Characteristics and Mechanism of Bedding Rock Slope Failure: A Case Study on No.5 Slope at Wutai-Yuxian Expressway

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Abstract: It is found by engineering geological exploration that No.5 slope in Wutai-Yuxian expressway is typical dip slope forming in ancient gneiss terrain. We conclude that slope deformation and failure mainly result from the gneiss and mica schist constituting the slope and the heavy precipitation in construction period. Besides, the insufficiency of geological exploration in revealing the complex geology and the deficiency of designation and constructing in preventing and controlling geohazards are the engineering factors causing landslide in No.5 slope. Slope cutting and reinforcement, draining and cutting off the surface water, and enhancing the displacement monitoring for potential sliding surface may serve as a reference for construction and supporting designation of deep cutting slope in this area as well as for constructing slope engineering in the areas sharing similar geology with this area.

Introduction

The weak intercalated layers in stratified rock mass system generally control the overall stability of that system because of the abrupt strength variation introduced by these layers [1,2]. When the stratified system bears heavy load, the initial failure tends to occur in the weakest part of the system, which is generally formed by the weak intercalated layers. And the larger the strength difference between intercalated layers and their surrounding rock mass is, the easier the overall system failure is to occur, and consequently endangers the engineering safety [3-5].

Considerable research efforts have been done on the deformation features, failure mechanism and process of the bedding slope, a typical stratified rock mass system. Liu et al. (1996, 2001) believed that the weak intercalated layers control the stability of bedding slope, and to study the creep behavior of the weak layers would enormously contribute to the investigation of slope failure[6,7]. Li et al. (2013, 2014) proposed that rainfall infiltration could severely affect the stability of unsupported bedding slope with weak layers, and apparent intercalated sliding would occur under the continuous light raining condition [8,9]. Shu et al. (2012) investigated the stability of bedding rock slope under hydraulic pressure [10]. Cheng et al. (2011) studied the effect of the weak layers' dip angle on the stability of bedding rock slopes, and concluded that bedding rock slope failure is most likely to occur when the dip angle of the layer ranges between10° and 25°[11].

In northern Shanxi, the metamorphic rocks belonging to an early era, mainly gneiss and schist with complex component and structure are widely distributed. Affected by Yanshan movement, rock mass integrity is compromised, causing some adverse impacts on the engineering built on the rock mass, e.g., landslide may occur during the construction stage. This paper presents a comprehensive mechanism analysis for a bedding slope sliding occurred in No.5 slope of Wutai to Yuxian expressway in Shanxi. In particular, the effect of the weak layer composed of Precambrian gneiss and mica schist on the slope stability is thoroughly analyzed. And then, corresponding countermeasures are put forward to deal with the slope failure.

Landslide Overview

Topography, meteorology and hydrology. The coordinate of the No.5 slope is about E113º25'40 ", N38º28'20", and the western slope of the terrain is pertaining to the Taihang Mountains which direction is near SN and local elevation is about 600m~1000m. In the view of the regional landscape, low mountains are formed by tectonic erosion, vegetation, shrubs and bushed is not developed in micro-topography of the slopes and gullies.

Climate of the No.5 Slope district is temperate continental monsoon climate, four distinct seasons, with an average annual rainfall of 500mm ~ 618mm, and rainfall concentrated in July to September.

Formation Lithology. The formation is Archean strata on Longhua River Group Huili formation (Ar3h) in amphibolite facies, with regional metamorphic foliation , eye-like structure and mylonitic schist structure being locally constructed. Lithology in the landslide zone is mainly gneiss, amphibolite rock, mica schist, diabase. Gneiss, mica schist, amphibolite plagioclase, and diabase are important parts of the sliding body and the first two is the most important factor for sliding.

The sliding surface including light-gray gneiss, Seyan spherical gneiss, mylonitic gneiss, thick-bedded m igmatized gneiss, mylonite rocks of amphibolite gneiss. Tectonic development of mylonitic rock damaged the integrity, reduced the rock strength greatly, andincreased its anisotropic mechanical properties. Mica schist is an important part of the sliding surface. Mica schist landslide include phyllitic mica schist, amphibolite mica schist, mica schist. These rock strengthsare weak,and there are some obvious differences in their weathering resistance, mechanical strength, mechanical properties and permeability anisotropy.

Geological settings. The No.5 slope of six section of Wumeng highway is located at a giant slope which belongs to ductile shear zone on the N-S extension [12,13]. Medium metamorphic rock and gneiss are the two main lithology of the slope, which has been experienced a destructive effect on the structure, with interlaminar shear damage playing a relatively big role.

The rock formation in this area is old, experienced multiphase and different nature tectonic movements and inherited the old and the new structural plane. The rock integrity is not good because of mylonitization, eye-like structure and foliation, schistosity development. The area gneissosity occurrence of 225,260$\angle$23 ~ 30, gneissosity tendencies and inclination have some change. Fig.1 shows the study area's the major strike of tectonic joints and small-scale faults is NE ~ NEE, with NW minor (the slope's strike is EW nearly).

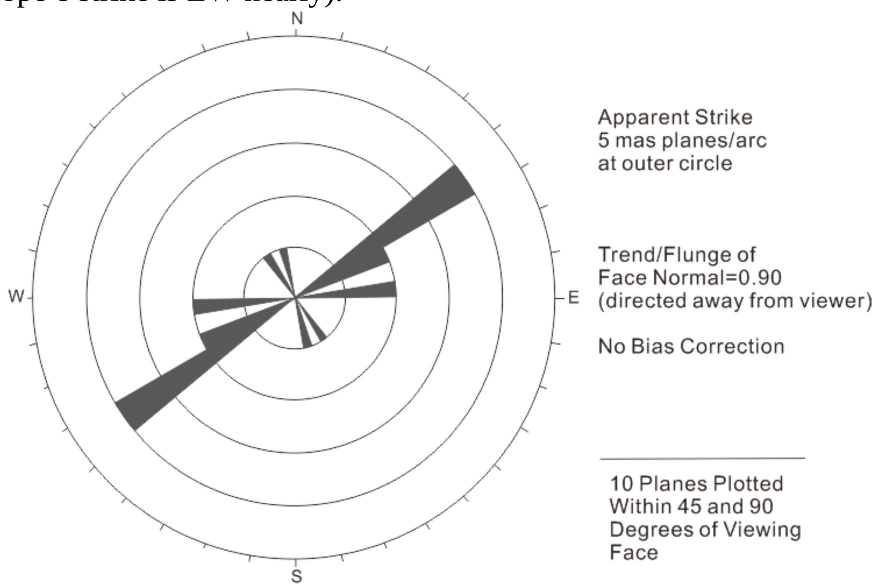

Fig.1 Rose diagram of joints and small-scale faults strike

Characteristics of No.5 Slope failure in Wutai-Yuxian

No.5 Slope in Wutai-Yuxian highway is located at about 250m northeast of Chunshudi, Yuxian. The embankment's left side is a high seven-step slope with 285m length (K23 + 375 ~ K23 + 660), maximum height 51.4m, direction 275 °, and the dip angle 38 °. The lowest level retaining wall' slope ratio is 1: 0.75 and the second and above level anchor retaining frame's slope ratio is 1: 1.25, with each 2m wide platform every 8m level.

These are small-scale collapse at K23+375-K23+431 in August 16, 2011. And the IV level slope is collapsed at K23+431~K23+500 in August 28. There appears a transcontinental road tank cracks at K23 + 431 in September 9, 2011. At K23 + 530 ~ K23 + 630, the embankment's left appeared to slip nd become a mass slide on September 18 the entire sliding Slope.

Fig.2 shows that there is a lateral side of the main slider sliding. This typical bedding slope's main sliding direction is 265º, and the sliding surface angle is 26º. The leading edge of its width is 300m, with the spindle 280m long, total area of 42 000 m^2, landslide thickness 5m~15m, average thickness of 11m, and a total volume of 460 $000m^3$.

Fig.2 The failure site of No.5 Slope (April, 2012)

No.5 slope's main slide direction is in the same direction with slope aspect. The leading edge of the slope has drumlin and radial tension cracks. Layered rock mass structure No.5 slope belong layered structure (type) of the same to the structure (subclass), slope failure types belong mansard destroyed, landslides after the formation of slope failure is a large middle bedding Slow Trailed rock landslide.

Landslide Mechanism

Natural causes

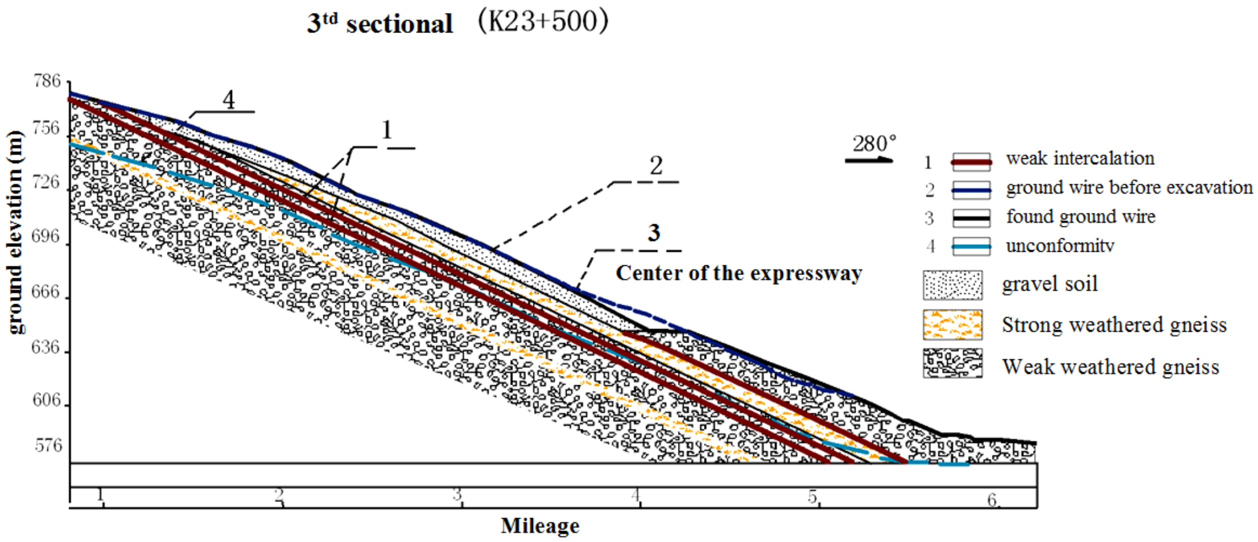

Fig.3 Engineering geological map of the central cross section of No.5 Slope

The existence of adverse potential weak slip control surface. Through field geological survey and engineering geological survey, an appearance was found that the presence of the upper part of the No.5 slope along the gneiss and amphibolite sandwiched in the thickness range and lenticular, continuity bad mica schist. In multi-stage tectonic movement, mica schist shear dislocation occurs; further evolved over time clay intercalation, constitute weak interlayer. Fig.3 shows that weak interlayer angle is 25 ° ~ 26º, slope angle 38º (1: 1.25), within the shear sliding surface friction angle 23º. And internal friction angle of inclination is less than weak interlayer, which is the effect factor for such relatively poor slope stability. Although no large-scale steep fracture, several weak interlayers become main component factors about controlling landslide occurrence, the deformation of slope failure.

Heavy rainfall in construction period. Rainfall infiltration of slope causing unsaturated zone substances' matric suction to decrease, and soil shear strength also to decrease, leading to failure. No.5 slope's failure time is between August and September, 2011, the rainy season in one year with seven steps slope's excavation. Yuxian district level higher than the same period of the rainy season precipitation, daily precipitation and slope failure time peak time substantially corresponds to the same. This is more prominent in July and September. For instance, only in early and middle September, the precipitation is 73mm higher the corresponding period. A large area of slumping occurs when the slope excavation to the second level in September 18, 2011, with the large-scale excavation exposed. In one word, the factors, intense rainfall, a lot of rain infiltration of slope and weak interlayer water softening, should be important natural causes landslides of the No.5 Slope.

Human Factors

Engineering Geological Survey physical workload, representative exploration hole location, core identification accuracy, complete and detailed geological catalogs, as well as a comprehensive analysis of complex engineering geological conditions and the level of awareness, all affect the depth of engineering and geological survey report complete evaluation of geologic conditions.

Table 1.Correspondence between the rock uniaxial compressive strength of saturated (R_C) and qualitative division of rock hardness[14]

R_C (MPa)	>60	60~30	30~15	15~5	<5
strength	hard rock	rather hard rock	rather soft-rock	soft-rock	extremely soft rock

The shear strength of the rock by engineering survey and detailed design report in Wutai-Yuxian expressway as c=12MPa and φ=40º, according to this data rock's unconfined compressive strength approximately is 67MPa. This belongs to hard rock(refer with: Tabel 1). Correspondence between the rock hardness of rock saturation (R_C) of the uniaxial compressive strength and qualitative division between Table 1. The point load test to get rock's compressive strength in situ is carried out in the April 23, 2012 and the test date is shown in Table 2.

Table 2.The point load test results table of the bid section 6 of No.5 Slope

Lithology	Compressive Strength (MPa)	Remarks
light gray gneiss	65.25	belongs to hard rock
mica schist	5.00	Belongs to extremely soft rock. Hydraulic pressure gauge pointer does not move substantially only mylonitic biotite hornblende schist strength slightly higher
amphibolite	37.12	belongs to rather hard rock

The conversion between the point load strength index $I_{S(50)}$ and rock saturated uniaxial compressive strength is as Eq.1 shown

$$R_c = 22.82 I_{S(50)}^{0.75} \tag{1}$$

An acquaintance was get from mechanical parameters based on comparative analysis that, hard core block interior mechanical experiments can not represent low mechanical parameters of weak interlayer.

The partial slide was began after July 2,2011, and large-scale landslide was occurred until September 18, 2011. The interval of the two time is more than two months. But during the site construction design track, you can change the design does not put forward initiatives to modify the design and targeted missed a valuable opportunity reinforcement. Site construction did not follow the specifications and design requirements for timely support facilities, measures the intensity of construction during the rainy season waterproof and timely support is not enough, increased infiltration along the crack to the objective of the slope body infiltration, reduces interlayer shear strength in different depths. And, slope deformation and failure process monitoring data has not been provided. Above human factors, though being not a major factor leading to slope instability, to some extent induce and accelerate the landslide occurred

Treatment scheme

Considering the thorough mechanism analysis above and the idea of water control first, the treatment scheme for slope failure is proposed as follows:

The existence of the weak intercalated layer in No.5 slope is a threat to the slope stability because the weak layer is potential sliding surface. Loose soil and severely weathered rock mass are found widely distributed above the layer. As a result, to install anchorage cable in the rock and soil above the layer is apparently inapplicable. We suggest cutting slope first, that is, removing the surface loose soil and weathered rock mass.

Enhancing the drainage system, i.e., constructing the surface draining channel, annular intercepting ditch, so as to reduce the rainfall infiltration, which could trigger or accelerate the sliding process.

It was noticed that the landslide hazard at No.5 slope has delayed the construction of expressway, formed a potential safety hazard to the expressway operation, and threatened the life and property safety of local residents. And therefore, a swift and reliable real-time monitoring using multiple monitoring instruments on the slope deformation is essential for not only the construction safety of the expressway, but also the subsequent operation safety.

Conclusion

Causes of the landslide hazard occurring at No.5 slope of Wutai-Yuxian Expressway fall into two categories: natural conditions and anthropogenic impacts. The former includes the special landform, rock type, geologic structure, the rainfall infiltration, and mainly the existence of weak intercalated layers. The weak layers which are mainly composed of gneiss and mica schist are in fact the root cause of the slope sliding, while the trigger of the sliding is the heavy rainfall during the construction stage. The anthropogenic impacts refer to the insufficient understanding of the complex geology in all the investigating, designing and constructing stage, as well as the lack of swift and effective countermeasures when a primary local instability occurs in the rainy season. The rapid surface excavation and the improper interpretation on the primary sliding failure are responsible for the secondary large sliding failure.

A treatment scheme for dealing with the rock slope failure is proposed, that is, cutting the slope and installing rock bolt, enhancing slope drainage system and conducting real-time monitoring. It was originally observed that No.6 slope, adjacent to No.5 slope, has been reinforced by anchorage cable, but proves ineffective. After the overlying rock mass above the weak intercalated layer were removed and an enhanced drainage system was built, the effectiveness of the anchorage cable was greatly improved. The treating method adopted here proves to be effective and is applicable to similar bedding rock slope with weak intercalated layers. If you follow the “checklist” your paper will conform to the requirements of the publisher and facilitate a problem-free publication process.

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