# Analysis of the deformation and failure mechanism of the Shawozi high rock slope near the Du-Wen highway

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**Abstract:** The Shawozi high rock slope is located near a highway under construction from Dujiangyan to Wenchuan, by the Minjiang River. The terrain is steep, and the largest height of slope up to 250m. The region of interest is sited in the narrow and small crustal block between two branches of the Mao-Wen fracture zone. Random illegal blasting in mining tunnels at the toe of slope has caused the rock mass to loosen and as a consequence has produced a series of collapses and tension fractures. The construction and operation of the highway has been directly affected and as a consequence this study on the deformation and failure mechanism of the slope is required to assess the slope protection.

In this paper the engineering geology environmental conditions; hydro-geological conditions; structure characteristics of the rock mass and soil mass; the deformation and failure characteristics of the slope are analyzed; and the deformation and failure pattern and the geological mechanics model are established. Through the analysis of the physical mechanical parameters and numerical simulation the influence factors, mechanism and evolution rules of the slope are summarized. Based on the analysis, the author presents recommendations of protective measures to the slope.

**Résumé:** La haute pente de roche de Shawozi localise sur la route nouvellement construite du Dujiangan au Wenchuan, au rive droit du fleuve Minjian. Le terrain est la pente abrupte, la pente est légère en haut et abrupte en bas. La hauteur de la pente maximum est de 250m. La zone de recherche se trouve sur un pétiti terrain entre deux branches des failles qui donnent sur le sud et sur le nord du failleux de Maowen. Le stratum global se développe au long du fleuve et s'appuyant sur la montagne. Le joint de fracture, la roche sont parfaits. Il est une structure de bloc ou entre la fragmentation et le chatonnment. L'effet géologique et physique est remarquable. La manifestation principale est la roche déchargée et la déformation de stradum et de fracture de traction. Il y a vingtaine trous de l'exploitation minière inregulière au pied de la pente, qui sont divisés une distance de dénivellation de 30m. A cause mise à feu à l'aise au cours de l'exploitation, La roche dans la pente est branle. Il y a l'effondrement et la fissure de traction partout dans la pente. Une foi la pente se déforme. Il influence directement la construction de route et l'opération de service. Etudier la déformation de sabotage de la pente a l'effet important pour protéger la pente.

Ce texte a analysé la condition d'environnement géologique des travaux, la condition de l'hydrau-géologique, la caractère de structure de la roche et de la roche argileuse, la déformation de sabotage de la pente. On a crée le mode de déformation de sabotage et la maquette géomécanique. Ensuite, selon l'analyse de paramètre de la physico-mécanique et l'étude de simulation numérique dans la salle, on a fait le bilan de la modèle de déformation de sabotage de la pente, le facteur de l'influence, le mécanisme et le règle d'évolution. Sur cette base, on a recommendé la mesure de protection de la pente.

**Keywords:** highways, deformation, excavations, landslides, slope stability, mechanism

## ENGINEERING GEOLOGICAL CONDITIONS IN THE RESEARCH AREA

### *Geological background*

The research area is located in the narrow and small crustal block between two branches of the Mao-Wen fracture zone, Motuo-Shilipu anticlinorium's northwest at the northwest edge of middle section of the fault and the back of the Longmenshan fracture zone. Mao-Wen fracture, closely related to the engineering, is 60~100m wide in the north branch of main fracture zone, 100~200m wide in effect zone, with general occurrences of N40°~80°E/NW∠60°~80. The fault rupture zone is composed of phyllite rocks, cataclastic rocks, lenticular fault gouges and quartz ribbons or blocks. The fault, about 0.4~0.7km away from the Shawozi high rock slope, extrudes compactly, with rupture on both sides of the fault. The exposed stratum consists of limestone interbedded phyllite rocks or phyllite rocks interbedded limestone of Yuelizai Group upside of Devonian ($D_y l^2$) as well as rockfall deposit and loose accumulation of Quaternary(see Figure 1.). The seismic intensity is VIII degree. Generally, the bedrock aquifer is not too fractured for two resaons; the weather is dry, so the average evaporation is much more than the average precipitation and due to the deeper incised valley and larger surface slope degree, the precipitation rapidly changes into surface runoff, which is adverse to recharge and accumulation of ground water.

**Figure 1.** The photo of shawozi high rock slope

## ***Structural characteristics of slope rock mass***

The exposed stratum consists of limestone interbedded phyllite rocks or phyllite rocks interbedded limestone of Yuelizai Group upside of Devonian($D_yl^2$), including talc mine, medium ~ crazing and monoclinic stratum with rock layer occurrence of N40°~80°E/NW∠60°~80 and inner slope trending. Limestone is dense, firmer, fragile and the landform always develops girder or steep slopes. Phyllite is soft and tends to develop to wind-erosion caves, with mild slopes or negative grooves mostly developed in the phyllite centralized segment. The geological structural cross-section is shown in Figure2. As a whole, it is an inter-related hard and soft rock structure.

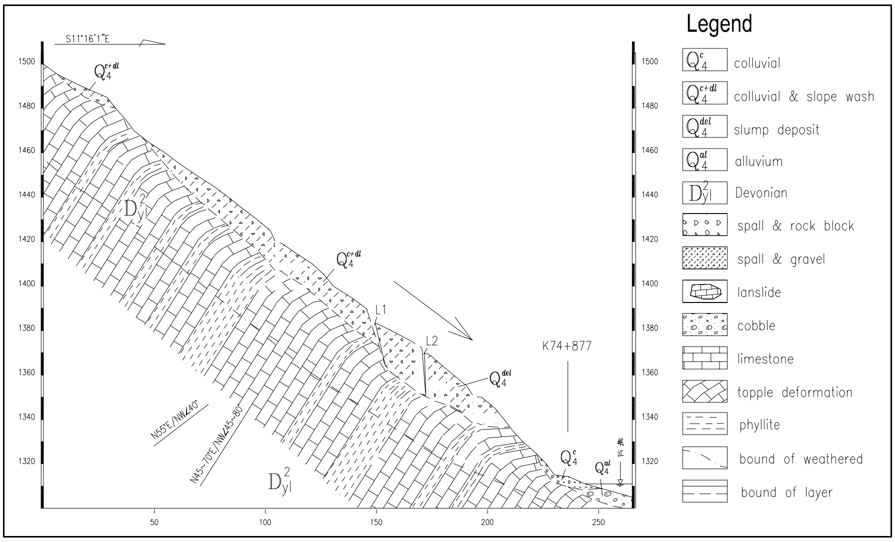


**Figure 2.** The measured section plan of geology of the high slope at Shawozi

According to the different proportions of hard and soft rock, the terrain of rock slope can be divided into seven rock groups from lower to upper: i) medium-metamorphic limestone, marble haphazard interbedded thin phyllite, ii) phyllite rocks interbedded thin limestone, iii) limestone interbedded phyllite rocks, iv) phyllite, v) limestone interbedded phyllite rocks, vi) phyllite rocks interbedded thin limestone, vii) limestone interbedded phyllite rocks. The terrane goes along the river and inner hill trending as a whole. By the influences of rock-fall of Maowen, the interlayer shearing-dislocation belt and NE-trending small fracture develop relatively. The interlayer dislocation belt generally developing in phyllite rock is 0.5~1.5m wide, composed of schist, cataclasite, lens shape clay gouge, quartz vein etc. and generally extruded tightly. The superior fracture groups are: (1) N40°~75°W/SW∠60°~85°; (2) N50°~80°E/SE∠65°~75°; (3) N45°E/SE∠30°~40°; (4) N15°W/NE∠70° with flat and long extended surface. Cut by cranny, the rock mass shows lack of integrity and appears massive or with a crazing studded structure.

The rock mass unloading, tensile crack and rock stratum tipping deformation are obvious. Revealed by PD1# adit of Sanping power plant, the strong unloading level of rockbed is 65m deep. In the strong unloading belts, fractures generally stretch 0.2~1cm, and individuals can get to 10~20cm. On the phyllite rocks interbedded limestone section; there are great tipping deformations of shallow rock masses, the level of which is greater than 40m in depth. The fractures in the cave mainly include:

(1) N55°~70°E/NW∠45°~60° (stratification plane);
(2) N50°~70°W/SW∠40°~60°;
(3) N50°~65°E/SE∠40°~50°;
(4) N50°~80°W/SW∠20°;
(5) N70°~80°E/SE∠70°~80°;
(6) N55°~70°W/SW∠80°, with flat and long extended surface.

Among which there are several developed compressive fracture zone and NW trending small along-slope fault, with width generally less than 1m. They are composed of mylonite, cataclasite, lens shape clay gouge etc and generally extruded tightly. In the unloading belts, the structure of rock masses is slack and always appears crazing~studded. In addition, affected by the fracture cutting and bank slope unloading, the shallow rock masses slack and rupture and the rock tipping deformation is intense. Beyond 65m deep of hole, the unloading of rock masses is weak, and rock masses are of relatively high integrity.

## BASIC CHARACTERISTICS OF ROCK SLOPE DEFORMATION

It is known by field surveys that there is a medium 1·landslide mass in the high rock slope, with obvious deformation and failure characteristics. The landslide body forms a asymmetrically negative "V" style on the surface, and an anisomerous dustpan in space. L1 tensile crack develops along the obvious right boundary of the landslide. The direction is across almost whole the right side of the landslide with N15~20°E trending. The upper of the fracture is widely open, with about 0.5~1.5m in width, about 3~5m in vertical displacement. While the lower is gradually narrow, with the minimum width about 1~5cm, and the displacement is small relatively, about 3~5cm. Because most accumulations, in the middle and on left of the landslide, slip down to the valley and are taken away by Ming River, there are limestone and phyllite rocks of the two sections of Yuezai Group ($Dyl^2$) appearing cataclastic structure shown on the slope.. Current accumulations mostly distribute on the left of the landslide, so the left boundary is not clear. But the one towards 135°trending can be judged by the escarpment on the left of landslide and part of the residual accumulations on the left of sliding-bed (see Figure1). The fracture on the landslide develops relatively. So far there have been 5 larger fractures developing on the landslide, among which the formation of fractures L1, L2, L3 is earlier (see Fig.1.), and L4, L5 are the fractures newly induced in the cutting slope of front landslide during the former period of construction, when the new deformation and damage will produce by original accumulations of landslide caused by the cutting slope of front landslide. It will not only make the new fractures appear, but also expand the original fracture. Specifically, in the path of the middle of L1 fraction, the displacement will expand into 1m±, and the aperture and displacement of L2 fraction have a bit expansion. As a whole, the landslide front edge appears to be under compressive deformation and meanwhile slipping outside the slope. The current deformation is relatively small. Tension- extension deformation is mainly happening in the middle and back of the landslide, with relatively higher deformation, of about 3~5m.

## THE FAILURE AND DEFORMATION MECHANISM OF SLOPE AND ANALYSIS ON ITS DEVELOPMENT TENDENCY

It is known from the analysis and research above that, The Shawozi high rock slope is a kind of inter related hard and soft structure consists of medium~thick-layered marbles, medium~thick-layered limestone, limestone interbedded thin phyllite rocks and thin phyllite rocks interbedded medium~thick-layered limestone.. Its deformation and failure models are mainly in compressing- bending-dislocating pattern which can finally evolve into landslides by the effects of exterior conditions. The process of deformation and failure can be divided into several phases as shown in Figure3.

- By the influence of Mao-Wen fracture, the crack in slope rock mass, interlayer shearing-dislocation belt and NE-trending fracture develop relatively, cracks are cut and the integrity of the rock mass is worse. During the process of long geological history, the gorge down cutting forms a high and steep slope, and the slope surface rock mass releases and rebounds to form release fracture or make the original fracture slake.
- Weak layers at the slope toe are compressed and extruded outside under the action of high ground stress and lead to a shear stress effecting on the interface. More over the direction of maximum principle stress near the slope toe is parallel with the slope surface and the minimum principle stress direction is nearly vertical to slope surface. Fractures occur in the relatively rigid limestone (see Figure3b.), so the rock mass of the upper slope mass deforms under the effect of gravity. Meanwhile, due to the excavation engineering in mining at the mining hole of slope toe, the blasting shock makes the upper rock mass further slake and the collapse or shrinkage of the hole aggravate the deformation of upper rock mass. The upper rock mass suffers from not only the flexure-tension fraction distortion, but also partly failures by shear stress and forms a crack surface slipping outside the slope.
- With the further aggravation of deformation, the stratum is broken and crushed. Due to the thin and soft phyllite stratum, the angle of bend and deformation may be large. The largest bend slope-break zone is easy to form a continuous tension crack surface slipping outside the slope. In the stratum, the original fracture in perpendicular direction turns to the slope outside which together with the fracture in the slope of limestone can form a run-through failure face. The continuous deformation of the slope controlled by the failure face

slipping outside the slope, will change into slipping (or creeping)-ripping deformation. Under the condition of ground water, the deformation speed will increase and finally evolve into slope.

- When slope toes suffer from the scour and erosion by Ming River or the lower surface appears on the slope surface by artificial slope cutting and excavating, the slope deformation will be accelerated to evolve into slope.

It is known from the field surveys and current data, the 1# slope mass on the slope is basically stable under the natural conditions. When the slope toe is excavated or the hole is blasted, the slope mass may creep and deform. Without any protective measures, the slopes mass is likely to lose stability.

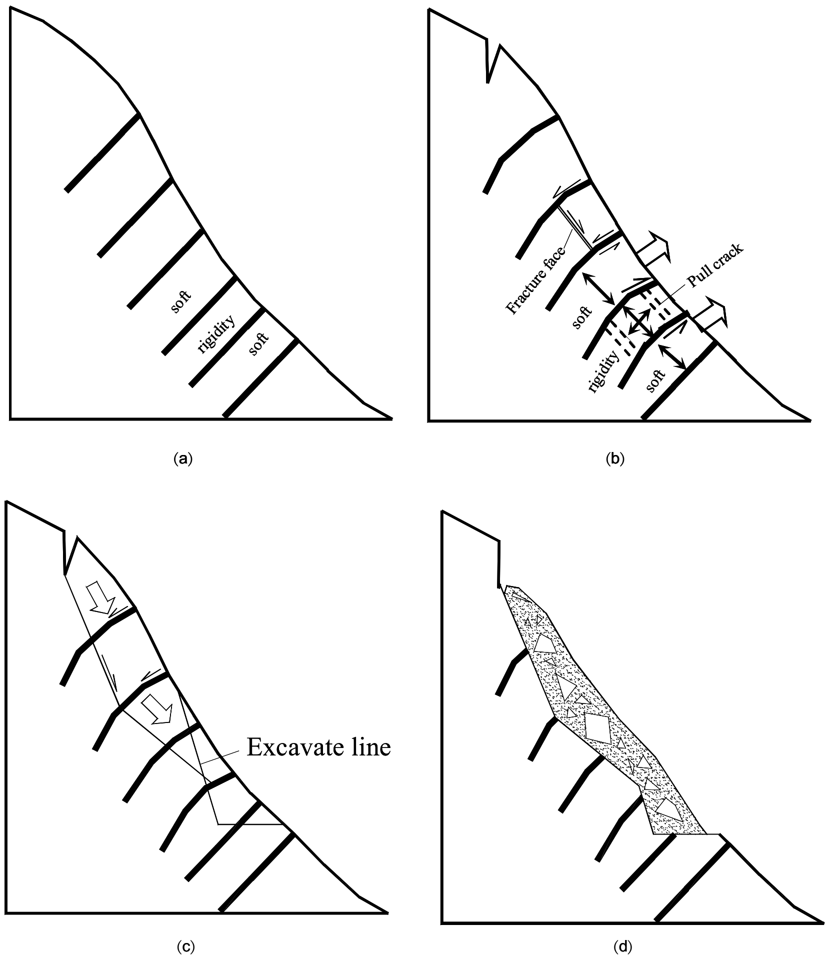


**Figure 3.** The trend of evolution of deformation of the high slope at Shawozi

## A FLAC-3D SIMULATING ANALYSIS ON SHAWOZI HIGH ROCK SLOPE

In order to further analysis the deformation and failure mechanism of the Shaowozi high rock slope, we selected Three-Dimensional Fast Lagrangian Analysis of Continua (Flac-3D)which was suitable for geotechnical stress –strain analysis to numeric simulating analyze the slope. The elastoplastic model of Mohr-Coulomb yield condition was adopted to calculate which was divided into four phases: i.e. natural condition phase, excavation engineering in mining hole phase, highway cutting slope phase and the phase of stabilizing pile used in reinforcing the earth wall. The analysis results are as following:

- Under the initial conditions of the Shawozi high rock slope, the shear stress on landslide mass in XY direction negative value, about 0.082MPa; and positive value on accumulations mass in YZ direction. When around the landslide, the value is bigger, about 0.078 MPa and the maximum can reach to 0.151MPa, but the value in other parts of the landslide is smaller than that which indicates the tendency of its down movement. The integrated displacement in the back of the landslide is larger, with 86.0cm, and gradually decreases when it moves forward. So, Shawozi high rock slope tends to slip down, but stable in a whole.
- Mining the lower landslide mass, after excavating, the shear stress in the XY, YZ, XZ directions all increases to some extent. Although the value is not too high, generally about 0.03~0.05MPa, the shear will cause a certain threaten to the stability of the slope and even lead the whole landslide mass to loss stability.
- After the construction of cutting slope on the highway, the shear stress in the landslide decreases by 0.3~0.4 MPa than one under the natural condition in XY direction; in YZ direction, it increases 0.008 MPa than one

under the natural condition; in XZ direction, the shear stress on the bottom of the back of the landslide concentrates locally, with the maximum of 0.037MPa which increases by 0.018 MPa than one under the natural condition. An additional displacement concentration phenomenon appears at the intersection of landslide mass toe and cutting slope (Figure 4~Figure 6), with the maximum values of 3cm, 8cm, and 1cm respectively. It is indicated that, after cutting on the slope, the shear stress in the landslide mass tends to decrease in XY direction, but the shear stress of landslide is concentrated locally and the displacement variation is relatively centralized, thus, the stability of the slope is greatly influenced and reinforcing the earth wall at the slope toe should be given priority consideration during the construction process.

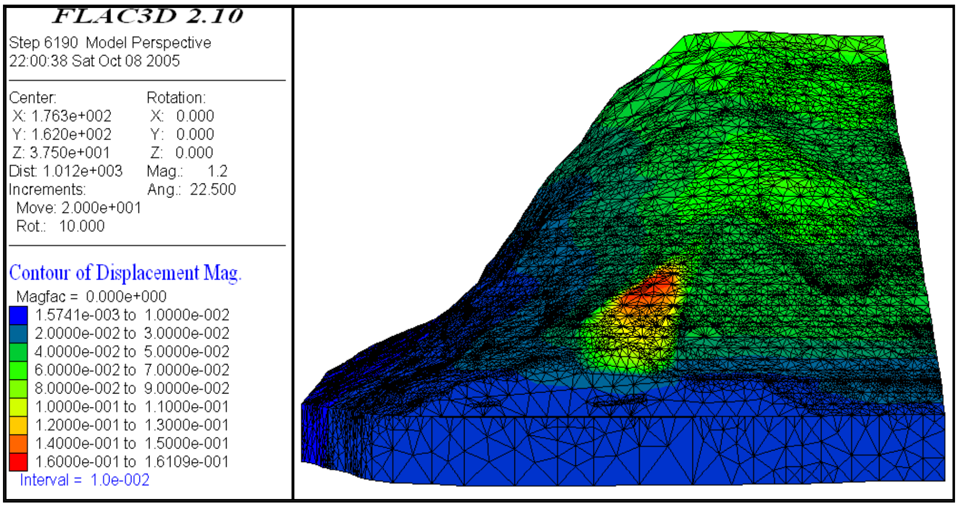


**Figure 4.** The whole deformation character after cutting slope

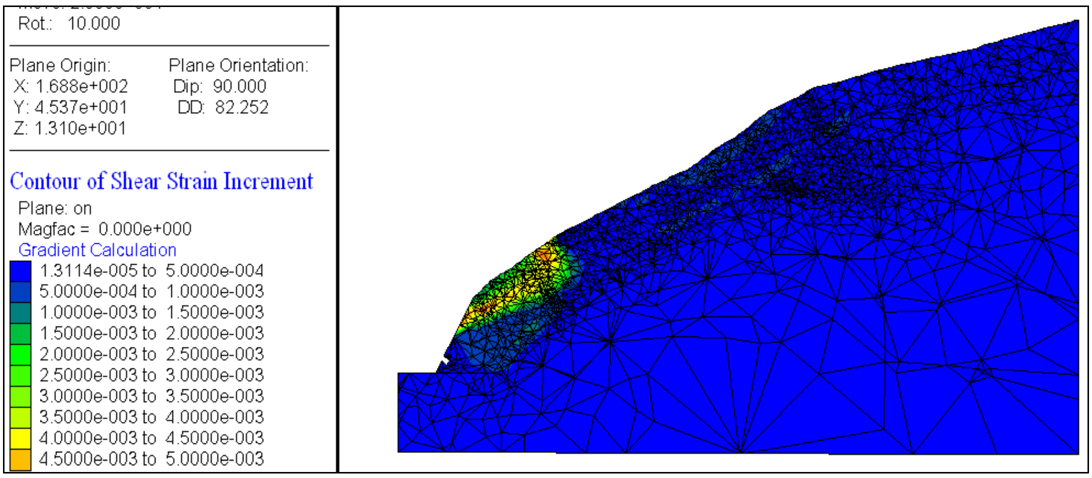


**Figure 5.** The strain increment character of landslide vertical section after cutting slope

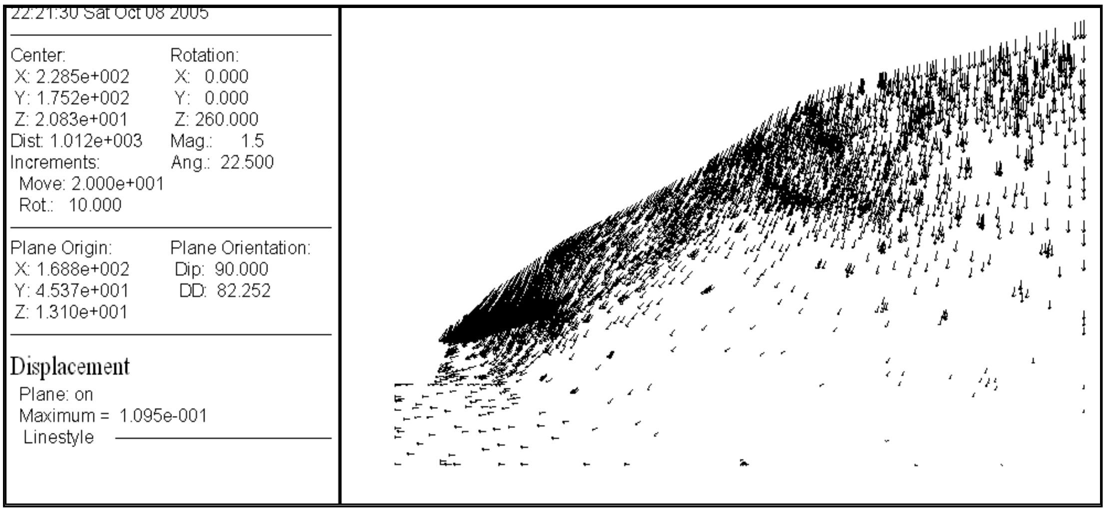


**Figure 6.** The deformation vector character of landslide vertical section after cutting slope

- When prestressed anchor cable applied, anchored piles have less effects on the values of minimum and maximum principle stress of inner part of $1^{\#}$ landslide, but more influences to distribution characteristics. The minimum principle is concentrated at the anchorage terminal, but mainly located in lower part of fresh rock mass. The total effect is to support the slope, by diffusing the concentrated shear stress, near the surface of landslide. The supporting engineering controls the deformation more greatly than the condition before supporting. According to the tracing curve of the front, middle and back of the landslide, anchored piles supporting engineering has a great effect on supporting no matter to displacement or plastic failure of rock mass. So the displacement decreases greatly, with maximum on the top of pile, about 3~4cm., while the area of plastic failure of rock mass decreases greatly too and can not form a run-through failure area.

## SUGGESTIONS FOR RENOVATION PLAN

Based on the research of engineering geology environmental conditions of the Shawozi high rock slop, the analysis of the failure mechanism and evolution tendency of the slope and the stability analysis of $1^{\#}$ landslide, the recommendations of protective measures were proposed as following:

- Considering the effect on Sanping power station engineering and financial considerations, avoidance of the geological hazards on the section by tunnelling or channel rehabilitation is not possible, with prevention and treatment being the only options for the Shawozi high rock slope.
- Due to the extreme effect on slope stability caused by nonstandard mine exploitation, all such activities should stop immediately and current mining refilled with concrete
- Scale the unstable blocks in the upper slope mass, supplemented by additional targeted spot bolting for larger blocks
- In the back of high rock slope on K74+770~K75+18, water-resistant drainage channel should be installed.
- Slope masses in the upper $1^{\bullet}$landslide and the weathering rupture rock masses on the sliding-bed surface have partly already been cleaned, but slope masses and rupture rock in the lower landslide are not suitable to excavate up. Because the cutting slope and excavation at the slope toe will accelerate the deformation of accumulations of upper landslide, meanwhile, the upper bending and deforming rock masses may further deform and then evolve into new landslide mass. In order to prevent and treat the deformation of $1^{\bullet}$ landslide mass and rock bed with lower part intensively deformation, the author recommended to set a prestressed anchor cable on the section K74+790~K74+900 of slope toe, or adopt stabilizing pile used in reinforcing the earth wall.
- For key positions with elevation greater than 1340m, wire mesh spray anchorage is adopted to support or SNS active network is applied to protection, among which the length of structure bolt can extent to 6~8m. As for K74+900~K75+180 section, with 1340m high, there is no need for slope mass to consider temporarily the protective measures.
- The author recommends establishing a surface and sub-surface displacement monitoring plan near the $1^{\#}$landslide section and posterior edge upwards.

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