

# Study on Formation Mechanism and Treatment Scheme of Consequent Bedding Landslide at K35+240~+620 Section of Wanda Expressway

Haitao Li<sup>1</sup>, Lingwei Kong<sup>2</sup>

<sup>1</sup>Jilin Tiedao University, Jilin, China;

<sup>2</sup>China Railway Northwest Research Institute Co., Ltd., Lanzhou, China

**Abstract:** Aimed at the consequent bedding rockslide at K35+240~+620 section of Kaijiang–Kaizhou section of Chongqing Wanda Expressway, this paper systematically analyzes the engineering geological conditions, deformation characteristics and failure mechanism of the landslide through field investigation, drilling exploration and mechanical calculation. The stability of the landslide under natural and rainstorm conditions is evaluated, and two control schemes are put forward and compared. The results show that the landslide is a typical rainstorm-induced consequent bedding rockslide controlled by the interface of sandstone and mudstone, with a total volume of about  $1.064 \times 10^6$  m<sup>3</sup>. The upper hard sandstone and lower soft mudstone structure, groundwater enrichment at the lithologic interface, and high cutting excavation and blasting disturbance are the main inducing factors. The stability coefficient is 1.05–1.11 under natural condition and 1.00–1.06 under rainstorm condition, which is in an unstable state. Scheme One (anti-slide piles + anchor cable ground beam + intercepting and drainage system) is recommended, with a total investment of about 18.1866 million yuan. The scheme has the advantages of high safety, good durability and reliable long-term performance, which can effectively ensure the operational safety of the expressway. The research results can provide reference for the investigation, design and treatment of similar consequent bedding rockslides in eastern Sichuan.

**Keywords:** Consequent Bedding Landslide; Geological Characteristics; Failure Mechanism; Anti-Slide Pile; Anchor Cable; Drainage System

## 1. Introduction

Landslide is one of the most common geological hazards in expressway construction and operation, especially the consequent bedding rockslides in layered rock mass areas, which are characterized by obvious sliding surface, strong concealment, rapid deformation under rainfall and great harmfulness [1]. In the process of expressway construction in mountainous areas of southwest China, a large number of steep and high slopes are often formed due to road cutting and excavation, which easily induce bedding sliding along the weak structural plane under the action of unloading and rainfall [2].

Traditional landslide treatment mostly adopts single support measures, which are difficult to adapt to the characteristics of deep sliding surface, large thrust and strong water effect of large-scale consequent bedding landslide [3]. In recent years, the combined support system of anti-slide pile, anchor cable and drainage has been widely used in the governance of super-large and thick-layered rock landslides, which can give play to the advantages of rigid support and active reinforcement, and realize the long-term stability of the slope [4-5].

Chongqing Wanda Expressway (Kaijiang–Kaizhou section) is an important inter-provincial channel connecting Chongqing and Sichuan. The K35+240~+620 section is a deep cutting cutting slope. After the operation, obvious deformation such as bulge of side ditch, cracking of protective wall and damage of bridge abutment appeared. In order to ensure the safety of expressway operation, it is necessary to carry out special investigation and governance design. Based on the field survey data and geological exploration results, this paper studies the deformation law and formation mechanism of the landslide, calculates the landslide thrust and stability, compares and optimizes the governance plan, and forms a complete set of

investigation and governance technology for large-scale consequent bedding rockslide, which provides a typical case for the prevention and control of similar geological hazards [6-7].

## 2. Project Overview

### 2.1 Engineering Background

Kaijiang–Kaizhou section of Wanda Expressway is the fifth ray branch of Chongqing expressway network, with a total length of 41.2 km, two-way four-lane, design speed of 80 km/h, connecting Wanzhou–Kaizhou Expressway and reaching the Sichuan–Chongqing boundary. The landslide is located in Wulong Village, Nanya Town, Kaizhou District, Chongqing, between the filled subgrade and Baxian Cave Bridge. The section passes through in the form of deep cutting cutting slope. The right side slope is 25–34 m high, with two to three stages; the left side slope is 11–17 m high, with one to two stages. The original design adopts the support forms of anchor frame, concrete retaining wall and slope protection wall. The expressway was opened to traffic in 2015. Minor deformation occurred in 2017, and the deformation developed significantly in March 2018. The side ditch and soil shoulder bulged and warped, the anchor frame and slope protection wall were cracked and sheared, and the pedestrian bridge and bridge head structure were damaged, which seriously threatened the driving safety and structural safety. The investigation and design were carried out from April to May 2018, and the special treatment was implemented.

### 2.2 Geological Conditions

#### 2.2.1 Meteorology and hydrology

The landslide area is a subtropical monsoon climate with abundant rainfall. The average annual precipitation is 1224.7 mm, and the precipitation from May to September accounts for 70% of the whole year. The maximum daily rainfall is 210.5 mm, and the maximum three-day rainfall is 357.7 mm. The surface water is developed with perennial gullies and fish ponds, which are the main supply sources of groundwater. The groundwater is mainly pore phreatic water and bedrock fissure water, which is concentrated in the sandstone–mudstone interface. The water inflow of six seepage points at the foot of the slope is 6.91–33.25 m<sup>3</sup>/d, which increases sharply after rainfall.

#### 2.2.2 Topography and geomorphology

The site belongs to the erosional structural low mountain and hill landform of eastern Sichuan Basin. It is a monoclinic mountain with a slope direction of SE20°–25° and a slope of 10°–14°. The micro-landform presents the characteristics of **two platforms + three slopes**. The first platform is about 370–390 m above sea level, and the second platform is about 425–450 m above sea level. Two gullies are developed in the landslide area, which cross the rear edge of the slope and become the main channels for groundwater recharge.

#### 2.2.3 Stratum lithology

The strata exposed in the site are Quaternary residual slope deposit (Q<sub>4</sub><sup>el+dl</sup>) and Jurassic Middle Upper Shaximiao Formation (J<sub>2s</sub>). The overall performance is **upper hard and lower soft** base structure:

Upper layer: medium-thick layered sandstone, gray-yellow, gray-white, medium-fine grain structure, calcium cementation, well-developed joints and fissures, strong water permeability;

Lower layer: purplish-red mudstone and sandy mudstone, muddy structure, soft when exposed to water, acting as a relatively water-resisting layer;

The sliding surface is strictly controlled by the sandstone–mudstone interface, with a dip angle of 9°–10°.

#### 2.2.4 Geological structure

The landslide is located in the monoclinic area between Renshan Syncline and Mingyuxia Anticline. The rock strata are consistent with the slope direction, which is a typical consequent slope. The occurrence of sandstone is NE64°–77°/SE8°–14°. Two groups of structural joints are developed, which provide channels for rainwater infiltration. The basic intensity of earthquake in the site is VI degree, which has little influence on landslide stability.

## 3. Deformation Characteristics and Formation Mechanism of Landslide

### 3.1 Deformation Characteristics

The landslide is divided into two stages: the rear stage landslide is about 380 m wide, 125 m long, 22.6 m thick on average, with a volume of 89.9×10<sup>4</sup> m<sup>3</sup>; the front stage landslide is about 280 m wide, 45 m long, 21.8 m thick on average, with a volume of 16.5×10<sup>4</sup> m<sup>3</sup>. The main sliding direction is SE22°, belonging to medium-scale consequent rock landslide.

The main deformation features are as follows:

1) The side ditch and soil shoulder of K35+370–+550 section are warped and bulged, with a length of about 180 m, the maximum warping displacement is 2–5 cm, and the ditch wall is sheared and damaged;

2) The slope protection wall and anchor frame at the first-stage platform are sheared and dislocated, and the cracks closed by asphalt are reopened;

3) Tensional and dislocation cracks appear at the top of the cutting slope, with a length of 85–90 m, a width of 5–8 cm and a dislocation of 2 cm;

4) The pedestrian bridge abutment is cracked, the diagonal brace is damaged, the expansion joint is narrowed, the bridge head roadbed is cracked, and the bridge plate is bulged, resulting in vehicle bumping.

The rear edge of the rear landslide has no obvious tension crack, but the bulge at the shear outlet is obvious, and there is a risk of traction sliding as a whole.

### 3.2 Formation Mechanism

The formation of the landslide is the result of the combination of internal and external factors. The core mechanism is unloading relaxation + water softening + structural slip along the layer.

#### (1) Stratum structure control (internal cause)

The upper hard and lower soft base structure is the fundamental condition for landslide formation. The thick-layered sandstone on the upper part is easy to form unloading fissures, and the mudstone on the lower part is soft in water and acts as a relatively water-resisting layer, leading to water enrichment at the lithologic interface, which reduces the shear strength of the sliding zone.

#### (2) Groundwater effect (key inducing factor)

Rainwater infiltrates along sandstone joints and bedding planes, gathers at the mudstone surface to form perched water and fissure water, which increases the pore water pressure and buoyancy, reduces the  $c$  and  $\phi$  values of the sliding zone soil, and greatly reduces the slope stability.

#### (3) Engineering disturbance (direct cause)

The construction blasting and high cutting excavation form a steep free surface up to 34 m, resulting in stress adjustment and unloading relaxation of the rock mass, expanding the seepage channel of groundwater, and directly inducing the slope to slide along the weak mudstone surface.

## 4. Stability Analysis and Thrust Calculation

### 4.1 Calculation Parameters

According to geological exploration and indoor test, the weight of the sliding body is 25 kN/m<sup>3</sup> under natural condition and 25.5 kN/m<sup>3</sup> under rainstorm condition. The mechanical indexes of the sliding zone are determined by inversion and empirical comparison:  $c=15$  kPa (natural), 14 kPa (rainstorm);  $\phi=6.13^{\circ}$ – $9.92^{\circ}$  (natural),  $6.13^{\circ}$ – $9.55^{\circ}$  (rainstorm).

### 4.2 Stability Evaluation

The stability of the landslide is calculated by the limit equilibrium method. The safety coefficient standards are: natural condition  $K \geq 1.20$ , rainstorm condition  $K \geq 1.15$ . The results show that:

Natural condition: stability coefficient 1.05–1.11, in an unstable state;

Rainstorm condition: stability coefficient 1.00–1.06, close to critical failure.

The landslide has a high risk of overall sliding under continuous rainfall, so it must be treated urgently.

### 4.3 Landslide Thrust

The landslide thrust is calculated by the transfer coefficient method, and the larger value under natural and rainstorm conditions is taken as the design thrust. The maximum design thrust of the rear landslide is 1172.54 kN/m, and that of the front deep landslide is 366.85–390.76 kN/m. The thrust is large, and a comprehensive support system is needed.

## 5. Landslide Control Scheme Design and Comparison

### 5.1 Design Principles

Adhere to the principles of dynamic design, information construction, safety and reliability, economic rationality, and one-time radical treatment. The construction process should be combined with monitoring to ensure construction and operation safety.

### 5.2 Scheme Design

Scheme One: Anti-slide Pile + Anchor Cable Ground Beam + Interception and Drainage System

#### (1) Anti-slide pile

Set 19 A-type piles and 30 B-type piles on the first-stage platform, with a section of 2 m×3 m, a pile length of 21 m, and a spacing of 6 m. The

long axis direction is consistent with the main sliding direction (SE22°).

(2) Anchor cable ground beam and anchor block  
Set two rows of anchor blocks on the first-stage slope, with a spacing of 3 m; set anchor cable ground beams between gullies and pedestrian bridges, with a spacing of 6 m. The anchor cable is 16–26 m long, with a dip angle of 25°, and the anchoring section is 10 m. It is composed of 6 or 8 bundles of 1860-grade steel strands.

(3) Drainage system

Set 63 inclined drainage holes at the foot of the first-stage slope, 30 m long, with a spacing of 6 m and an inclination angle of 5°; build a 120 m intercepting drain on the top of the slope to block surface water; compact and seal the top cracks with clay.

(4) Total cost: about 18.1866 million yuan.

Scheme Two: Full Prestressed Anchor Cable Reinforcement

Set three rows of anchor cables on the first and second-stage slopes, with a maximum drilling depth of 45 m. It is equipped with inclined drainage holes, intercepting drains and crack sealing. The construction speed is fast and the cost is low, but the construction difficulty is high and the durability is poor. Total cost: about 16.2144 million yuan.

## 6. Construction Monitoring and Traffic Organization

### 6.1 Monitoring Content

In order to ensure construction safety and master the deformation law, three monitoring items are set up:

- 1) Surface displacement monitoring: 1 time/day during construction and 1 time/week after completion;
- 2) Support structure displacement monitoring: the same frequency as surface displacement;
- 3) Deep hole displacement monitoring: 2 times/week during construction and 1 time/15 days after completion.

The monitoring period after completion shall not be less than two hydrological years, and early warning shall be carried out according to the deformation rate.

### 6.2 Traffic Organization

During the construction, the half-closed lane and emergency parking area are adopted, with two-way single-lane traffic. Set up warning area, transition area, buffer area, working area and

termination area, and set up obvious signs to ensure driving safety.

## 7. Conclusion

1) The K35+240–+620 section of Kaijiang–Kaizhou section of Wanda Expressway is a typical consequent bedding rockslide controlled by sandstone-mudstone interface. The total volume is about  $1.064 \times 10^6$  m<sup>3</sup>, which is a medium-scale landslide.

2) The landslide is formed under the combined action of upper hard and lower soft stratum structure, groundwater enrichment and high cutting excavation disturbance. It is extremely easy to slide under rainstorm conditions and has strong harmfulness.

3) The stability coefficient under natural condition is 1.05–1.11, and under rainstorm condition is 1.00–1.06, which is in an unstable state. The maximum landslide thrust is 1172.54 kN/m, requiring strong support.

4) The recommended treatment scheme is anti-slide pile + anchor cable ground beam + interception and drainage system, which has the advantages of safety, reliability and good durability, and can ensure the long-term stable operation of the expressway.

5) The dynamic design, information construction and real-time monitoring during the treatment process are important guarantees for the successful treatment of large-scale consequent bedding rockslide.

This study forms a complete set of technical process for investigation, mechanism analysis, stability calculation and scheme optimization of consequent bedding rockslide, which can provide reference for the prevention and control of similar landslide hazards in mountain expressways.

## Acknowledgments

This work was financially supported by Research on Key Technologies for Construction and Disease Prevention of Road Engineering in Plateau Cold Regions Project No.: RI 2023-Major-01 fund; Key Technologies for Engineering Improvement and Durability Enhancement of Typical Problematic Soils in Arid Regions 2025 Special Project 08.

## References

- [1] Li X, Zhao L H. Deformation mechanism and stability control of consequent bedding rockslides in expressway cutting slopes[J].

- Chinese Journal of Rock Mechanics and Engineering, 2020, 39(S2): 3356-3366.
- [2] Wang F, Zhang J M. Analysis on failure mode and treatment technology of consequent bedding landslide in Three Gorges Reservoir area[J]. Journal of Engineering Geology, 2019, 27(3): 589-597.
- [3] Liu Y, Wei C F. Application of combined support system of anti-slide pile and anchor cable in large-scale landslide treatment[J]. Rock and Soil Mechanics, 2021, 42(S1): 399-408.
- [4] Zhou W, Zhang Y B. Key technologies for investigation and design of extra-thick consequent bedding rockslide[J]. Bulletin of Soil and Water Conservation, 2022, 42(2): 156-163.
- [5] Hu P, Kong L W. Study on rapid treatment technology of expressway landslide under operating conditions[J]. Railway Investigation and Surveying, 2023, 49(2): 41-46.
- [6] Chen J L. Design and application of drainage system in consequent bedding landslide treatment[J]. Highway, 2021, 66(5): 123-128.
- [7] China Railway Northwest Research Institute Co., Ltd. Code for Design of Landslide Prevention Engineering[M]. Beijing: China Railway Publishing House, 2019.