen on-site safety inspection work, safety education work and safety technical clarification;
Incomplete certificates of machinery and equipment, unlicensed operation of machinery and equipment	Mechanical injury	Strengthen on-site safety inspections, establish an on-site safety punishment system, and impose penalties on undocumented operators
The ground drainage system is not unblocked	Collapse, soil falls and hurts people.	The ground drainage plan is formulated and put in place before construction can be carried out.
Earthwork excavation	Ground subsidence, and ground building collapses.	Develop safety protection plans and emergency plans. Full-time safety personnel during the excavation work will follow-up and deal with problems in time.
Anchor rod construction, steel grid erection	Falling from high altitude, insufficient safety protection, arch frame collapse, injury to people, dust	Protection measures are put in place, safety education and training work on site, and construction workers' awareness of safety prevention

Vertical and horizontal transportation of earthwork,	Mechanical injury, wire rope breakage, and transportation equipment failure Strengthen site management	Formulate safety protection measures and put them in place, and regularly check the good condition of machinery and equipment
Electricity in the cave.	Insufficient electricity protection in humid environment, leakage and injury.	Regularly check the safety of on-site construction electricity; strengthen safety education and training to enhance the safety awareness of all construction personnel
Tunnel ventilation	High-pressure wind hurts people, dust	Strengthen safety education and training, and strict safety technology disclosure system
Failure to carry out advance support as required	Collapse	Strict safety and technical disclosure system and strengthen on-site management
Inadequate protection of underground pipelines	Leakage of pipelines and interruption of communication information	Establish full-time safety management personnel to work on duty to implement protection of underground pipelines
Rebar lashing, welding	scratches, stab wounds	Strengthen safety education and training, and enhance the safety awareness of construction workers
Working at heights	Falling from heights	Strengthen safety education and training, strictly explain safety technology, and regularly check the

		implementation of safety protection equipment for construction workers
Electricity for construction	Illegal operations and electric shocks	Formulate penalties for illegal operations on the construction site, strengthen safety education and training, and enhance the safety awareness of construction personnel
The second lining form-work is not firmly reinforced	collapses, and the mold runs	Regular inspections are performed, and problems are found to be corrected in time
Personnel did not wear safety protection equipment	bumped, smashed	Formulated penalties for illegal operations at the construction site, strengthened safety education and training, and enhanced the safety awareness of construction personnel

4.4Technical countermeasures for tunnel risk events

4.4.1 Collapse risk level

According to the results of "Tunnel Risk Assessment" combined with the actual construction geology, it is known that: projects rated as "extremely high" risk are not; projects rated as "High" risk have collapse and deformation; rated as "medium".Projects with risk levels include water gushing and mud bursting and rock burst.

4.4.2 Risk treatment

According to the provisions of the tunnel risk acceptance criteria and the risk treatment measures adopted, medium risks are acceptable, and the corresponding treatment measures are “no risk treatment measures are required, but monitoring is required”; extremely high and high risks "We must attach great importance to and avoid, otherwise we must reduce the risk at least to an undesirable level at any cost." To this end, the project department determined the following risk technical countermeasures:

High and medium risk tunnels: While strengthening construction monitoring, strengthen advanced geological forecasting work and do a good job in design review, especially on-site geological verification and complete geological analysis. The main method of advanced geological prediction is advanced horizontal drilling. Formulate special safety technical measures and emergency plans, and strengthen on-site drills.

Strengthen construction process management and process connection control to ensure that the project quality and process follow closely. Actively work with owners, supervision units, and design units to change the design plan to avoid risks; strengthen monitoring and measurement, and if necessary, closely cooperate with professional designers to use mechanical inversion technology to timely repair parameters. Prepare tunnel monitoring and measurement plans, carefully implement monitoring and measurement, and identify the stable state of surrounding rock through recording, analysis, and feedback; if necessary, cooperate with the design unit, use measured data, and large-scale civil engineering software to predict surrounding rock deformation or perform mechanical back analysis, modify design parameters in time to ensure construction safety.

According to Section 4.5.10 of "Technical Regulations for Monitoring and Measurement of Railway Tunnels" (TB10121-2007)[24], on the basis of monitoring measurement, data processing and analysis, the construction time of the secondary lining is determined to ensure timely construction of the secondary lining .

Strengthen construction supervision to ensure that the measures are in place; strengthen process management to ensure that the process is closely followed, especially the reasonable step distance between the excavation and initial support, initial support and lining, and the advance construction of the invert and the second lining of the arch wall control.

4.4.3Technical measures for protection at the cave entrance

The entrance section of the main tunnel includes construction of reinforcement ring beams at the entrance of the cave, and construction of advanced support. Combining the engineering geological and hydrogeological conditions of the tunnel entrance, it is necessary to strengthen the observation, analyze the force system, and analyze the monitoring measurement data to ensure the stability of the entrance.

4.4.4 Preventing shallow buried

(1) Follow the construction principles of "short footage, frequent measurement, strong support, and early closure" during construction and adjust the excavation method and optimize the construction process. For the shallow buried section of surrounding rock, collapse is likely to occur during the tunneling construction. In order to ensure the safety and quality of the construction, the construction should be carried out according to the requirements of the design drawings first, with short footage, frequent measurement and strong support. Promptly implement small conduits for advance support, and adopt full-face grouting measures for the sections underneath Xincheng Road and Industrial East Road. During the grouting process, if the grouting pressure and the amount of grouting differ too much from the design requirements, the construction should be stopped, the exploration hole should be advanced, the surrounding rock conditions of the tunnel should be truthfully grasped, and the design institute should be reported to the design institute based on the advanced exploration hole geological data to change the construction plan. The footage per cycle is controlled within 45 to 55cm. After excavation, the tunnel face and vault are first sprayed and sealed, and steel frame and bolting and spraying support shall be applied in time. The steel frame spacing shall be implemented strictly in accordance with the design requirements. If necessary, the steel frame spacing shall be reduced, and the steel frame connecting plate shall be equipped with lock-foot steel pipes. The system anchor rods are arranged staggered on both sides of the steel frame and welded firmly to the steel frame. The steel mesh is close to the initial spray surface, and the longitudinal and circumferential overlaps are at least one grid length to strengthen the support and ensure the safety of construction. The inverted arch closely follows the face of the tunnel to seal the initial support into a ring as soon as possible.

(2) Strengthen monitoring, reserve sufficient settlement, ensure construction safety and design thickness of secondary lining.

(3) Strengthen advanced geological forecasting, and adjust design parameters in time with monitoring measurement analysis.

(4) For sections with inverted arches, it is necessary to consider advance excavation face and inverted arches, strictly control the steps between inverted arching, back-filling and secondary lining, and operate strictly in accordance with specifications to complete the secondary lining pouring as soon as possible .

(5) During the construction operation, the on-duty technology is on duty 24 hours a day, recording the situation of the work face at any time, and reporting problems in time to prevent missing the best processing time.

(6) Before entering the tunnel, the vertical and horizontal sections of the entrance section and the shallow buried section should be measured, and the vertical and horizontal sections should be drawn to confirm the rock burst, so as to grasp the thickness of the rock and soil layer on the roof of the cave at any time, and adjust the support accordingly Parameter and job process deployment.

(7) Do a good job in the registration of entry and exit personnel, strictly control and manage entry qualifications, and reduce unnecessary damage.

(8) Prepare emergency plans and equip with necessary rescue materials.

4.4.5 Construction countermeasures for large deformation

Adopt the active control principle of "reinforce surrounding rock, improve deformation, be flexible before rigid, release before resisting, leave enough deformation, and strengthen bottom". The first is to improve the mechanical properties of the surrounding rock and actively strengthen the surrounding rock so that it can bear part of the load; the second is that the initial support allows flexible deformation to consume the energy stored in the surrounding rock; the third is to reserve enough deformation to prevent the intrusion of the initial support. Lining; the fourth is to increase the reinforcement to strengthen the second lining in case of large deformation; the fifth is to strengthen the structure of the tunnel bottom.

(1) Deformation is likely to occur during the tunneling construction. In order to ensure the safety and quality of the construction, first perform the construction according to the design drawings to

achieve short footage, frequent measurement, and strong support. Promptly implement the small conduit for advance support, truthfully grasp the surrounding rock conditions of the tunnel, and report to the design institute based on the advance exploration geological data to change the construction plan. The footage per cycle is controlled within 45 to 55cm. After excavation, the tunnel face and the vault are first sprayed to seal, and steel frame and bolting and spraying support are installed in time. The steel frame spacing shall be implemented strictly in accordance with the design requirements. If necessary, the steel frame spacing shall be reduced, and the steel frame connecting plate shall be equipped with locking foot anchor pipes. The system anchor rods are arranged staggered on both sides of the steel frame and welded firmly to the steel frame. The steel mesh is close to the initial spray surface, and the longitudinal and circumferential overlaps are at least one grid length to strengthen the support and ensure the safety of construction. The inverted arch closely follows the face of the tunnel, and the distance is kept within 40m, so that the initial support is closed into a ring as soon as possible.

(2) After tunnel is excavated, the on-site technician should immediately observe the engineering geological conditions, including: the lithology of the surrounding rock near the working face, the nature of the filling material on the contact surface, the observation of the stable state of the excavation surface; whether the excavation surface is loose or collapsed signs, whether there is underground water seepage and other phenomena.After the initial support is completed, observe the status of the initial support, including whether the support spray layer has cracks, peeling and shear failure, and whether the steel support is buckled. Observations outside the cave include observations of surface conditions, surface subsidence, and surface water penetration.

(3) Strengthen monitoring, reserve enough settlement to ensure construction safety and the design thickness of the secondary lining.

(4) Strengthen advanced geological forecasting, and combine monitoring measurement analysis to adjust design parameters in time.

(5) Inverted arch section must consider the advance construction of excavation face and inverted arch, strictly control the steps between invert arch, backfill and secondary lining, work strictly in accordance with the specifications, and complete the secondary lining pouring as soon as possible.

(6) During the construction operation, the on-duty technology is on duty 24 hours a day, recording the situation of the work face at any time, and reporting problems in time to prevent missing the best processing time.

(7) Do a good job in the registration of entry and exit personnel, strictly control and manage entry qualifications, and reduce unnecessary damage.

(8) Prepare emergency plans and equip with necessary rescue materials.

4.4.6 Other special preventive measures

(1) Carry out pre-job training for new workers on the field, so that everyone has a certificate and everyone knows the safety issues in tunnel construction, and the technical and safety clarifications are handed over to every person on the operation floor for effective implementation.

(2) Carry out civilized standard chemical field activities, and place various warning slogans and signs in place to effectively play a warning effect.

(3) The invert construction strictly implements the safety distance standard, the distance from the tunnel face is not more than 40m, and the distance between the two linings from the tunnel face is not more than 70m, so that the excavation section is closed in time to ensure the overall stability and deformation.

(4) Geological advance forecasting shall be implemented in time as required to accurately grasp the geological conditions before excavation, so as to facilitate timely adjustment of the construction plan. Avoid water seepage, collapse and other phenomena.

(5) Regulate electricity usage for construction, and earnestly achieve the principle of one machine, one gate, one leakage, and three-level power distribution two-level protection. Full-time electricians and non-electricians are forbidden to open the distribution box. It is strictly forbidden to use unsafe lamps such as iodine tungsten lamps for lighting at the construction site, and it is strictly forbidden to have naked open wires. The cave shall be illuminated with a safe voltage of 36V.

4.5Risk source publicity board

On-site construction personnel should conduct regular inspections of all hazard sources on the construction site in accordance with relevant laws, and conduct pre-job training and education for workers in related types of work, so that they understand the importance and necessity of safe work at their posts, and during construction operations Able to execute in accordance with relevant operating procedures and no illegal operations. For the identified hazards, control and management are carried out by formulating objectives and management plans, establishing and implementing operation control procedures, and emergency plans. According to the identified hazards at the construction site, the major hazard sources are publicized to improve the construction personnel ability to face the tunnel risk accidents. The construction site major risk source publicity signs are established.

Table4.4 major risk sources

Signboard for major hazards at the construction site										
Construction unit:			Supervision unit:				Date:			
No.	Risk source	Premonition	Operating location	Probability	Loss grade	Risk level	measurement	Principal	Phone number	P.S.
1										
2										
3										
4										
...										

4.6 Information management

4.6.1 Information safety

Due to the various types of work involved in tunnel operations, many people enter the tunnel, such as survey personnel, monitoring personnel, etc. Therefore, during the tunnel construction process, accidents caused by asynchronous information often occur, such as excavation or excavation in the tunnel. At this time, if the outside surveying, monitoring and other technical personnel are not clear about the situation and enter the tunnel, risk accidents will occur. Therefore, it is necessary to formulate relevant measures to avoid such incidents. The specific operation is to indicate what kind of construction is being done in each time period with a construction process safety connection sign at the entrance of the cave, so that people outside the cave know when they can safely enter the tunnel, avoiding accidents due to asynchronous information and reducing risks.

We can set up a road tunnel construction process connection sign at the tunnel entrance. When the sign is under a certain process, it indicates that the process is in progress in the tunnel. If the sign is red, non-on-site construction personnel are forbidden to enter; the sign is green, indicating that it is possible to enter.

4.6.2Risk information report and notification

After a safety accident occurs at the tunnel construction site, the construction team must report to the branch within 10 minutes, and the branch reports the situation to the project manager within 30 minutes. At the same time, within 30 minutes, use all rapid means such as telephone and fax to report the brief situation. The Office of the Emergency Leading Group of a Class Company. According to relevant regulations, reports must be reported to the local government authority or other relevant parties. To ensure the comprehensive standardization of the report, the content of the report shall be reviewed and reported by the emergency leading group of the project manager department. Within 1 hour after the accident, the branch where the accident occurred shall be reported to the local safety production supervision administration at or above the county level, and the project department shall report to the supervision project department, the Southern Company and the quality supervision station. According to the above reporting procedures, a brief written report should be submitted within 24 hours after the accident occurs.

The content of the written report shall meet the requirements of relevant regulations. The external reports and announcements of major safety incidents are under the unified management of the Emergency Leading Group Office of the Project Manager Department.

4.7 Summery

According to the topographic and geological characteristics of the tunnel, combined with the analysis of the influencing factors of the tunnel construction safety risk, the safety risk assessment of the tunnel is carried out, and the construction of the site safety system is proposed. The main contents are as follows:

1. Through the topographic and geological conditions of the tunnel, a careful analysis of the entire section of the tunnel is made, and the tunnel construction risk list, through the list, you can intuitively understand the main risks of the tunnel construction and the issues that should be paid attention to;

2. Simple control measures are proposed for the risks of tunnel collapse and water and mud inrush;

3. Determine that unreasonable site management will bring risks to tunnel construction and cause accidents. On this basis, continue to analyze the types of accidents and the degree of harm that may occur;

4. Aiming at the characteristics of tunnel engineering, according to different safety types, a targeted safety accident emergency organization system is proposed;

5. Based on experience, an information reporting procedure was designed to ensure the timely and effective transmission of information, combined with the corresponding security monitoring facilities in the tunnel, the process of handling tunnel warning information was discussed;

6. Explains the perfect on-site safety management system and how to control and rescue on-site safety.

5.Emergency Plan

5.1 Emergency group

5.1.1 Emergency leading group

Emergency response plan leading group should be headed by the first responsible person on site, and other team members composed of operators. It is responsible for emergency rescue work on site accidents.

Table 5.1 tunnel emergency plan leading group

Serial number	Name	Position	P.S.
1			
2			
3			
...			

5.1.2Field commanding group

The investigation found that in the construction road tunnels, there are few on-site command structure systems for tunnel construction safety risks. Some have such institutions but in fact they are useless. When a risk accident occurs in a tunnel, it cannot be dealt with in time, resulting in increased risk loss. It has been pointed out in the above that how much risk can be reduced and avoided by timely avoiding the probability of accidents. Therefore, an emergency leading group was established at the tunnel construction site to lead and organize the prevention and safety of the construction of the tunnel.

Emergency handling work is very necessary. Considering the actual situation of the project, it is recommended that the project department form an on-site safety command structure with the executive deputy manager as the team leader and the heads of each department as the team members. An emergency response center is set up in the *Comprehensive Management Department.* According to the settings of various functional departments, emergency organizations are set up under the leadership of the emergency leading group of the project department. The division of labor is clear and each has its own responsibilities.

During the emergency response period of an accident, the team leader is responsible for overall command and dispatch of all members for rescue, and the deputy team leader is responsible for concentrating manpower and material resources, and deploying disaster relief materials to assist rescue activities.

Table 5.2 the safety command structure and team duty

The safety command structure	Team duty
Fire Fighting Team	Responsible for the on-site connection of water sources or fire-fighting equipment to extinguish fires, and responsible for fire, accident site and surrounding security, and danger zone alert.
Rescue evacuation team	Responsible for rescuing the trapped persons and the materials in the cave that can be transferred; transferring the items that may cause new sources of danger to a safe area; protecting the accident scene during and after the rescue work.
Supply indemnification team	Responsible for the supply of various materials needed for emergency rescue work such as tunnel rescue equipment, water supply and drainage, power supply and lighting, transportation tools, food and clothing.
Medical rescue team	Responsible for the rescue, treatment, and transfer of various injured people on the scene, and assist in the prevention of secondary disasters.

5.2 Emergency supplies

In order to ensure that there are enough supplies for rescue in the event of an emergency at the scene, rescue supplies are available at the scene at ordinary times. According to the risk of the tunnel, the following rescue supplies are mainly configured: loaders, rescue vehicles, arches, medical drugs, stretchers, woven bags , Grouting equipment, grouting materials, pumps, water shoes, rain gear, emergency lights, mud pumps, electric welders, jacks, etc.

Table 5.3 emergency supplies notes

Logistic emergency supplies management notes								
Item	Date	Use place	Purpose	Use number	Remain	Applicant	Phone number	P.S.
1...								
2...								
3...								
4...								
...								

5.3Emergency plan

5.3.1 Emergency plan for collapse

Tunnel collapse refers to a large-scale and above-scale earth-rock collapse accident caused by a sudden change in the weak or broken surrounding rock during tunnel construction. It is one of the more common and serious geological disasters in tunnel construction. Under normal circumstances, it will cause greater economic losses; sometimes cause injuries and deaths to construction personnel, and irreparable losses to the construction unit. Therefore, the construction area should pay great attention to it. When there is a sudden change in geological conditions, corresponding construction technical measures should be taken in time to prevent serious losses, prevent trouble beforehand, and ensure that no tunnel collapse accident occurs. When tunnel collapse occurs, try to ensure that avoid casualties, control the losses, reduce the degree of casualties, minimize the damage of the accident, and actively organize manpower, material and financial resources to make up for the collapse loss, and resume normal construction and production as soon as possible.

5.3.2 Preventive measures of tunnel collapse

(1)Geological advance detection

In order to predict and prevent in advance, according to the geological data of the design documents, the geological advance drilling, advance exploration geological conditions and groundwater conditions are used to detect the strength, lithology, degree of rock formation and water influx in the fault fracture zone section. Wait for the situation.

(2) The construction principles are " early forecast, pre-grouting, pipe advance, short steps, strong support, tight sealing, and frequent measurement " . First, strengthen construction monitoring. During construction, continuous measurement of surface settlement, surrounding rock convergence deformation, surface settlement monitoring, etc. shall be carried out. If necessary, construction support stress shall be measured; construction of advanced anchor rods or advanced pipe sheds in shallow buried sections , When the geological conditions are poor and the surrounding rock is broken, the small pipe should be pre-grouted in advance, and if necessary, the long pipe roof grouting should be used for pre-support; in the water-rich area, curtain grouting

and peripheral grouting should be adopted according to the forecasted water inflow. Ultra-fine cement grouting and other measures; under the premise of advanced support, the shallow buried section follows the construction principle of short footage, and according to the geological conditions; strong support is the main measure to prevent landslides. After digging, make a more accurate judgment of the surrounding rock conditions in time, and provide timely support within the self-stabilization time of the surrounding rock, which can effectively limit the free development of the surrounding rock deformation and prevent the rock mass from collapsing due to loosening, disengagement and dislocation; In the lower half of the section, in order to prevent the upper half of the arch from hanging in the air and the supporting structure from instability, a lock-foot anchor rod is added at the arch foot or the arch foot is added to establish a steel rib support.

5.3.3 Emergency treatment measures of collapse

① When a collapse is found, the person who is found should issue a warning signal in time, and the personnel in the dangerous area should immediately evacuate, and at the same time, prohibit other staff from approaching or entering the dangerous area.

②After the staff evacuated to a safe location, timely count the number of on-site construction personnel to check whether there are casualties.

③The person in charge of the scene or the security officer on duty, the work team leader, etc. immediately report to the leader of the work area, and immediately initiate emergency rescue procedures.

④In the event of casualties, emergency rescue work should be taken immediately, and more than 2 people must be protected during rescue, and rescue work should be carried out under the condition that there is no life safety threat to rescuers; if the collapse continues to be unable to rescue, wait in a safe place in order to carry out rescue in time. The life safety of rescue personnel must be ensured during the rescue process to prevent the collapse and damage from further expanding.

⑤When the wounded people are rescued, according to the number of wounded and the degree of injury, medical personnel will take corresponding treatment measures at the scene, and adopt the principle of "first heavy and then light" to send the wounded to the hospital for rescue and treatment in time.

⑥ If the collapse is particularly serious and your own rescue capability is limited, you should immediately report to the local government or relevant rescue department to request emergency rescue, and at the same time do related rescue work.

⑦Construction technical measures corresponding to the extent and scope of the collapse are taken on site to control the further development of the collapse. Under the environment to ensure the safety of construction personnel, actively carry out collapse treatment and resume normal construction and production as soon as possible.

5.3.4 Emergency treatment for water gushing and mud outburst

The underground excavated tunnel geology in this section will become muddy when it meets with water.During construction, groundwater seepage and seepage channels should be prevented. In addition to the use of dewatering wells for groundwater, according to the actual situation in the cave, water diversion in the cave is used when necessary to ensure the stability of the surrounding rock of the working face and prevent accidents such as mud influx.

Emergency measures:

(1) Strengthen the dewaterability of dewatering wells to ensure that the groundwater is reduced to 1m below the working surface.

(2) According to the actual situation and the precipitation effect, if necessary, adjust the position of the precipitation well through the design institute.

(3) Adjust the construction plan of the tunnel, and take the water leakage in the tunnel to prevent the occurrence of secondary disasters.

5.3.5 Emergency plan for crossing bad geological areas

This underneath tunnel excavation crosses Gongye East Road and a river ditch, and the buried depth of the tunnel vault under the section is about 5.5-9m. The cover soil of the vault is mainly plain fill and silty clay, and the cave body is located in the silty clay layer and fully weathered. The mixed gneiss layer has a high groundwater level, and the excavation is prone to over-excavation, causing local collapse, causing deformation of the initial support, local block loss and other hazards.

Countermeasures: In order to ensure the safety and normal use of municipal roads in this section of the tunnel crossing section, it is necessary to reduce the impact of excessive settlement of the ground during the construction process.Strengthen the advance support, during the construction process, control the excessive deformation of the ground, and use the full-face grouting reinforcement for the undercut section of the road. At the same time, strengthen the monitoring of surface settlement and pipelines during the construction process, and take corresponding measures in time if abnormal situations occur.

5.3.6 Emergency measures for crossing buildings and municipal pipelines

The tunnel passes though many shallow foundation buildings, and some houses have poor structure, which is prone to cracks and adverse consequences. The tunnel vault is covered with soil about 12 to 14 meters, and the mining method is of great risk. The tunnel excavation causes settlement and deformation of surrounding buildings. Response measures: The proponent cooperates with the owner to demolish the buildings in this section, and on the premise that the demolition is completed, adopt appropriate measures and then adopt the underground excavation method.

Some section tunnels pass under Xincheng Road, Gongye East Road and Yingbin Road. There are many municipal pipelines on both sides of the road, including municipal drainage, water supply and natural gas pipelines. Interval tunnel excavation and ground precipitation will cause surface settlement, which will cause cracks and water leakage in the drainage pipe joints, and cause damage to the natural gas pipeline.Response measures: In order to ensure the safety of the surrounding pipelines, it is necessary to monitor the pipelines, and take measures such as compensation and tracking grouting based on the monitoring results. details as follows:

(1) Before construction, a detailed and comprehensive investigation should be carried out on the pipeline underneath the tunnel, and the relationship between the pipeline and the route should be drawn.

(2) The construction should be carried out in accordance with the principles of " pipe advancement, strict grouting, short footage, early support, quick closure, frequent measurement,

and quick feedback " . Strengthen monitoring and measurement of tunnel excavation support and structures during construction. According to the monitoring feedback information, follow-up grouting is set up at the bottom of the pipeline at any time, and if necessary, temporary supports are added or the excavation support construction sequence is adjusted, or the secondary lining is implemented in advance.

5.3.7 Emergency measures for other emergencies

In order to prevent disasters and reduce the occurrence of hazardous accidents, in accordance with the principle of " people-oriented, avoiding casualties " and the policy of " prevention first, combined prevention and resistance " , a leading group for emergency accident prevention and handling and a professional rescue team are established, rules and regulations are formulated, and equipped responsibility system shall be implemented for rescue machinery, equipment, materials and personnel. The project department of each bidding section shall strengthen the education of safety knowledge for all personnel and implement the safety production system. Regularly inspect the construction site, analyze the causes of potential safety hazards, formulate rectification and preventive measures, and rectify and inspect within a time limit, and prepare emergency rescue personnel and materials.

Table 5.4 the emergency treatment for other tunnel risk

Fire accident	Start the alarm system in time.
	In the early stage of a fire, use fire extinguishers, water pipes and other fire fighting equipment to extinguish the fire as soon as possible.
	When the fire is out of control, you should know the direction, quickly determine the location and safe place, and organize the operators to escape to the cave or nearby shelters according to escape routes;
	Report to the project department, supervision unit, and owner in time
	Accident investigation and handling.

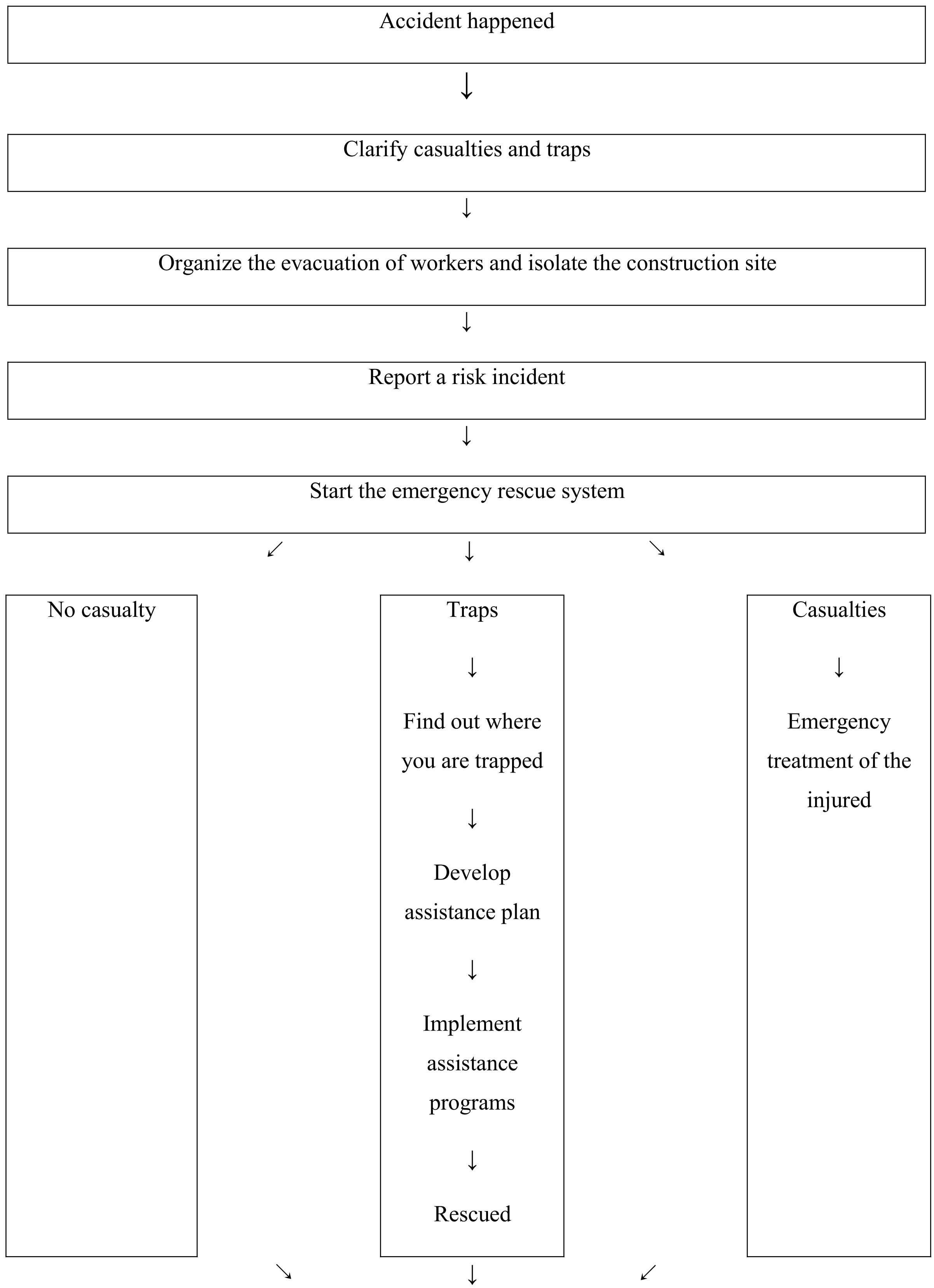
Natural hazard	Collect meteorological and geological data at any time.
	The project needs to avoid the installation of unfavorable geological locations, and it must be higher than the historically highest flood level investigated.
	When natural disasters may occur, construction should be stopped immediately, a vigilant inspection of the construction site and protective measures should be taken.
	After the alarm is lifted, it is necessary to confirm that there is no source of danger before proceeding.
Heavy rain	When the geological topography of the cave entrance may cause water inrush due to rainfall, reinforcement measures and construction of the cave door should be taken as soon as possible.
	When encountering strong winds, measures to prevent dumping and sliding of various large machinery should be taken, and measures to strengthen and protect temporary equipment and scaffolding should be taken.
	During winter operations, in order to prevent ice and snow disasters, various temporary equipment, scaffolding, etc. should be reinforced and protected.
Electric shock	Strictly control the "three-phase five-wire system", "three-level power distribution and two-level leakage protection", "one machine, one gate and one leakage system".
	Set up full-time electrician maintenance.The working voltage of the working face adopts a safe voltage not greater than 36V, and the power line is separated from the lighting line.

5.4Summery

According to the results of the risk assessment, the risk sources of the tunnel in this subsurface excavation section are collapse, deformation, water seepage, electric shock, and ventilation. The major risk sources are collapse and water seepage and mud influx. The above risk sources should be the focus of control during the construction process. Other risk events must be monitored and various risk treatment measures must be implemented to prevent the occurrence of various risk constructions.

When a dangerous situation occurs during tunnel construction, a judgment should be made quickly, emergency rescue procedures should be started immediately, and relevant emergency rescue work such as accident detection, alert, evacuation, personnel rescue, and engineering rescue should be carried out quickly. The personnel on duty and the person in charge of safety shall immediately notify all operators in the tunnel to evacuate urgently through the alarm device. Danger information is reported to the construction unit as soon as possible; the executive deputy manager of the project management department is responsible for directing the evacuation. The personnel responsible for dispatching at all levels should stick to their posts, keep communication unblocked, and provide timely feedback on personnel evacuation and the emergence of dangers; when the rescue cannot be effectively carried out In case of emergency, it should be reported to the local government or relevant rescue department in time to request emergency rescue and do relevant cooperation work.

Figure 5.1Tunnel disaster accident handling and rescue procedure diagram



Formulate engineering rescue plan

↓

Implement engineering rescue plan

↓

Accident summary and handling

6.Conclusion

6.1Summary

Because tunnels can effectively alleviate traffic pressure, in recent years, under the premise of vigorous development of the national transportation industry, tunnel construction has been rapidly developed. Therefore, while the tunnel project has made contributions to China's transportation industry, the risks of the tunnel project have also brought serious consequences for the country and the people. Constrained by the structural conditions of the tunnel and the construction environment, if the safety risks of tunnel construction cannot be properly avoided, once the risk occurs, it will cause serious casualties and economic losses to the country. In this project, the risk assessment and safety management of Wanhui tunnel, the related research on the safety risk of tunnel construction and site management.

6.1.1Analysis and Identification of Safety Factors in Tunnel Construction

①Though case analysis,expert investigation method is adopted to determine the influence index of tunnel construction risk factors. The factors affecting the safety of tunnel construction are preliminarily drawn: collapse, gas, water gushing and mud outburst, large deformation, and rock burst risk. Through the study of these factors, the risk influencing factor index of tunnel construction is determined;

②Summarized the preventive countermeasures after the tunnel construction risk occurred, through studying the disaster-causing factors of the tunnel construction safety risk of collapse, gas risk, water inrush and mud outburst, large deformation risk, and rock burst risk, corresponding preventive countermeasures were established system.

6.1.2Tunnel construction risk early warning system and risk acceptance criteria

① Through the study of the signs of the tunnel construction risk factors, the early warning system of the tunnel construction safety risk factors was studied;

② Established the standards of tunnel construction safety risk acceptance criteria from two aspects: the probability of construction safety accidents and the loss of consequences.

6.1.3Tunnel construction risk assessment and site safety system research

① Through careful analysis of the topographic and geological conditions of the tunnel, the entire section of the tunnel was carefully analyzed, and a list of tunnel construction risks was given. Through the list, you can intuitively understand the main risks of the tunnel construction and the problems that should be paid attention to; for tunnel collapse and water gushing Simple control measures are proposed for mud outburst risk;

② It is determined that unreasonable site management will bring risks to tunnel construction, which will lead to accidents. On this basis, continue to analyze the types of accidents that may occur and the degree of harm;

③ According to the characteristics of tunnel engineering, according to different safety types, a targeted safety accident emergency organization system is proposed; an information reporting procedure is designed based on experience to ensure the timely and effective transmission of information, combined with the corresponding safety monitoring facilities in the tunnel, The process of handling tunnel early warning information is discussed; the complete on-site safety management system and how to control and rescue on-site safety are explained.

6.1.4Emergency plan management of tunnel construction

①It is proposed to set up an emergency leading group at the tunnel construction site to be responsible for leading and organizing the prevention and emergency treatment of the tunnel construction safety of the entire line

②According to the risk of the tunnel, it is ensured that there will be sufficient supplies for rescue in the event of an emergency at the scene, and rescue supplies are available at the scene in peacetime.

③Based on relevant laws, regulations and construction principles, detailed emergency management plans have been formulated for different hazards.Clarified the work flow during emergency response.

6.2 Problems and prospects

At present, the problems of tunnel construction safety and site management have received extensive attention in the industry. In order to ensure the safety of tunnel construction and improve the ability to avoid tunnel construction risks, various technical means are needed to achieve this. The results of the thesis can be used for the risk and safety of tunnel construction and the site

Management provides certain technical support. The article also made relevant statistics on the risk-causing factors of tunnel construction, made some tentative work on its preventive and early warning technology, and put forward some suggestions for on-site safety management emergency measures. There must be certain problems. Further research is needed.

① The evaluation of the risk factor index and weight of the tunnel safety construction currently generally relies on the expert evaluation method or the survey method, so the same problem may have different results under different expert evaluations. If a systematic risk accident statistics database can be established, it will provide authoritative data for the evaluation of risk factor indicators and weights;

② This paper has made relevant research on risk prevention and early warning technology, but has not made relevant analysis on specific early warning indicators. If we can study the early warning index factors in detail, it will greatly improve the reliability of tunnel construction safety warning;

③ This paper has done some tentative research on the management risk of tunnel construction site, but due to the special environment of the tunnel construction site, the research on it is only limited to the project based on this article. So it has certain limitations. It is recommended to study a wider range of on-site risk factors in order to establish a more common on-site management model to ensure the safety of tunnel construction.

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Appendix

This is a statistical table of tunnel construction safety accidents in recent years, including accident location, tunnel name, accident type and reason, and remarks.

Table of tunnel construction accidents in recent years

No.	Tunnel name	Type of accident	Main reason of accident	P.S.
1	Shan Xi gaozhuangliang tunnel	Collapse	Geological and excavation factors	The maximum height of top collapse is 6m.
2	Yun shan tunnel	Collapse	The development of groundwater	The volume of collapse is 4000-5000m^3
3	Fu Jian wenfeiyangling tunnel	Collapse	Geological factors	The collapse height is 32.5m and volume is 3750m^3
4	Hai Nan qingling tunnel	Collapse	Excavation and monitoring factors	The collapse height is 40m and volume is 15000m^3
5	Lurong zhulinping tunnel	Collapse	Geological and excavation factors	There are 4 people buried
6	Yun Nan dafengyakou tunnel	Collapse	Groundwater factors	There are 16 locations collapse
7	Lijiajun tunnel	Collapse	Geological factors	The first supporting system is collapsed and all tunnel is sealed

8	Fan jialing No.1 tunnel	Collapse	Geological factors	The collapse height is 70m and the volume is 3700m^3
9	Qin ling extra-long tunnel	Collapse	Geological and monitoring factors	There are 42 locations collapse
10	Hu nan jinzhongzao tunnel	Collapse	Geological and excavation factors	The first support system is broken and there is local deformation
11	Chong qing jiuyang yunaliangshan tunnel	Collapse	Geological and excavation factors	
12	Gao tian tunnel	Collapse	Bad terrain geological factors	A cavern with a length of 6m, a width of 7m, and a height of 8m appeared on the vault. The collapse volume was about 350 m^3, which almost closed the entire tunnel.
13	Sujiawan tunnel	Collapse	Bad terrain geological factors	
14	Yun wu highway dahuashan tunnel	Collapse	Design and groundwater factors	The initial support has cracks within about 10m, the width of the joint is about 4mm, and the length of the joint is from the arch toe on the

				right side to the vault.
15	Da ling bei tunnel	Collapse	Excavation and monitoring factors	Totally smashed 3 steel arches
16	An mao highway Phoenix mountain tunnel	Collapse	Excavation and construction factors	The upper and front part of the vault collapsed
17	Zhang shi highway tunnel	Collapse	Bad terrain geological factors	The collapse height is 2.6m and the volume is 200m^3
18	Lan yu railway caiziping tunnel	Collapse	Bad terrain geological and monitoring factors	The width of the crack is about 20 cm, and it collapses to the surface, forming a collapse with a diameter of about 10 m and a depth of about 1.0 m.
19	Jiang xi province mingshan tunnel	Collapse	Geological and groundwater factors	The collapse volume is about 800m^3 with seepage
20	Jiang xi province nashaling tunnel	Collapse	Groundwater, terrain geological and excavation factors	The initial collapse was about 100m^3, accompanied by water seepage, the cavern was 4-8m high, 8m long and 8-11m wide
21	Yong taiwen railway tunnel	Collapse	Bad terrain geological and groundwater factors	The landslide caused about 900 square

				meters of soil to be poured into the cave, forming a pit with a length of about 15m, a width of about 14m, and an average depth of about 4.5m.
22	Yun Nan yingjiang Power station tunnel	Collapse	Geological ,construction and groundwater factors	A large surface collapse was formed. A funnel-shaped collapse pit with a diameter of 20 meters and a depth of 5 meters appeared on the 54-meter-high surface.
23	Si chuan province nifigou tunnel	Collapse	Design and excavation factors	The mountain surface cave is 45m long and 36m wide. Preliminary estimate of the landslide volume is about 14000m^3
24	Qing zang highway tunnel	Collapse		Cracks appear in the initial support of the vault within 12m of the excavation surface
25	Da lian shimen mountain tunnel	Collapse	Bad terrain geological and groundwater factors	The cavern is about 6.0m long, the maximum height is 7.0m, and the

				circumferential length is 12.0m
26	Baoxi railway No.2 tunnel	Collapse	Design and monitoring factors	A total of 6 collapses occurred, followed by ground collapses
27	Yu mian tunnel	Collapse	Design,construction and monitoring factors	A funnel-shaped collapse cavity with a diameter of 3.7 m and a depth of 3 m is formed on the ground and the collapse volume is 50m^3
28	Guang xi luozhan tunnel	Collapse	Human errors and construction factors	Emergency transferring 257 villager
29	Gao yang village tunnel	Collapse	Human errors and geological factors	35 death and 1 injury
30	Jigong mountain tunnel	Collapse	Geological and construction factors	1 death, 1 injury
31	Xiao pingqiangkou tunnel	Collapse	Human errors and geological factors	3 death
32	Yu xi mo le gai tunnel	Collapse	Groundwater factor	
33	Sam Fernando	Gas	Human errors and management factors	Fire, explosion and 17 death
34	Port Huron	Gas	Human errors	Explosion and 22 death

35	Greata pennine tunnel	Gas	Geological factors	Fire, multiple explosions, direct or indirect deaths 97 people
36	Akosombo tunnel	Gas	Human errors	Explosion and 11death
37	Hongrin water conduction tunnel	Gas	Management and construction factors	Explosion and 5 death
38	Chinggaza water conduction tunnel	Gas	Geological factors	Explosion
39	EI Colegio tunnel	Gas	Geological factors	
40	Da cheng railway pao tai mountain tunnel	Gas	Geological and monitoring factors	Gas explosion
41	Dongjia shan right highway tunnel	Gas	Human errors and management factors	
42	Yan jiao village tunnel	Gas	Geological and management factors	5 times explosion and 40 death
43	Pao tai mountain tunnel	Gas	Geological and management factors	Twice explosion and 13 death
44	Zi ping pu tunnel	Gas	Geological factors	Once explosion and 44 death
45	Yuan san quan highway tunnel	Water gushing	Geological and weather factors	The water inflow is large, the maximum water inflow is 112086 m^3/h.After that, the amount of water gushing decreases

46	Da lu liang zi tunnel	Water gushing	Geological factors, topography and landform conditions, stratum lithology	During the excavation of the peripheral hole, water inrush occurred to varying degrees when drilling on the vault. High pressure water and a large amount of mud and sand were ejected from the hole, and the maximum water influx was 480m^3/h.
47	Tian bei mountain tunnel	Water gushing	Geological factors, topography and landform conditions, stratum lithology	The maximum water inflow is 2,000m^3/d, and the design is only 1100m^3/d. The drainage system cannot meet the drainage requirements
48	Xin luo nan tunnel	Water gushing	Geological and weather factors	
49	Ping ling tunnel	Water gushing	Topography and landform conditions	The 668-meter excavated section was silted, with a total of 32,000 cubic meters of silt.

50	Tai zhong yin railway tunnel	Water gushing	Geological and weather factors	
51	Tong yu tunnel	Water gushing	Geological and weather factors	The gushing water brought out a lot of mud and stones, which instantly caused about 100 meters of flooding. 3 people died, 1 was seriously injured, 2 people are missing, and 3 people survived.
52	Ni ba mountain tunnel	Rock burst	Geological and supporting factors	Exfoliated rocks accumulate in large quantities, with a maximum depth of 3.6 meters
53	Guan jiao tunnel	Rock burst	Geological and supporting factors	2 people minor injury
54	Hu ma ling tunnel	Rock burst	Geological factors	1 people minor injury
55	Hua jin mountain tunnel	Rock burst	Geological factors	1 people serious injury
56	Mu zhai village tunnel	Rock burst	Geological factors	Delay 15 days
57	Ming ya zi tunnel	Rock burst	Geological and supporting factors	1 people minor injury
58	Bi jing bi xi tunnel	Rock burst	Geological and supporting factors	

59	Xiang shan tunnel	Rock burst	Geological and supporting factors	
60	Zhi fang tunnel	Rock burst	Geological factors	3 people minor injury
61	Ma jin mountain tunnel	Large deformation	Human errors and geological factors	Machine damage and personal injuries
62	Cang ling tunnel	Large deformation	Geological and groundwater factors	2 people injuries
63	Er lang shan tunnel	Large deformation	Geological and excavation factors	
64	Da xiang ling tunnel	Large deformation	Geological factors	
65	Fu tang ba tunnel	Large deformation	Geological and tunnel depth factors	1 people minor injury
66	Jiu hua shan tunnel	Large deformation	Geological factors	2 people minor injury and 1 seriously injury
67	Luo bo gang tunnel	Large deformation	Geological factors	3 people minor injury and 1 seriously injury
68	Hou gang tunnel	Large deformation	Excavation factors	1 people minor injury
69	Jin ping shan tunnel	Large deformation	Geological factors	1 people minor injury
70	Si pu jian tunnel	Large deformation	Geological factors	13 days delay and 2 seriously injury
71	Shuang jiang kou No.2 road tunnel	Large deformation	Tunnel depth factors	10 days delay

72	Tong yu tunnel	Large deformation	Excavation factors	1 people minor injury
73	Xue shui ling road tunnel	Large deformation	Tunnel depth factors	
74	Zhong na shan road tunnel	Large deformation	Tunnel depth factors	2 people minor injury