



## Views &amp; Comments

# Challenges and Countermeasures for Construction Safety during the Sichuan–Tibet Railway Project

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## 1. Introduction

The Sichuan–Tibet Railway is the most important part of China's 13th Five-Year Plan. It is an important part of the external transport channel of the Tibet Autonomous Region of China, and will act as an essential conduit of people and resources to guide the industrial layout, promote land development along the railway, and integrate tourism resources. The planning and construction of the Sichuan–Tibet Railway is of great and far-reaching significance to the economic and social development of Tibet Autonomous Region, Sichuan Province, and even other regions in Western China.

The question of how to develop forward-looking plans, adopt high standards, and ensure high quality for constructing the Sichuan–Tibet Railway is not only a hot topic of general concern in current Chinese society, but also a major issue for the construction organizers and managers. Based on the authors' many years of experience and research achievements in railway construction management, this paper briefly discusses the two aspects of *what must be done* and *how this must be done* regarding the safety risks of the Sichuan–Tibet Railway construction.

## 2. General situation and main challenges of the Sichuan–Tibet Railway

### 2.1. Engineering overview

The Sichuan–Tibet Railway starts from Chengdu City, Sichuan Province in the east and continues westward through Ya'an City, Kangding County, Qamdo, Nyingchi, and Shannan to finally reach Lhasa, the capital of the Tibet Autonomous Region. The operation length of the whole line is 1567 km. The Chengdu–Ya'an section (Chengya section) of the line was opened on 28 December 2018, and the Lhasa–Nyingchi section (Larin section) began construction in December 2014 and is expected to be completed in 2021. The Ya'an–Nyingchi section is a new section with an approximate total length of 1008.45 km and 24 new stations (excluding Ya'an Station and Nyingchi Station); its total length of bridge and tunnel is 965.74 km and its proportion of bridge and tunnel is 95.8%. There

are 93 newly built bridges in the new section with a total length of 114.22 km, which means 11.33% of the line length, and 72 tunnels which are also newly built with a total length of 851.48 km, which means 84.43% of the line length.

### 2.2. Main features and challenges of the project

The engineering environment of the Sichuan–Tibet Railway is complex. The railway line passes through five geomorphic units: the Sichuan Basin, alpine-canyon area in western Sichuan, alpine-plain area in western Sichuan, the Hengduan Mountains area in southeastern Tibet, and river basins in southern Tibet, with an average altitude of 3800 m and dramatically fluctuating topography. The route crosses seven rivers and passes through eight mountains. Along this route, the weather and climate changes are intense, the water system distribution is complex, the internal and external dynamic geological functions are intense, the earth plate motion is still continuing, the seismicity occurs frequently, unfavorable geology and special rock and soil develop, the engineering geological conditions are extremely complex, and natural disasters occur frequently. The route passes through dozens of national protected areas in which nearly 100 rare plant and animal species live, such as giant pandas. The ecological environment is sensitive and the task of environmental protection is arduous.

There are many difficult projects within the overarching railway project, including three suspension bridges with kilometer-scale span; seven steel truss girder bridges, arch bridges, and rigid-frame bridges with a span of over 200 m; 23 tunnels with a length of more than 15 km, in which the longest tunnel, Yigong Tunnel, has a length of 42.5 km; and many deeply buried tunnels with a maximum depth of 2100 m. The structure of the entire railway project is complex and the technical difficulty is enormous. The project is also subject to the geological, hydrological, climatic, and traffic conditions of the bridge and tunnel sites. Safety risks are numerous and construction conditions are difficult.

The construction management of this project is also difficult. Located in high-altitude areas, the railway line passes through high mountains, deep valleys, and low-populated regions. The construction must also contend with situations including: low

efficiency under cold and anoxic conditions; a short effective operation period; a weak regional industrial foundation; inadequate transportation capacity along the line; a lack of building materials such as steel, cement, and sand aggregate; inadequate power grid and communication network coverage; and many key sub-projects with a construction cycle of about 10 years, which determine the progress of the whole railway project and make construction organization difficult.

Generally speaking, the Sichuan–Tibet Railway has many complex-structure bridges and super-long deep-buried tunnels, which are characterized by severely fluctuating topography, complex engineering geology, sensitive ecological environments, harsh climatic conditions, frequent natural disasters, and difficult construction conditions. The project management faces the two major challenges of extreme geologic hazards and extremely difficult engineering, which will result in extremely high safety risks to the construction and operation of the project.

### 3. Risk assessment

#### 3.1. Risk factor identification

Given the natural environment and engineering characteristics, the main safety risks during the construction period of the Sichuan–Tibet Railway can be divided into four categories: hazard in plateau, climatic disaster, geologic hazard, and engineering construction disaster. The disaster classification and its main risk factors during the construction period are shown in Fig. 1.

#### 3.2. Analysis of the disaster impact on engineering structure

The main types of engineering structure in the Sichuan–Tibet Railway include tracks, bridges, subgrades, tunnels, station buildings, and temporary projects. Considering the characteristics of the engineering structures and the disaster impact, an estimation formula of the safety risk (human and property risk) of engineering construction under a single disaster can be established as follows:

$$R = R_a \times \gamma_0 \times Q \times K \times P \times P_t \times P_s \quad (1)$$

where  $R$  is the risk impact factor of a single disaster on the engineering structure;  $R_a$  is the risk level of a disaster (property loss

and potential deaths);  $\gamma_0$  is the coefficient for importance of structure;  $Q$  is the quantitative distribution ratio of structure;  $K$  is the vulnerability coefficient of structure;  $P$  is the probability of disaster occurrence;  $P_t$  is the probability of a disaster reaching disaster-bearing bodies (property and personnel); and  $P_s$  is the probability that a single disaster will cause an accident to the disaster-bearing bodies (property and personnel).

The structures of the Sichuan–Tibet Railway may be affected by four kinds of disasters. The formula for calculating the total risk of engineering construction under multiple disasters is as follows:

$$R_t = \sum_{i=1}^n R_i \quad (2)$$

where  $R_t$  is the total risk of an engineering construction under multiple disasters; and  $R_i$  is the impact factor of an engineering structure under different types of single disaster.

The structural safety risks of the Sichuan–Tibet Railway are calculated by means of data investigation and expert questionnaires, as shown in Tables 1 and 2.

The risk for different types of engineering structures in the Sichuan–Tibet Railway is estimated according to Eqs. (1) and (2). The estimated results are shown in Fig. 2, which indicate that special attention should be paid to the impact of geologic hazard on the project construction of the Sichuan–Tibet Railway. As far as the types of projects are concerned, temporary projects and tunnels carry the highest risk.

Temporary projects include temporary roads, beam-fabricating yards, track slab yards, mixing stations, components and accessories processing yards, construction crew stations, and temporary communications. Such projects are often exposed to the natural environment; they may also be close to rivers, ravines, wind gaps, depressions, the foot of mountains, and steep slopes. Open-air construction sites have similar characteristics, and are extremely vulnerable to floods, gales, and geologic hazard. On 7 August 2010, the Zhouqu debris flow disaster in Gansu Province resulted in the deaths or disappearance of 1841 people. On 15 March 2019, a landslide in Xiangning County in Linfen City, Shanxi Province, killed 20 people. On 18 June 2016, near the Datudi Tunnel of the Chengdu–Guizhou Railway, a landslide occurred behind the station of one construction crew, destroying houses and causing seven deaths.

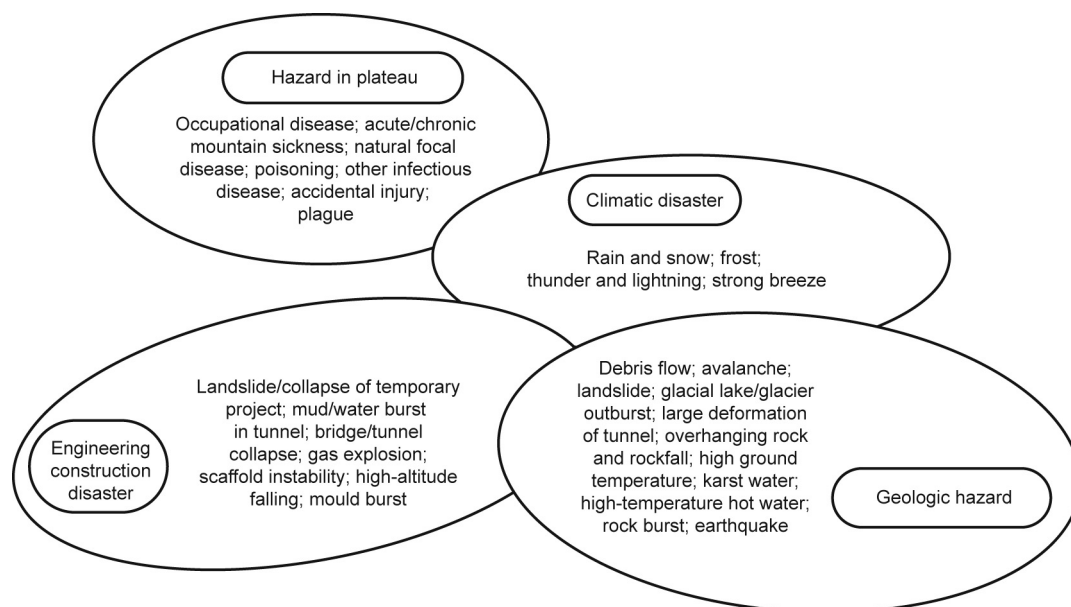


Fig. 1. Disaster classification and its main risk factors of the Sichuan–Tibet Railway.

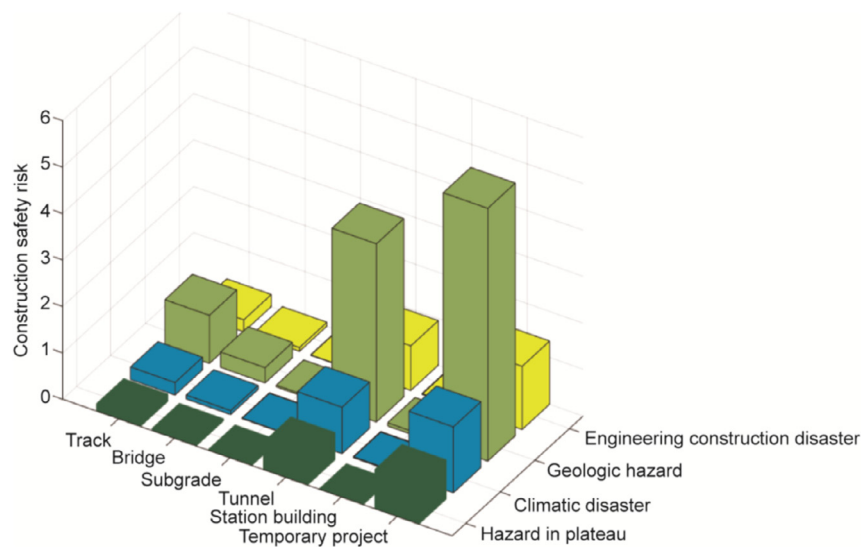
**Table 1**  
Risk impacts of different structures.

Item	Division	Calculation basis	Tracks	Bridges	Subgrades	Tunnels	Station buildings	Temporary projects
$R_a$	Estimate in 10 grades from 1 to 10	Using expert questionnaires according to the project cost and the number of participants	3	6	2	9	5	7
$\gamma_0$	Calculate in terms of level I (>1.1), level II (1.0) and level III (0.9)	According to GB 50216–1994	1.0	1.1	1.0	1.1	1.0	0.9
$Q$	0–1	Calculating by the proportion of the linear meter length (or regional distribution) of the engineering structure line <sup>a</sup>	1.000	0.113	0.043	0.844	0.030	1.500
$K$	Estimate in 10 grades from 0.1 to 1.0	Estimating according to the design criteria and repairability by expert questionnaires	0.6	0.7	0.9	0.8	0.8	1.0
$R_a \times \gamma_0 \times Q \times K$			1.800	0.522	0.077	6.684	0.120	9.450

<sup>a</sup>  $Q$  is calculated according to the proportion of the linear meter length. The expansion coefficient of station buildings should be set as 2.0, considering its large distribution area; the expansion coefficient of temporary projects should be set as 1.5 because of the linear meter length of the construction sidewalk (nearly 3000 km of new sidewalk along the whole line) and the variety of temporary projects.

**Table 2**  
Risk impacts of different types of disasters.

Item	Division	Calculation basis	Hazard in plateau	Climatic disaster	Geologic hazard	Engineering construction disaster
$P$	Calculate by 0–1	Using investigation and estimation based on existing data by calculating annual average probability of disaster occurrence during construction period	0.3	0.5	0.9	0.6
$P_t$	Calculate by 0–1	Using unified estimation by expert questionnaires according to the distribution of the projects	1.0	0.6	0.8	0.8
$P_s$	Calculate by 0–1	Using unified estimation by expert questionnaires according to analysis based on structural characteristics	0.3	0.5	0.8	0.3
$P \times P_t \times P_s$			0.090	0.150	0.576	0.144



**Fig. 2.** Construction safety risk estimation of different types of disasters for the engineering structures of Sichuan–Tibet Railway.

These are all examples of serious casualties caused by geologic hazard in residential areas, and the lessons are very painful. The geological and climatic conditions of the Sichuan–Tibet Railway are even more complex. Thus, geologic hazards pose a greater threat to temporary projects, especially to construction crew stations and open-pit construction sites, which need to be focused on disaster prevention.

There are also many tunnels in the Sichuan–Tibet Railway: Some are super-long and super-deep, some are located in high-geostress areas, fractured zones, or extremely high geotemperature areas. According to previous experience with railway constructions

[1–4], the probability of accidents in tunnel construction is the highest, including collapse, mud burst, and water burst. Therefore, the prevention of these disasters must be focused on.

#### 4. Integrated management of formal and temporary projects

##### 4.1. Integrated management framework

For the risk management of engineering construction, the railway system has mature methods and experience. For the specific

case of the Sichuan–Tibet Railway, while applying the basic methods of risk management and the basic ideas of project standardization management [5], we should vigorously promote innovation in the management systems, mechanisms, and methods, and ensure safety by management innovation.

Safety risk management involves all the parties occupied in the railway construction and relevant local departments. Its time span is the whole life-cycle of the project, and its management scope includes both formal and temporary projects. The necessary knowledge for such management involves geology, hydrology, meteorology, engineering structure, construction facilities, and more. Therefore, the safety risk management of the Sichuan–Tibet Railway falls under typical giant-system engineering management, which should be managed by system engineering methods [6]. At the same time, as the high risks of temporary projects, formal projects and temporary projects must be integrated into a single management system that includes the following four aspects: survey and design, construction and management, disaster monitoring, and emergency rescue. The management framework model is shown in Fig. 3.

#### 4.2. Integration of survey and design

Integration of survey and design means that survey and design—as well as consultation and examination—should be arranged for both formal and temporary projects. Based on current regulations, the design institute is responsible for the design of large temporary projects. However, the actual situation is that the design institute mainly takes charge of the drawing design of the large temporary projects, but is not responsibility for the small temporary projects such as construction crew stations. If the Sichuan–Tibet Railway is handled in this mode, temporary projects and constructors will face extremely high risks of geological and natural disaster, which is unacceptable. Therefore, all temporary projects should be included in the survey and design work. The key points related to this topic are shown in Table 3.

#### 4.3. Integration of construction and management

The integration of construction and management involves the equal treatment and integrated management of participating units and relevant institutions, workers and migrant workers, occupational health monitoring and construction safety, and formal projects and temporary projects.

Integrated management of participating units has been applied in railway construction projects for many years, which involves a virtual enterprise architecture with the construction units as the leading layer and the participating units as the management layer and execution layer. The Sichuan–Tibet Railway involves more units and has a longer management chain. Therefore, it is necessary to add a support layer, as shown in Fig. 4. Under this architecture, key management points include the following:

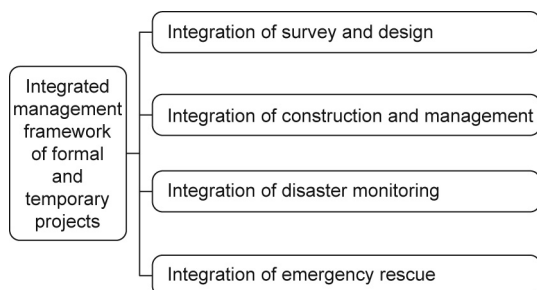


Fig. 3. An integrated management framework of formal and temporary projects.

Table 3

Key points of the integration of survey and design.

Integration item	Key points
Geological exploration	Carry out hydrological and geological exploration for the temporary construction sites of bridges, tunnels, and subgrades
Project site selection	Evaluate all kinds of disasters during site-selection schemes for temporary projects and construction sites to avoid location in high-risk areas
Design standards	Study and formulate design standards for temporary projects, including road standards, building seismic standards, wind-resistant standards, flood-resistant standards, etc.
Capacity matching	Research whether the capacity of the structures matches requirements. For example, the supply capacity of road transportation and mixing stations should match the construction requirements of bridge and tunnel concrete engineering
Engineering design	Formal and temporary projects should be designed with the same accuracy and formal construction drawings should be provided
Engineering consultation	Survey and design data of all temporary projects and construction sites, especially survey data, should be included in the scope of design consultation
Engineering inspection	Temporary projects must be inspected together with formal projects, including feasibility studies, preliminary designs, and construction drawings
Construction arrangement	Priority should be given to the construction drawings for temporary projects in order to ensure that temporary projects take the lead in construction

(1) The construction management task includes both the project and the team. The team includes workers and migrant workers. Migrant workers are the backbone of construction, and must be included in the organization of design and construction units. They should eat, live, and train with the other workers to prevent the occurrence of migrant workers living in random locations spread out across the site and lacking medical treatment and medicines.

(2) The prevention and control of mountain sickness during the construction of the Sichuan–Tibet Railway are equally important to construction safety. Medical camps should be established according to scientific research programs. Systems such as step adaptation, rotational rest, and working time restriction should be established to ensure that no accidents of patients and fatalities with mountain sickness occur. Occupational health monitoring and construction safety should be managed by the same department.

(3) Temporary projects should be included in inspection and evaluation at all levels of the construction process, especially in safety inspection. Temporary projects, construction sites, and tunnel projects should be taken as key areas and should not be neglected due to their remote location or small scale in order to achieve full coverage.

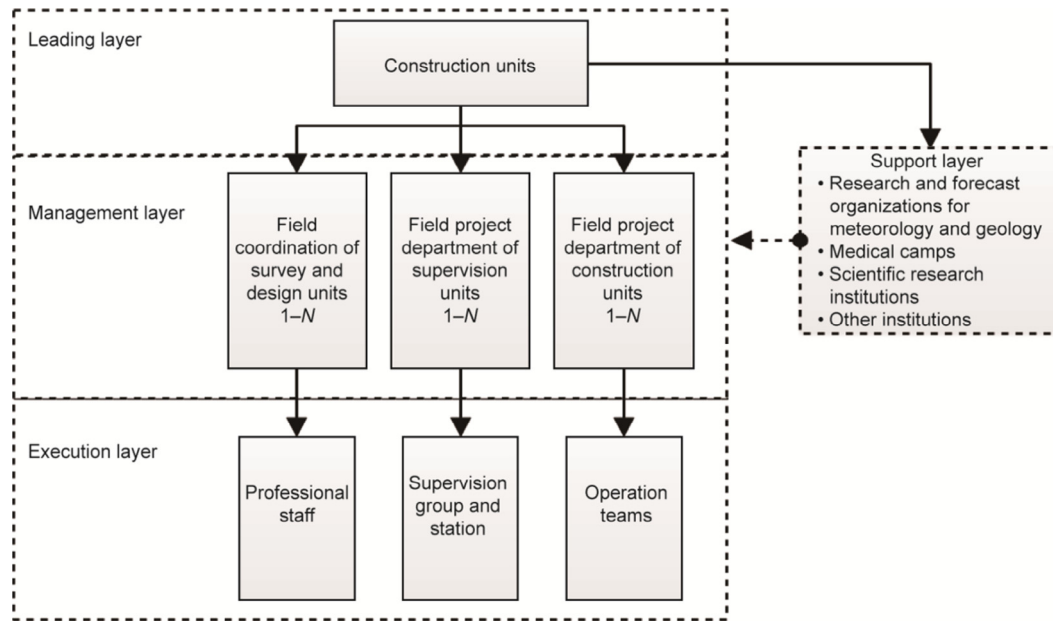
#### 4.4. Integration of disaster monitoring

The integration of disaster monitoring involves the integration of formal and temporary projects monitoring, construction safety and occupational health monitoring, and epidemic situation monitoring. The main points are as follows:

(1) To set the monitoring points for geological and climatic disasters, it is necessary to give overall consideration to the whole project and highlight the key points. The construction crew stations and bridges or tunnels construction sites should be set as the key monitoring points, floods, debris flows, landslides, and avalanches should be set as the key monitoring items.

(2) The monitoring of the local epidemic situation mainly relies on the health and epidemic prevention departments. Occupational health monitoring—especially the monitoring of mountain





**Fig. 4.** Integrated management of participating units and related institutions.

sickness—should be carried out according to the prevention and control plan.

(3) Monitoring should be carried out under unified deployment of construction units and separate implementation of each department. The monitoring standards must be clear and the monitoring data are shared.

(4) The disaster monitoring specialization can make full use of social resources.

#### 4.5. Integration of emergency rescue

The integration of emergency rescue involves the integration of emergency response and rescue by all parties involved in the construction and in local governments. The main points are as follows:

(1) A unified emergency rescue command system must be established. The project-level command organization is led by the main leaders of the construction units and all participating units should participate. At the same time, local fire control and medical units are included in the system. Section-level and district-level command organizations are respectively led by the main leadership of the management department and of the work area, with the participation of design and supervision units.

(2) Emergency preplans must be formulated for formal and temporary projects.

(3) A professional rescue team must be established. The source for rescue team members mainly relies on the national emergency rescue team. General, professional, auxiliary, and personal rescue equipment is allocated to the Sichuan–Tibet Railway professional rescue team according to the national tunnel emergency rescue team equipment allocation scheme.

(4) Rescue plans, teams, and equipment for mountain sickness and other diseases should be handled according to the opinions of the medical departments.

(5) The emergency rescue station and equipment allocation during the construction period should take into account the needs of the operation period and should be arranged as a whole.

### 5. Technical measures for risk management and control

The main technologies involved in controlling safety risks are monitoring, forecasting, communication, information

management, intelligent construction equipment, rescue equipment, and so on. The technical measures and equipment of the Sichuan–Tibet Railway safety risk control should be advanced and practical, and should be adapted to the plateau and alpine environments. The system framework is shown in Fig. 5. Based on an analysis of current technological achievements and development trends, the following technical measures should be considered.

(1) Space–sky–earth integration communication should be established by using the Beidou satellite and the 4G public communication network. In the survey, design, and temporary project construction phases, Beidou satellite communication should be fully utilized, and a 4G wireless communication network along the Sichuan–Tibet Railway should be built or improved, so as to realize full coverage of the public network when the project officially starts.

In order to study new signal transmission technology inside the tunnel, the use of a two-level architecture comprising a wireless backbone network and a wireless access network has been proposed in order to achieve full signal coverage in tunnels. This proposal should also be determined by comparing different schemes.

(2) An informationalized engineering management platform [7] should be established. That is, a whole-life-cycle management platform based on building information modeling (BIM) and geographic information system (GIS) technology should be built, which can manage, track, analyze, and make decisions regarding bridge and tunnel projects, subgrades, temporary projects, and construction sites in terms of the safety, quality, and progress of engineering construction, in order to realize precise management and control.

(3) Disaster monitoring should be performed. A monitoring and early warning system for geological and climatic disasters must be established based on ground sensors, including sensor subsystem, data transmission subsystem, data processing and monitoring subsystem, auxiliary support subsystem, and so on. The sensors should include Beidou receivers, rain gauges, water pressure gauges, earth pressure gauges, crack gauges, and high-definition cameras. At the same time, integrated disaster monitoring technology for space, the sky, and the earth should be studied.

For the monitoring of geologic hazards in tunnels—in addition to the surrounding rock measurement information systems that

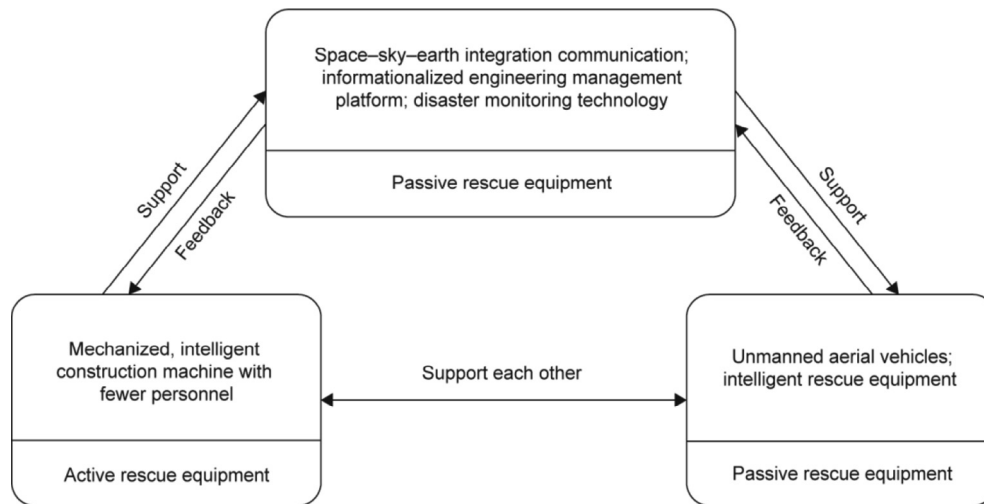


Fig. 5. Framework of technical measures for risk management and control.

are used at present—data acquisition methods based on mobile applications to control the onsite total station, input the data to the intelligent terminal, interfere the key tunneling parameters of shield tunneling machine, and read the identification card should also be used to collect field data and identify the possibility of geologic hazards occurrence.

(4) Intelligent devices should be incorporated. Intelligent tunnel boring machines (TBMs), rock drilling trolleys, lining trolleys, and wet spraying manipulators are widely used in tunnel construction. It is also necessary to develop tunnel construction robots. Intelligent cranes and pile drivers are used in bridge construction. Intelligent lifting and welding equipment adapted to assembly construction should also be developed.

(5) Rescue equipment should be equipped. Unmanned aerial vehicles (UAVs) and intelligent rescue equipment should also be equipped.

## 6. Conclusions

The natural environment, climate conditions, engineering hydrology, engineering geology, design criteria, structure types and traffic conditions of the Sichuan–Tibet Railway have been comprehensively analyzed in this article. It is emphasized that the main challenges of the Sichuan–Tibet Railway construction are extreme geologic hazards and extremely difficult engineering.

Given the natural environment and engineering characteristics, the main safety risks of the Sichuan–Tibet Railway during its construction period can be divided into four aspects: hazard in

plateau, climatic disaster, geologic hazard, and engineering construction disaster. Of the different types of project within the construction of the Sichuan–Tibet Railway, temporary projects and tunnels carry the highest safety risks.

An integrated management framework and key points to address the safety risks of formal and temporary projects have been put forward. Technical measures for safety risk management and control—including space-sky-earth integrated communication, an information platform for engineering management, disaster monitoring, rescue equipment and other measures—have been discussed. These provide basic support for the safety risk management and control system of the construction of the Sichuan–Tibet Railway.

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