Research on safety impact analysis and Countermeasures of geological Disaster for China-Pakistan Karakorum Highway

Jian Tian¹, Zhiqiang Li¹*, Zhigang Luo² and Hui Shao³

¹ China Academy of Transportation Sciences, Beijing 100029, China
² China Road & Bridge Corporation, Beijing 100011, China
³ School of Transportation, Jilin University, Changchun, Jilin, 130022, China

*Corresponding author’s e-mail: zhiqiangli1005@126.com

Abstract. Safety problem of highway construction is serious because China-Pakistan Karakorum Highway is located in the mountains, deep valleys, steep terrain, and variety of geological disaster types are widely distributed. On the basis of analysis of geological disaster types and consequences, researching the influence of the geological hazards for construction of bridge, tunnel and etc., corresponding risk control measures are put forward.

1. Introduction

The China-Pakistan Karakorum Highway (abbreviated as the China-Pakistan Highway) is a road connecting western China with Pakistan and a strategic link of the China-Pakistan economic corridor. Located in the hinterland of the Pamir Plateau, the China-Pakistan Highway passes through the areas with the most active geological structure, the strongest seismic activity and the most intense undercutting erosion in the world. Along the highway, mountains overlap, valleys are deep, rivers are turbulent, and some sections are located at high altitudes above 3000 meters, natural disasters occur frequently, many sections of pavement, bridges and structures are often destroyed, dangerous situation and road breakage occur from time to time. Domestic scholars have carried out a large number of studies on geological disasters and disaster prevention and control of China-Pakistan Highway [1-6], but most of them focus on the hazards themselves. Frequent geological hazards bring great safety risks to the construction of the China-Pakistan Highway. This paper analyses the potential impact on the construction of the project, and puts forward targeted construction safety countermeasures based on the systematic study of the types and hazards of geological hazards along the China-Pakistan Highway.

2. Geological hazard characteristics

The China-Pakistan Highway passes through the Himalayas, the Karakoram Mountains and the Hindu Kush Mountains and so on, which converge in Pamir and make the Pamir Plateau the father of mountains. In Pamir, there are the most precipitous snow mountains in the world.

Along the line, the mountains are high, the valleys are deep, the rivers are dense, the flow is turbulent, the ratio of riverbed is large, the drop is large, and the ability of scouring and cutting is very strong. In the route corridor, rock joints and fractures are developed, rock masses are relatively broken, and adverse geological phenomena are widely distributed. The main types of geological disasters are debris flow, collapse, landslide and other common geological disasters, and there are also avalanche
disasters peculiar to alpine and cold areas, which are very harmful (shown in table 1). There are 355 adverse geological phenomena across the line.

| No | Types of disasters       | Characteristics and consequences of the disaster                                                                 |
|----|--------------------------|---------------------------------------------------------------------------------------------------------------|
| 1  | debris flow              | The hazard of debris flow is to destroy the bridge or roadbed.                                                 |
| 2  | landslide                | Sliding will destroy the whole subgrade, cut off the road, serious harm.                                        |
| 3  | collapse                 | The collapsing substances continue to collapse, encroaching on roads, burying side ditches, destroying road drainage facilities and affecting traffic. |
| 4  | water damage             | The steep bank slope, narrow valley and turbulent flow often cause large-scale collapse of the river embankment, which leads to block traffic. |
| 5  | avalanche                | The avalanche snow falls rapidly along the mountain trench, which has great thrust, strong destructive force and harmful force. Large-scale avalanche will block the river highway. |

2.1 debris flow
Debris flow is the most common and frequent geological disaster on the China-Pakistan Karakorum Highway, and there were 177 mudslides along the line. The debris flow is distributed in a belt, along which there are freeze-thaw debris flow, glacier-glacial lake outburst debris flow, rainfall-glacier debris flow, etc., as shown in figure 1. Debris flow has the characteristics of suddenness, fast flow rate, large flow rate, large material capacity and strong destructive force. Mudslides often destroy highway facilities and even villages and towns, causing great losses.

Figure 1. The mudslide broke out and destroyed the embankment.

2.2 collapse
Collapse is one of the most extensive and serious geological disasters along the China-Pakistan Karakorum. There are 139 collapses, including falling rocks, rockslides, rolling stones, scattered rocks and cone slope deposition. Collapse is a geological phenomenon in which the rock and soil mass on a steep slope suddenly breaks away from the parent body under the action of gravity, rolls, and accumulates at the foot of the slope (or valley). It often occurs in the natural steep slope, the form of disaster is that a large number of stone falls off and all or part of them stores at the foot of the slope.
Collapse occurs frequently along the highway, which has a significant impact on highway construction safety, as shown in figure 2.

Figure 2. Impact of collapse on highway construction.

2.3. Water damage
Water damage is a common highway natural disaster. According to the causes of the flood, the flood can be divided into mountain torrents caused by local rainstorms and river floods caused by heavy rainfall in flood season. In addition, there are ice flood, dam break flood, snowmelt flood and so on. The project section is located in the structural fracture zone, the river channel is folded, the stream gradient is large, the water level rises and falls rapidly, the water flow is rapid, resulting in severe erosion, side erosion, top scouring erosion, erosion of the roadbed, especially the slope foot of the roadbed adjacent to the concave bank of the river, which also washes out the revetment wall, causing roadbed collapse and destruction, affecting construction safety, as shown in figure 3.

Figure 3. Embankment collapse.

2.4. Avalanche
Avalanches are distributed in the north of Hongzha, and there are 21 large and medium avalanches along the whole line. There are two kinds of avalanches along the route, one is slope avalanche and the other is trench avalanche. Most of them occur in overcast slope, most of them are gully type, and a few of them are slope type. Slope avalanches have large slopes, thin snow, and high frequency of outbreaks, but the scale is small and the disasters are mild. Due to its large snow source area, thick snow cover and large drop, the trench avalanche also has a large potential energy. Although the frequency of the outbreak is low, it has a serious harm because of its large scale. There is an avalanche at K671+100, which happens once a year, which affects the operation of highway, endangers the safety of driving and causes great harm.
2.5. **Barrier dam**

In 2010, the cliff wall near the village of Atabad on the right bank of the Hongzha River collapsed, and the accumulation body fell into the Hongzha River, causing the mud at the bottom of the river, together with the collapsed gravel on the right bank and leaping to the cliff on the left bank of the Hongzha River. The wall of the left bank gorge collapsed under the impact, instantly buried the highway below, and blocked the Hongzha Valley to form a barrier dam, as shown in Figure 4. The damming dam piled up to 2.97 kilometers, completely blocked the Hongzha Valley, causing the river to be cut off, interrupting the Karakoram Highway, and forming a giant dammed lake of more than 20 kilometers in the short-term.

![Figure 4. Barrier lake dam.](image)

3. **The influence of geological hazard on the construction of diversion section**

Due to the serious natural disaster in 2010, the route of China-Pakistan Karakorum Highway needs to be changed. Through the on-the-spot investigation along the re-route section of the highway, the types of disasters faced by the sites along the highway and the degree of impact on construction safety are analyzed, as shown in Table 2.

| No | Site               | Geological disasters            | Degree of influence                                                                 |
|----|--------------------|---------------------------------|-------------------------------------------------------------------------------------|
| 1  | The construction site | debris flow, water damage       | Due to the limited terrain, the site is vulnerable to debris flow, flood and other disasters, which is very harmful. |
| 2  | Roadbed construction | collapse, landslide             | Because there are many landslides along the line, it is easy to induce landslides, which is more harmful. |
| 3  | Slope construction  | collapse                        | Because the mountain soil along the line is relatively loose, coupled with construction disturbances, it is easy to induce landslides, which is very harmful. |
| 4  | Tunnel construction | collapse                        | There are faults or accumulations in the tunnel area, which poses a serious safety hazard. |
| 5  | Bridge construction | water damage                    | The bridge site area is on the riverside, which is harmful. |

3.1. **The influence of geological disasters on temporary facilities**

Due to the restrictions of the site, the construction station, mixing station, steel processing plant and other facilities are often built on the side of the river, at the foot of the mountain or on the side of the road. The construction site of the operation team is susceptible to landslides and other disasters. Debris flow, flood and other disasters are very easy to cause serious harm to construction sites, mixing stations and other facilities. Because of the barrier dam formed in the Hongzha River Valley in 2010,
the water level of the lake rose by 100 meters, forming a huge barrier lake. There is a risk of dam break, especially in the rainy season, the inflow of reservoirs increases sharply and the water level rises, which leads to the increase of the probability of dam break and the disastrous consequences.

### 3.2. The influence of geological hazard on tunnel construction

The valleys along the China-Pakistan Highway are deep and the construction site conditions are limited. Especially in the construction section of the barrier lake, the traffic conditions are bad. Because both sides are cliffs, it is necessary to open the construction road first, in order to carry out the tunnel construction, the construction is full of difficulty, as shown in Figure 5. The section K655+420-K655+590 at the entrance of No. 2 tunnel is a collapse body. The source of collapse is the Quaternary slope alluvial debris stone. The collapsed accumulation body is banded and has a great influence on the tunnel, as shown in Figure 6. The joint cracks in the rock mass of No. 3 tunnel are developed, the structure is loose and the stability is poor. Blasting construction, excavation and other activities will destroy the existing mechanical balance and induce new disasters. When the collapse and the landslide occur at the tunnel entrance, it will cause the blockage of the tunnel entrance, which will do great harm to the construction.

![Figure 5. A construction ramp on a cliff.](image1)

![Figure 6. Accumulation body at entrance section of tunnel.](image2)

### 3.3. The influence of geological hazard on roadbed construction

Collapse often causes harm to highway operation, flying stones threaten traffic safety and traffic is blocked by collapse. There are many areas of collapse along the line. Most of the collapses are small in scale, but they are characterized by strong repeatability and periodic activities. There are large risks such as landslides and landslides during the construction of roadbed. The construction of roadbed retaining walls and anti-slide piles is vulnerable to falling rocks and collapses of broken slopes, and some cliff sections have major risks such as falling from high places and falling into the river. Due to the limitation of terrain, the artificial slope excavated in the process of highway construction is
relatively steep, and some sections are nearly vertical, which enlarges the free surface of the front edge of the slope, destroys the balance of the loose deposits in the natural state, provides the sliding space for the upper loose deposits, reduces the stability and contributes to the occurrence of collapse.

3.4. The influence of geological hazard on bridge construction
Debris flow and water damage scouring the bridge makes the foundation empty and impact the bridge pier and the structure damage, which has a great impact on the bridge construction. The secondary geological disasters caused by floods, such as debris flow, collapse and landslide, may cause the construction site of bridges to be buried, thus affecting the construction.

4. Safety measures for construction of China-Pakistan Highway
In view of the geological disasters and potential impacts faced by the highway reconstruction project of China-Pakistan. We always adhere to the concept of "putting people first and putting life first", put the safety of life and property of the majority of employees in the first place, and put forward targeted safety countermeasures from the aspects of technology and management.

(1) According to the characteristics of geological environment of China-Brazil highway, from the aspects of site and station construction, construction site safety protection and so on, a safety protection guide for construction site of China-Brazil highway is compiled to guide the participating units to strengthen the prevention and control of geological hazards and construction site safety protection. In order to ensure the safety of construction sites, it is forbidden to set up temporary sites in areas prone to landslides, mudslides or floods, so as to avoid the occurrence of mass casualties.

(2) From the project construction unit to the construction unit, according to the emergency guiding principles of "horizontal to side, vertical to the end" and "self-rescue as the main" and around the construction and construction sites such as roads, bridges and tunnels, in view of the emergencies such as debris flow, collapse and water destruction, the emergency plan system for the construction of China-Pakistan Highway is established, and the full amount of emergency rescue equipment and equipment is allocated. We will strengthen emergency drills for geological hazards and enhance the emergency response capacity of participating units. Specialized personnel are assigned to monitor the water level of the barrier lake and the stability of the dam body. Once multiple cracks are found to increase significantly and the settlement is significantly increased, we will increase the risk warning level and inform the downstream dangerous areas to strengthen the warning.

(3) In view of the current situation of multi-type and wide distribution of disasters along the China-Pakistan Highway, it is necessary to pay attention to the risk assessment of geological disasters along the China-Pakistan Highway, strengthen the monitoring and early warning of key disaster points in the construction process, timely grasp the dynamic information of geological disasters along the China-Pakistan Highway, and take preventive measures. Through the comprehensive evaluation of engineering hazard sources, the investigation of risks and hidden dangers, the continuous and dynamic monitoring of the hazard sources, the regular analysis and timely warning, the risk disposal measures are proposed. Strengthen the safety inspection on the construction site, find out potential safety hazards, study and judge the production safety situation regularly, and timely send the safety warning information to the front-line safety management personnel through the mobile phone mass distribution platform and other information platforms, so as to improve the timeliness of the information. We have strengthened the disaster knowledge of construction personnel, carried out various forms of publicity and training to improve construction safety and enhance the awareness of disaster prevention and reduction.

(4) Strengthen the prevention and control of geological disasters such as mudslides and collapses, and integrate the disaster prevention and reduction concept of "prevention first" and disaster management countermeasures into project management, and realize the optimization of disaster decision-making. For the prevention and control of debris flow, take "prevention first, prevent before treatment", improve the prediction and forecast of debris flow, and stop the occurrence of disasters as much as possible. Take corresponding control engineering (such as retaining, supporting engineering,
etc.), in order to control the occurrence and harm of debris flow. Clean up the falling rocks and loose deposits in the collapsed area and set up safety warning signs to ensure safe driving. There are a large number of roadside slopes in highway construction. During the excavation process of roadside slopes, the construction plan should be optimized to avoid destroying the integrity of the slope rock mass and forming new potential collapse points. The subgrade of the water-damaged road section is adjacent to the concave bank of the river, and the top of it is washed and eroded, causing the roadbed to collapse and destroyed. The river channel remediation plan such as the picking dam and the spur dam is used to cooperate with the revetment wall and the wire cage to carry out comprehensive treatment.

5. Conclusion
(1) Deep ravines, broken rocks and frequent natural disasters along the China-Pakistan Highway cause great harm to the construction safety of the highway. This paper analyses the geological hazards and their potential consequences, and analyses the influence of geological hazards on engineering construction and potential safety risks from the aspects of construction sites, tunnels, bridges and roadbeds.

(2) In order to prevent and control the hazards of geological hazards in the reconstruction section of China-Pakistan Highway and its impact on engineering construction, this paper proposes construction safety countermeasures from the aspects of technology and management.

Acknowledgments
This work is supported by the Construction Science and Technology Projects of MOT(Grant No. 2013318J01100).

References
[1] Liu T, (2008) The Prevention and treatment of highway geological hazards in plateau and mountain areas [J]. Subgrade Engineering, 139(4): 211-213.
[2] Zhang X, (2013) Study on the distribution characteristics and control for geological disasters along international Karakoram Highway (KKH) [J]. Journal of Chongqing Technology and Business University (Natural Science Edition), 30(2): 45-48.
[3] Wang M, Pang B, Wang Y, et al. (2013) Landscape characteristics and tourism demand along the China-Pakistan International Karakoram Highway [J]. Journal of China & Foreign Highway. 33(4): 6-8.
[4] Lao L, Zhu Y, Yang Z, et al. (2013) Debris flow hazards and prevention optimization along international Karakoram Highway [J]. Geological Science and Technology Information. 6(6): 168-170.
[5] Zhu Y, Yang Z, Liao L, et al. (2014). Glacialized geomorphologic geohazard along China-Pakistan International Karakoram Highway [J]. Journal of Catastrophology. 29(3): 81-84.
[6] Fang C, Qian D, Xu S, et al. (2016). Debris flow susceptibility evaluation of Karakoram Highway based on extenics and entropy weight [J]. Journal of Natural Disasters,(6): 18-26.
[7] China Academy of Transportation Sciences, MOT. (2018) Research report on construction safety and emergency disposal of the China-Pakistan International Karakoram Highway [R].