Post-evaluation of effect of large-scale landslide control based on monitoring measurement

Zhongping ZHANG[(1)], Honggang WU[(1)]

(1) Northwest Research Institute Co., Ltd. of CREC, Lanzhou 730000,
ztxbywhg@yahoo.com.cn

Abstract

Post-evaluation of effect of landslide processes is essentially prevention information collection, analysis and feedback process. This paper based on an analysis by long-term monitoring data of landslide of underground drainage holes, anti-sliding pile deformation of retaining structure, internal displacement of the Sichuan-Tibet highway bridge before bleaching ~ gentian section landslide No1, Monitoring data shows that after years of adverse conditions landslide No1 as a whole remained stable for the time being, there are no obvious signs of quick slide. But the partial slope is still in the process of stress adjustment under the adverse effects of external environmental factors which have a small settlement and creep deformation, thus it should be added to the necessary engineering measures. It will provide the basis for the future control design.

Keywords: landslide, monitoring measurement, post-evaluation

1.Introduction

In terms of the evaluation of effect of landslide process, most of us only have a completion acceptance according to the specification. However, we know little about the operating conditions of the process after it completed. In this field, there's still not a unified standard and evaluation system(Wang,1998). Deng proceeded a study on the effect of highway slope maintenance engineering in Shaanxi, and Zeng did an evaluation about the treatment effect of Sichuan-Tibet Highway Erlang Mountain slope(Deng,2002). But their studies are only limited to some kind of construction or effect in the landslide control engineering, such as the stress form of anti-slide pile, the influence of underground water to the sliding surface, and so on. There are little studies on the post-evaluation of effect of landslide processes based on monitoring measurement. Restricted to the quantity of the treatment engineering and observational data, people do not have a study in this field for a long time. This paper is for the post-evaluation of landslide process in the Sichuan-Tibet Highway Qiandiao Bridge to Longdan Stream (K2710+600~K2732+200). It's based on the monitoring measurement data of underground drainage holes, anti-slide pile and retaining structure deformation and deep landslide displacement. And it do a deep analysis on the data changes before, during and after the engineering in order to evaluate landslide stability under adverse conditions for many years.(Liu and Yu ,1984)

2. The landslide group profiles of Qian-Long paragraph in Sichuan-Tibet Highway

The paragraph Qiandiao Bridge to Longdan Stream (K2710+600~K2732+200) of Sichuan-Tibet Highway, whose full-length is 22.8Km, located at the east slope of Erlang Mountain and upstream of TianQuan River, is the key in the transportation between Sichuan and Tibet(Zeng,2003). This paragraph is in a complex natural environment. At the same time, due to the construction behaviors of human being in rainy season, some sub grade diseases like collapse and landslide happened inevitably in this road. Two rainstorm between July and August 1997 brought the road a more serious disasters(Zhang,2000). The subgrade and pavement of two kilometers road from K2730 to K2732 deformed severely, and the rainstorm also induced the resurrection of some old landslides including No.1 landslide. According to the on-site inspection, there were many longitudinal jagged cracks on the cement board pavement between road (K2729+920~K2730+425) No.1 landslide, among which the longest cracks reached about 60 meters. About 10cm dislocation happened in this paragraph and local roads even appeared the pavement floating phenomenon. Both sides of the highway had different degrees of slump. The rear edge of slope occurred a ring tension crack which nearly cut through the slope. (Fig.1).

3. Controlling measures

No.1landslide belongs to the large complex landslide. The slope had been broken and attained limiting equilibrium condition. So it must be governed timely. As most of the slope average thickness are above 35 meters, general anti-slide pile is difficult to meet the requirements of stabilizing force Instead of prestressed anchor rope friction pile and prestressed anchor cable frame beam were used in the main works combined with the comprehensive management of drainage works. Figure 2 is the specific engineering measures. The project used a variety of measures including pile, anchor frame, drain dyke, anti-slide retaining wall, and elevation drain hole.

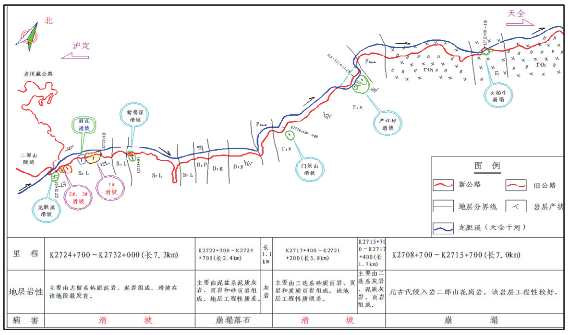


Fig.1 The landslide and stratification distribution diagram of the Sichuan-Tibet Highway from Qiandiao Bridge to Long danxi Bridge

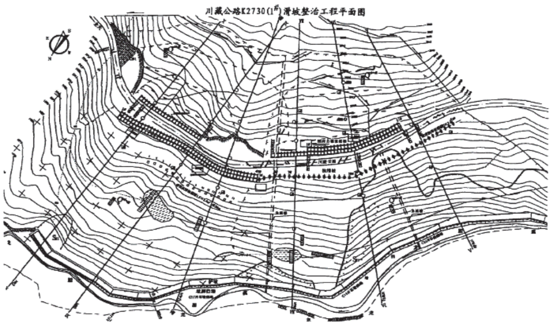


Fig.2 The layout of the No.1 landslide stabilizing structures of segment of K2730 in Sichuan-Tibet Highway

3.1 Anti-slide piles

Western part: The west part of No.1 landslide is the most active, the most severely damaged section. It is the main target to restore. So 42 prestressed anchor rope friction piles, which are made of C25 reinforced concrete, are set up in this range (Figure 3). In view of most anchor rope friction piles setting deeply, there are 2 rows for a total of 20 grouting anchors with diameter 36mm under every pile.(Zheng,2005)

Fig.3 Anti-slide piles of western part

Eastern part: 14 general anti-slide pile are set up in the east part of No.1landslide. The piles are made of C20 reinforced concrete (Figure 4).

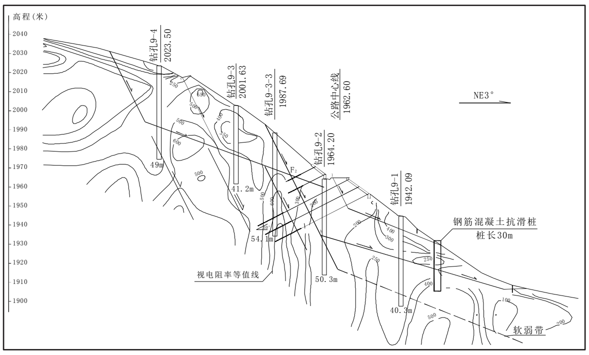


Fig.4 The east part of section (section photograph XI-XI)

3.2 Prestressed anchor cable frame

Inside: Three pieces of anchor cable frame are installed on the inside of the road. They are controlled by highway mileage and the distance from the center of the road which is 8m from the center for all frames (Figure 5). Among them, 23 rib-columns are set up from K2729+990 to K2730+78; 10 rib-columns are installed from K2730+182 to K2730+222; and there are 31 rib-columns from K2730+222 to K2730+342. The material of rib-column and beam is C25 reinforced concrete.

Outside: We use 47 rib which are controlled by the control point coordinates on the outside of the road. Every rib-column has 3 bundles of anchors whose specification is 15Φs15.2.

Fig.5 Prestressed anchor cable frames

3.3 Retaining walls

Retaining wall of the riparian toe plays the significant role of retaining toe and erosion prevention. It's the necessary measure to prevent the failure of anti-slide pile and frame caused by the continuing erosion of the toe down to the slope. The design height of the wall is 8 meters, following Figure 6.

3.4 Drain dyke

Drain dykes are divided into intercepting drain outside the landslide and drain inside the landslide. There are two drain dykes outside the landslide and two groups of drains inside the landslide. The total length of drains is 950 meters. The former should be constructed as soon as possible, and the later may be relatively lagging ,following Figure 7.

Fig.6 Retaining walls

Fig.7 The rapid stream slot for drainage

3.5 Elevation drain hole

deep drainage project design is a stronger technical work. Whether the accurate determination of water points or the actual construction could be carried out is extremely difficult to. 11 elevation drain holes are supplemented timely after the investigation for the additional design in the flied.

3.6 Slope processing

Slope processing is to supplement and improve the whole project. It can be a part of the retaining wall or slope protection construction, mainly to stabilize the slope, to fill cracks and green protection.

4. Long-term dynamic monitoring process

The occurrence of roadbed disease in this paragraph caused great attention of Ministry of Transportation Highway Division and Sichuan Provincial Communications Department. They had organized landslide experts to view the situation on the scene and discuss countermeasures for many times. After several expert reasoning conferences, the remediation for original line program was adapted finally. To this end, Sichuan Provincial transportation Department entrusted Northwest Research Institute of C.R.E.C to process an engineering geological survey on the sections of the landslide and produce a treatment project design based on the survey in 1998. In November 2000, Northwest Research Institute of C.R.E.C were commissioned by Sichuan Provincial transportation Department again to do a long-term monitoring on the landslide with dynamic methods. And during 2002 to 2004, the institute were third commissioned to carry out a follow-up observation after the project of No.1 landslide and No.2landslide completed for two hydrological years in order to assess the project objectively with scientific data and facts.

5. Monitoring and measuring results and analysis

5.1 The monitoring results of deep displacement

The results observed during many years before 2004 reveal: deformation of the No.1 landslide mainly focuses on the road and the shallow and middle parts of slope below the road, severe deformation phase is also mainly focused on the rainy season when more rainfall concentrated from July to September every year, which indicates that slope affected by the factor of rainfall is more prominent. Summarized as follows:

5.1.1 Judging from the nature of the landslide

The rock and soil, constituting the No.1 landslide, is crushed, loose, severe weathered and the slope is high and steep, vegetation developmental, irregularity, of which the structure is very conducive to the infiltration of surface water which can cause apparent effect on the erosion and softening for the sliding soil, which leaded the slope to astatically develop. Analysis from the evolution process of landslide, just because of the stability losing of preceding stage of the landslide cause hinder stage of the landslide to lose support force and be towed to come into being deformation. And now Sichuan-Tibet Highway is just local to the junction of preceding stage and hinder stage of the landslide, which appears apparent deformation by towing and pushing.

5.1.2 Judging from effects of the project before and after treatment

Before the treatment (from March 1998 to October 1999): stability of landslide is relatively poor, basically in a state of instability. Deformation is mainly in the middle slide zone of lower stage of landslide, however deeper layers appear intermittent creep deformation, the higher slide zone of landslide mostly appear shallow deformation. In the construction of treatment (from October 1999 to the end of 2002): disturbance in construction has apparent effect on the stability of the slope. Mainly after the construction of anti-sliding pile and anchor cable, just as "worse", whereas increasing loose surface, which cause internal stress of the slope to concentrated release. After completion of the treatment (from the end of 2002 to the end of 2004): landslides tend to be stable. In October 2002, retaining and strengthening works was coming to late stage, the constructions of anti-sliding pile and anchor were gradually playing a supporting role, but intermittent or seasonal deformation persists, destructive deformation may still occur. As a result of the treatment, the deformation phenomenon of the landslide has been inhibited. Whether the deep displacement monitoring of landslide or the results of stressing deformation monitoring of anti-slide piles all reveal which compared with before the treatment, deformation in shallow and middle layer of the landslide has been largely discontinued, which in deep layer only appears seasonal or intermittent creeping, having no impact on the overall stability of landslides. The observations of 2008 revealed: during observations, new slide zone was not found in all of the three drilling holes, and there were not any phenomena of sudden deformations which once appeared in the old slide zone. Therefore, deformation of the landslide is still greatly influenced by rainfall and activities of groundwater, the probability of coming up sudden destruction is very small. As shown in table 2-4.

5.2 Observation results of the structure stress

In order to detect the stress of anti-sliding piles and retaining structure, in November 2001, three piles embedded inclinometer tubes, including No.5plie (general anti-slide pile), No. 8 pile and No.20 pile (anti-sliding pile with prestressed anchor cable), were chosen as testing piles to observe. As of November 2004 observations are as follows (as shown in table 5).

5.2.1 The monitoring for No.5 pile

No.5 pile, is a general pile, was located on the nature slope outside the highway in section Ⅸ-Ⅸ and was completed on July 20, 2001. Monitoring of deformation of the pile in early days has fully verified that general piles belong to the passive mechanical structure. The pile, at the beginning of completing, does not immediately play a supporting role.

When the thrust of landslide act on the pile, it makes the pile come into being displacements and deformation, only after the formation of subgroup reaction, can the pile play a supporting role.

The observation results of 2008 show that the displacement at the top of the pile was not obvious and the overall trend was still in a small state. From

Table 1 The statistic table of observation points of No.1 landslide at the present stage

Position	Section No.	Hole No.	Depth(m)	The time of forming hole	Detect depth at the moment(m)
West part	Section Ⅵ-Ⅵ	New 6-2#	67.0	2001/7/25	65.0
	General pile	5#	30.0	2001/7/20	30.0
East part	Section Ⅸ-Ⅸ	New 9-2#	61.5	2002/1/5	47.5
		9-3#	40.2	1998/3/5	40.0
	Anti-sliding pile	8#	47.5	2001/10/12	47.5
		20#	63.5	2001/12/12	63.5
	Total		309.7		293.5
Soil pressure	General pile	5#	24	2001/7/20	4
	Anti-sliding pile	8#	29	2001/10/12	25
		20#	39	2001/12/12	13
	Anchor frame	16#	16	2001/10/12	14
		25#	18	2001/12/12	13
	Total		126		69
Steel bar gauge	General pile	5#	20	2001/7/20	3
	Anti-sliding pile	8#	22	2001/10/12	15
		20#	32	2001/12/12	13
	Anchor frame	16#	18	2001/10/12	15
		25#	18	2001/12/12	13
	Total		110		59
Dynamometer	Anti-sliding pile	8#	4	2001/10/12	0
		20#	4	2001/12/12	4
	Anchor frame	16#	3	2001/10/12	3
		25#	3	2001/12/12	3
	Total		14		10

the test data of earth pressure cells and steel bar gauge buried in pile, the three test results from 2008 come to be approximately equal, which show thrust from the mountain side of the pile varies little.

5.2.2 The monitoring for No.8 pile

No.8 pile, a prestressed anti-sliding pile, was located on the nature slope outside the highway in section Ⅶ-Ⅶ and was completed on October 20, 2001. Preliminary observations indicate that the pile was in elastic deformation during the observation period from 2001 to 2002, the pile bore obvious stress. The data tested from the earth pressure cells and steel bar gauge buried in the No.8 pile before 2004 displays the basic law is that earth pressure close to the side of the mountain gradually increased, which decreased to the side of river, and the resistance of landslide is twice of the thrust. It shows the rocks around the pile are soft-hard inter phase, especially the rocks ahead the pile to the side of river, was in poor stability, which moved down the slope. The compressive stress of steel to the side of mountain continued to increase, the same to the tensile stress of steel upper to the side of river, which caused by the thrust of landslide. The top of the pile grew displacement toward the side of river, which caused anchor cable to elongate and the ensile stress to be larger.

5.2.3 The monitoring for No.20 pile

No.20 pile, a prestressed anti-slide pile as well, was located on the nature slope outside the highway in section Ⅵ-Ⅵ and was completed on December 10, 2001. Preliminary observations indicate that the pile was basically in elastic deformation in 2002, with the same deformation characteristics as No.8 pile, and there was significantly obvious weighted phenomenon within the depth range from 42 meters to 48 meters. The data tested from the earth pressure cells and steel bar gauge buried in the No.20 pile before 2004 displays that the readings from earth pressure cells located in the lower part of pile close to the side of the mountain increased, from which can judge that in the role of thrust coming from the middle layer of the slide zone above making the anti-slide pile generated rotation, which can be described as the top of pile moved to the side of river and the bottom of pile moved to the side of mountain. Meanwhile, the landslide was mainly creepy in the middle and deep layer. The tensile stress of steel bar meter by the river side more than 19 meters continued to increase, which is because the thrust of landslide to the side of mountain acting on the pile made the top of the pile come into being large displacement and the tension of the anchor increase.

The observation results of 2008 show that the displacement at the top of the pile was not obvious and the overall development trend was in a stable state. From the test data of earth pressure cells and steel bar gauge buried in pile, the three test results from 2008 come to be approximately equal, which show thrust from the mountain side of the pile varies little this year.

Table 2 The S-T curve graph of 9-2# hole of 1# landslide in LongQian part of the Sichuan-Tibet Highway

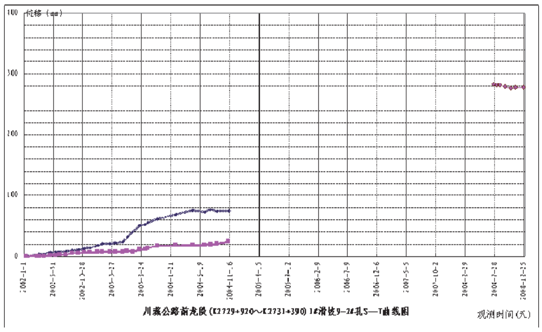


Table 3 The S-T curve graph of 9-3# hole of 1# landslide in Long Qian part of the Sichuan-Tibet High- way

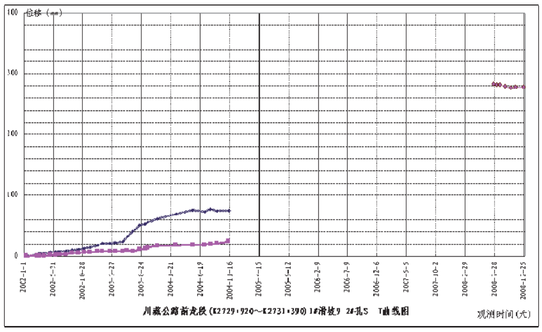
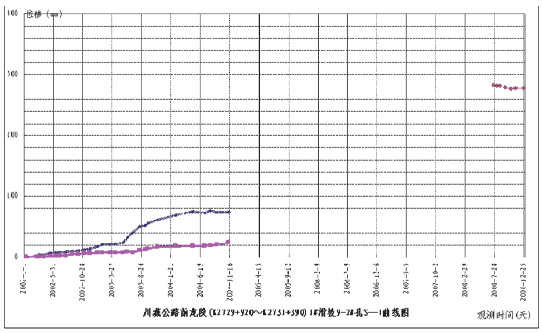


Table4 The S-T curve graph of 6-2# hole of 1# landslide in LongQian part of the Sichuan-Tibet Highway



Tab.5 The comparing of the observation results of 2008 with before of No.1 landslide in Long Danxi

Hole No.	Test depth (m)	Slide zone depth (m)		Annual cumulative value of displacement (mm)					Total cumulative amount	Annual inclination of the pile (°)					Inclination (°)
				2001	2002	2003	2004	2008		2001	2002	2003	2004	2008	
$20^{\#}$	63	Top	∑S(mm)	--	37.52	73.45	24.01	7.6	262.6		0.06%	0.12%	0.04%	0.01%	4.81%
			Tendency (°)	--	300	313	311								
$8^{\#}$	47.5	Top	∑S(mm)	13.18	14.49	35.61	24.1	27.2	248	0.03%	0.03%	0.08%	0.05%	0.05%	5.04%
			Tendency (°)	63	43	346	70								
$5^{\#}$	30	Top	∑S(mm)	46.98	11.01	8.12	5.32	12.4	153.6	0.16%	0.04%	0.03%	0.02%	0.04%	0.59%
			Tendency (°)	15	14	66	8								

6.Conclusion and recommendations

This paper based on the monitoring data, through the observations for years and field reconnaissance, judging on the basis of whether the control targets and effects have reached, reveal that the I ＃ landslide temporarily remain stable overall, and there is no obvious sign of rapid sliding, which can provide the basis for the future engineering design of landslide control.

This area of the landslide was in complex situations on geological conditions, the causes and mechanisms of landslide deformation, and many affective factors existed. Local parts of the slope was still in the process of the adjustment of stress, which would appear deformation of tiny sedimentation and creep age under the adverse effects of external environmental factors, then necessary engineering measures should be added for it.

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