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Health Monitoring and Analysis on Deep Consequent High Rock Slope

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ABSTRACT

The sliding surface of deep consequent high rock slope located under the free face is apparently differs from soil slid slope, which is a special case of rock slope. There is a shear opening at the bottom of the landslide slope and the sliding surface is not a single linear one. The soil of the sliding surface has the nature of single properties and large thickness. And the anti-sliding segment is apparent. This paper, taking a deep consequent high rock slope of LanYong high way as background. The anchor stress and surface of slope displacement during the process and end of slope supporting are monitored by the monitoring test. Since the end of the slope support: maximum displacement speed is 0.17mm/d < 0.5mm/d, maximum displacement accumulated variation is less than 10mm. The monitoring results indicated prestressing anchor lattice beam retaining structure conducts obvious effect on the complex high rock slope. The test has certain reference value for the reinforcement design and monitoring analysis of similar high rock slope in the future.

Keywords: deep consequent high rock slope; prestressed anchor cable; anchor; stress; health monitoring

1. INTRODUCTION

With the implementation of the national western development strategy, a variety of road traffic construction projects are developing rapidly, such as highway engineering, railway engineering, bridge engineering and so on. There are many different sizes of cutting slope appeared in front of builders, and the unstable sliding of deep consequent rock slope has become the common problem(Feng Jun etc.2005). The stability study and supporting design of deep consequent high rock slope also become the research object of many scholars(Chen Jing-xi etc.2002).

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Health monitoring has obtained the rapid development in recent years, which is regarded as an important tool to analyze the slope stability and slope engineering. The slope and its supporting structure as a whole of coordinated development, the monitoring of supporting structure is equal to the slope monitoring in a certain extent. Liu Zu-qiang etc (2004)carried out stress monitoring of anchor in some high slope support structures in the Three Gorges Project. Song Xiug-uang etc (2005)carried out stress monitoring of anti-slide pile and anchor cable in a cutting slope support structure. Guo Yong-jian etc (2013) carried out stress monitoring of anchor and lattice beam in high rock slopes located on both sides of a highway. The study results show that these monitoring measures had the better effect for the slope stability in the reinforcement stage and after the slope supporting, and it can help scholars analysis and evaluate the slope stability in the different levels.

This paper depends on a deep consequent high rock slope of LanYong first class highway. A variety of sensors installed on the high slope and the retaining structure are used to monitor the slope stress and displacement, and used to research their change laws. Through researching the reinforcement effect of the prestressed anchor cable lattice beam and anchor lattice beam to the deep consequent high rock slope, it provides a reliable basis of similar slope supporting design and monitoring for future.

2. PROJECT OVERVIEW

LanYong first class highway is east from new town of Lanzhou city, and west to Yongjing County Gucheng village, which total length is about 48.25km. High fill and deep excavation cutting slope distribute along the road. Most of deep excavation cutting slope is high slope, and the maximum height of slope reach to 63.0m.This slope is located in K23+890~K23+975 period of LanYong highway, belonging to deep excavation cutting slope. The roof location of the slope lies between K23+940~K23+950, the height is 36.4m.Because of the effect of topography, rock mass distribution and properties, the slope is a deep consequent high rock slope. Slope field is shown in Fig.1, Fig.2.

Fig.1 before the supporting

Fig.2 after the supporting

2.1 Geological and landform conditions

The geomorphic units of slope area is belong to engineering area of geological tectonic and denudation bedrock. The slope lithology is cretaceous sandstone and mudstone layer. Affected by the tectonic of rock mass, it is broken. It is collapse easily after excavation and the clay rock weathering flake easily. Rock mass with weak swelling, softening, easy to collapse, rock bedding. Strata occurrence is 55°∠15°, which develops two groups of joints, and the occurrence of them are 75°∠82°and 280°∠82°. The structural plane combination is poorer, and it exist inwardness structural plane. Due to the joint development and affected by the tectonic seriously, local fall or falling phenomenon is happened after disturbance by artificial excavation, rain or seismic action. The slope strata and 75°∠82°joint combination has a larger effect on the slope stability.

2.2 Hydrological conditions

The slope field geological investigation and field survey show that groundwater is not seen in the area of slope.

3. SLOPE SUPPORT PROGRAM

The slope height is 36.4m. There is a band four slope after excavation ,and it is belong to deep excavation cutting slope. From the standard, the slope safety grade is first, and there is no attached Load on the top of slope. Due to the sandstone and mudstone layer, it is the special case of consequent rock slope. The mudstone layers are all likely to become weak intercalation.

This slope is reinforced by prestressed anchor-cable lattice beams and anchor lattice beams. First grand ratio of Slope is 1:0.5, and slope height is 10m. The second grade and the third grade ratio of Slope both are 1: 0.75, and slope height both are 8m. The fourth grand ratio of slope is 1:1, and the support height is 8m. Among them, the first grade and the second grade slope are supported by prestressed anchor-cable lattice beam, and the design value of anchor cable prestress is 410KN.The third grade and the fourth grade slope reinforced by anchor lattice beam, and the anchor is full-length grouting. After the design change, the slope of the fourth grade is shaved, and the supporting structure is canceled. Slope supporting design is shown in Fig.3 and Fig.4.

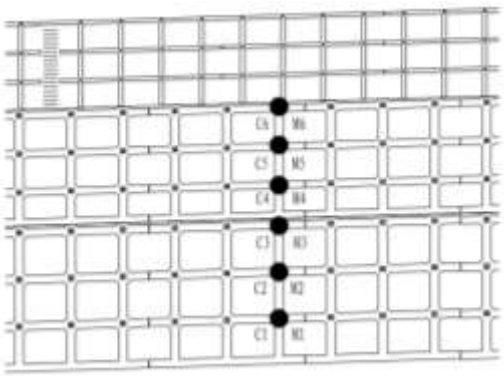

Fig.3 elevation of slope supporting

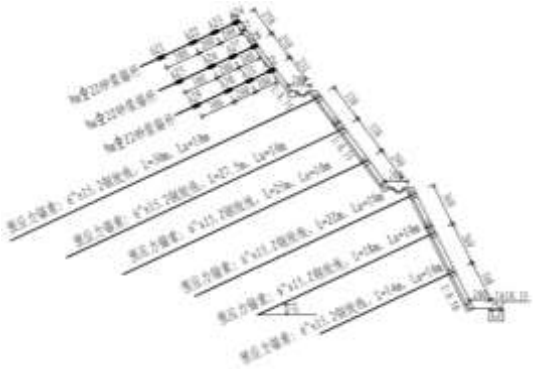

Fig.4 profile of slope supporting

4. MONITORING DESIGN

Combined with the supporting design, a health monitoring scheme is designed for this deep consequent high rock Slope, which is used to monitor the slope itself and the its supporting structure. All instruments are connected to the data acquisition system through the cable conductor. The data acquisition system sent monitor data to the computer by wireless communication module in order to realize the remote automatic monitoring of the slope and its supporting structure.

4.1 Monitoring purpose

Through health monitoring test to the slope, the teat is to master deformation and anchor stress changes of the supporting structure, meanwhile determine the trend of slope deformation and stress. It is possible to send out the warning for slope stability.

Though the monitoring test, the reinforcement mechanism on anchor and anchor cable of the deep consequent high rock slope can be Studied and analyzed. Though analysis the trend of slope supported deformation by the prestressed anchor cable, meanwhile determine the reinforcement effect of the anchor-cable lattice beam to this slope. Due to the monitoring data of anchor, researching the development of internal cracks in the slope

4.2 Project design

According to the slope monitoring principle, combined with the actual situation of the slope, selecting the profile near the top of the slope to design the monitoring scheme:

(1) There are 4 stress meters arranged each one anchor bolt, which used to monitor the anchor stress. The first one is located in the anchor head, and then arranged others along the anchor in turn interval 2m, 2m, 3m. The stress meter is

arranged on the anchor by welding;

(2)Anchor dynamometer is used to monitor the prestress loss and change tendency in the process of stretching and using.

(3)Single point displacement meter is used to monitor the deformation of slope surface displacement and lattice beam.

The installation position of sensor is shown in Fig.3 and Fig.4: A21-A32 for stress meter, M1-M6 for anchor dynamometer, and C1-C6 for single point displacement meter. Sensors and monitoring system are shown in Fig. 5 and Fig. 6.

Fig.5 sensor installation

Fig. 6 data collection box

5. ANALYSIS OF MONITORING DATA

With the whole process of slope supporting, all the sensors are installed. The automatic monitoring began in July 1, 2015, and the data record was beginning from then on. The Sampling frequency of the data is 12 hours. The time interval of data used in the paper is 24 hours.

5.1 Analysis of anchor cable anchorage force

The prestressed design value of the slope is 410kN and the tension is divided into three stages. After the anchor cable tension lock, the lock value decreases sharply by the influence of concrete lattice beam deformation, fracture of rock and soil, anchorage or other factor. With adjustment of the reinforced slope soil stress, anchor cable anchorage force will appear small amplitude fluctuation and then slowly tends to steady state. When the slope appears sliding trend, the anchorage force will rise greatly.

With the monitoring the anchorage force change of the anchor cable locked, there is found that the change of the anchor cable anchorage force is divided into three stages(Meng Xiang-ming 2012).As shown in Fig.7 for anchor cable dynamometer anchor hold variation curve.

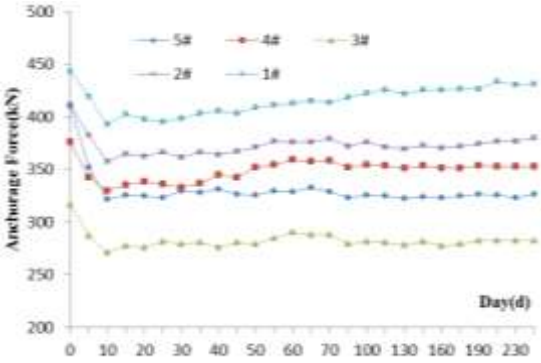

Fig. 7 anchorage force variation curve.

The first stage is the accelerated loss of anchoring force. 10 days after locking anchor cable, anchor anchoring has a most loss. There are a few reasons as followed. The slope has much larger rock mass fractures, which lead to the shrinkage deformation increase in the tension process. Steel strand stress relaxation is a influencing factor of the accelerated loss for anchoring force. In addition, there is a anchor clip obviously loose phenomenon in the process of drawing, which may be lead to the accelerated loss of the anchoring force.

The second is anchoring force fluctuation stage. Slight fluctuations of the cable anchorage force and slowly lifting phenomenon appeared in this stage, and it continuous about 30 days. The slope stress is adjusted constantly by the anchor cable and slope rock impacted with each other.

The third is anchoring force sustained stable stage. It shows that the anchoring force and the slope internal force tend to equilibrium after. At this stage, the adjustment of slope internal force has already come to an end. The anchor is already into the loading stage. It also shows that the anchor cable has a the better reinforcement effect to this slope.

5.2 Analysis of anchor stress

After the anchor cable locked, three root of anchor stress change trend is basically the same along the rod length. This paper only takes the second anchor monitoring data and its variation curve to analyze the stress change trend. Fig.8 shows the anchor stress along the rod length variation curve after supporting by five sets of data. Fig.9 for anchor stress change curve with time after supporting

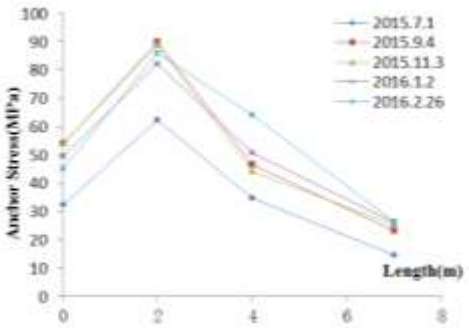

Fig. 8 the curve of anchor stress along the rod length

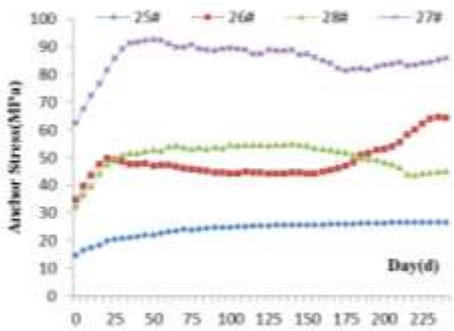

Fig.9 the anchor stress curve with time

The data curve showed that the anchor stress value has always existed in 2M site for the peak stress after supporting, and all the data are showing an overall "bow" change. The stress of each position showed varying degrees of increase at the first 30 days. After then, the stress tends to be stable. The stress which site 4m has a special downward trend. About in December 2015 28th, it appeared significantly increased trend, and then became stable.

The author believes that there is may be exist a dangerous fissures at 2m site because of the slope internal joint development. After the slope supporting and anchor cable locked, slope unloading is started, and the phenomenon of prestressed loss accelerated is appeared. At the moment, there is a larger adjustment of internal force, which leads to the fissures increase and slide rupture. The slope internal force is adjusted constantly results in the anchor stress increase slowly at the first 30 days. The anchor stress change stable with the adjustment of slope internal force is over. At the slope stress adjustment stage, the increase and reduce of slope internal force may be lead the internal fissures growth slowly. It results in the anchor cable be into the loading stage, and the corresponding position anchor stress increase also begin to increase. Thus ,there may be a fissures at 4m site along the rod length. Because of the anchor played a supporting role, the anchor stress of 4m site tended to the flat Steady state. Therefore, prestressed anchor cable lattice beam and anchor lattice beam of the slope have the obvious strengthening effects and anchor and prestressed anchor cable play the better ability to work together.

5.3 Analysis of slope horizontal displacement

Because of the concrete of lattice beam and the slope surface bonding performance is better, the two have a stronger coordinated deformation ability. The lattice beam displacement is also reflect the corresponding position of slope displacement. The single point displacement meter contains a displacement sensor, rod

and anchor head. The anchor head is fixed in the bedrock, and the displacement sensor is fixed on the structure surface. The rod connects the anchor head and sensor. When the anchor head and the displacement sensor have tensile or compression change, the relative slip occurs between the coil in the sensor and the rod. At the time, the sensor obtains the displacement. In the setting of sensor, there is 50mm relative displacement between rod and coil as the initial displacement value. Monitoring results shown in Fig.10 and Fig.11.

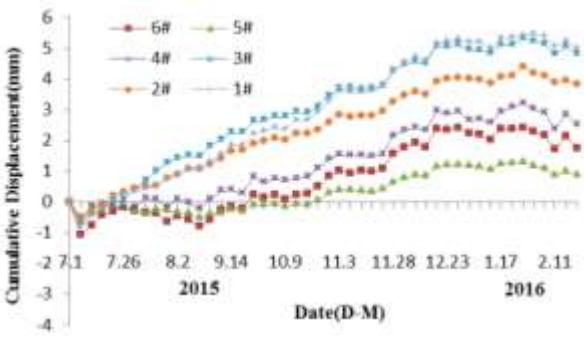

Fig.10 Cumulative displacement curve of slope

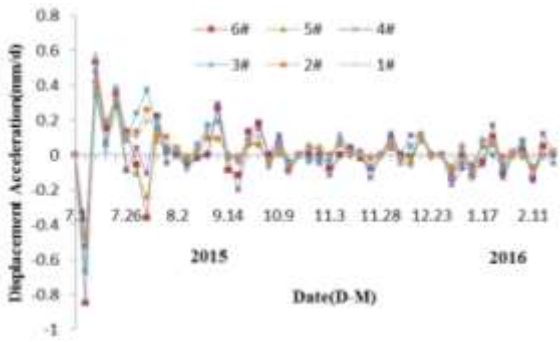

Fig.11 Displacement acceleration curve of slope

Each displacement meter change is basically consistent. In July, the displacement is more obvious. Specially, it has a sharp fluctuation in the first few days, and the change speed is between -0.83~0.57mm/d. This time is in the anchor cable tension stage, the displacement sensor has the deformation in the slope direction during the anchor cable tension process, and the displacement decreases sharply. In a few days after the tension, the displacement increase rapidly because of anchorage force loss larger. About 30 days later, the slope is in the unloading stage, and the displacement is volatility change due to the internal stress adjustment of the slope. In this stage, the change speed is between -0.20~0.57mm/d. After then, the displacement of each monitoring point is basically stable.

Deadline of the end of February, the displacement of 1~6# sensor cumulative change is 5.00mm, 3.85mm, 4.79mm, 2.5mm, 0.87mm and 1.76mm.The maximum displacement change speed after the supporting is 0.17mm/d less than 0.5mm/d, and the maximum cumulative displacement amount of all monitoring points is less than 10mm(Ruan Fei-peng 2007). At the present, the slope is in stable state.

6. CONCLUSIONS

Through the analysis and research on the health monitoring results for the deep consequent high rock slope of LanYong first class highway, the main conclusions are drawn as follows:

(1) After the prestressed anchor cable locked, anchor cable hold variation with the previous research similar: initial acceleration loss, fluctuations in the middle and be stable in the late. But compared to the previous changes, the time of anchor cable anchorage force rebounds ahead, and the time of active load bearing is ahead .

(2) The prestressed anchor cable and anchor of the slope have the obvious strengthening effects, and the two play the better ability to work together. The monitoring result shows that there is may be exist a dangerous fissures at 2m site. But, limited for the current research capacity, its accurate site is set to be further study.

(3)Slope surface displacement impacted by anchor cable anchorage force is larger. The change is significantly in the initial stage and be stable in the late.The maximum displacement change speed after the supporting is 0.17mm/d less than 0.5mm/d, and the maximum cumulative displacement amount of all monitoring points is less than 10mm[10]. At the present, the slope is in stable state.

(4)The health monitoring system can be helpful to master the slope deformation and internal force changes, and help to judge the stability of the slope.

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