A case study on slope instability of Punatshangchhu Hydroelectric Project Authority-I Dam in Bhutan

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Abstract

The stability of the slope is a greater concern to engineers and geoscientists as the socioeconomic consequences of the failures are huge. One such case is the slope instability of right bank of Punatshangchhu Hydroelectric Project Authority (PHPA-I) dam, Bhutan. The main geology of dam site is characterized by coarse-grained quartzo-feldspathic and biotite- muscovite gneiss. Since the start of the project in 2008, project encountered several geotechnical problems. During excavation at dam pit area, the shear zone got day-lighted which triggered a huge movement of right bank of dam in 2013. As such, project authority has carried out various stabilization measures in arresting movement of right abutment of dam. In this paper, subsurface profile construction from boring log data using Rockwork software (Rocscience) for PHPA-I dam site is presented. The subsurface profile once constructed can be used for identifying the critical slip surface and can also be used in modeling for slope stability analysis. Moreover, it can be a database for future use in that part of the study area.

Key words – *Rock slope, shear zone, slope stability, subsurface profile*

Introduction

Geologically, PHPA-I lies within Bhutan Himalayan Tethyan belt which is situated in north of main central thrust. The proposed dam site is located within the Sure Formation (Thimphu Group) of Precambrian age. The main rock consists of high-grade metamorphic rock. The rocks of Thimphu group are characterized generally by quartzo-feldspathic which is coarse-grained and biotite-muscovite gneiss which contains bands of mica schist and quartzite. In the dam site, the bedrock exposed is represented by garnet and K-feldspar bearing para-gneiss with well-developed banding. The Precambrian gneissic rocks are exposed upslope of terrace on left flank and on the right flank and is uncomfortably overlain by thick layer of colluviums or talus. At places rock exhibits tight “S” type folding on right bank and “Z” type of folding on the left bank which indicates mega synclinal structure. The geological map of Bhutan also shows thatthe axis of syncline is passing through the study area slightly upstream of the dam axis. Apartfrom foliation joint, the rock mass has traversed by several joint sets (Gajbhiye & Ghoshal, 2009)

Geotechnical assessment on movement of right abutment

Since the start of project in 2008, first sign of instability of right abutment of PHPA-I occurredin 2011 (NGI, 2017). Excavation work came to a hold in July 2013, when the hill mass of right bank started sliding towards the dam pit. The maximum movement was up to 4 m and crown of the slide extended up to El.1,450 m and the toe of the slide lies between El.1,110 m and 1,090 m, from 150 m upstream to 140 m downstream of dam axis. Due to the movement of slope, opening of joints and cracks were observed with opening between 2 to 40 cm. Uplift offloors and deformed ribs in the grouting gallery (El.1,169m) were first observed as instability sign.

From August 2013 to December 2013 investigations were carried out including drilling of boreholes at different location at 38 locations to an aggregate depth of about 3.7 km. The experts from different organizations tried to find the causative factor of this major displacementand proposed many suggestions but major emphasis was on systematic monitoring andinstrumentation of the whole area. As per the data source, effective monitoring for both surfaceand subsurface was started from January 2015 while the slide occurred in July 2013. Therefore,the data interpretation and co-relation of data faces difficulty.

The stabilization measures were carried out in accordance with technical solutions evolved bythe designers, from above the dam top i.e. El. 1,205 m to El.1,340 m was completed as per schedule well before start of monsoon 2015. Series of preventive measures including grouting,cable anchor, RCC pile of 2 m diameter, micro pile (325 mm) and shotcreting were carried outat various levels and benches.

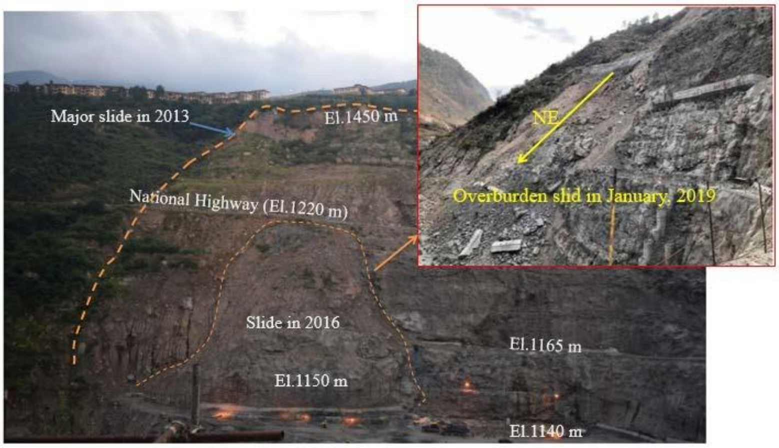

Fig. 1. Slide boundary of right abutment of PHPA-I, Dam

On 12th August 2016, another slip had occurred at right bank downstream of dam axis between National Highway & EL. 1,140 m bench. The excavated cut slope at cable car bench(El.1,260 m) to Dam pit (El.1,082 m) of PHPA-I dam on right abutment shows the presence of medium to course grained, highly jointed Quartzo- Feldspathic Gneiss with thin band of micaschist. The instability in the right bank started due to daylighting of a shear zone in the slope which has dip angle of 30-40 degrees and dip direction of N45E.The size of the unstable area on the slope is under-estimated. Signs of instability and sliding was seen at elevations around El.1,600 m along the axis of the dam.

Methodology

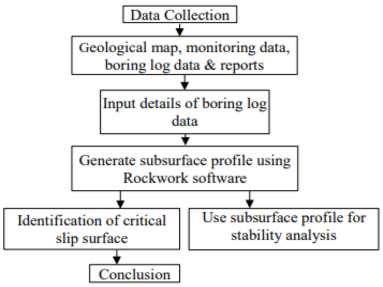

Fig. 2 Flowchart of Study

Subsurface profile construction

For the present study, 41 numbers of geotechnical boring logs data were used. The data were prepared to develop data base for the subsurface profile in order to study the geotechnical conditions of underlaying layer. The depth of drill core ranges from 36.60 m to 194.0 m out ofwhich 3 are inclined at certain angle. The plan of the boreholes along with contour map and fence diagram is shown in Fig. 3 which was generated with the help of Rockwork2016 (Rocscience) software. Both 2D and 3D cross-sections can be generated.

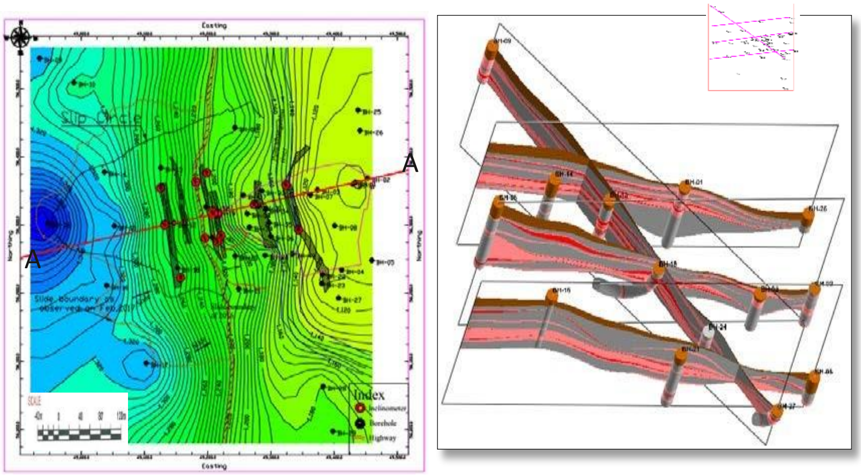

Fig. 3 Layout of boreholes (left) & 3D fence diagram (right)

The general subsurface profile mainly consists of surficial soil of sandy clay with boulder of gneiss (colluvium), quartzo feldsphathic gneiss with biotite, fracture zone with highly weathered zone in places & shear zone consisting crushed rock with clay gouges. The details of the layers are given in Table 1.

Table 1 Main types of rock layers from boring logs

Sl. No. Stratigraphy	Rock Description	Depth Range (m)
Colluvium	Surficial soil & boulder of gneiss (large boulders/rock block set in a sandy to clayey matrix. (colluvium)	0-54.5
Quartzo	Light Greyish to Greyish, Medium Strong to Strong,	
Feldspathic	Slightly weathered, Medium to Coarse Grained,	
Biotite	Well foliated Biotite rich Quartzo feldspathic gneiss	0.7-100
Gneiss	with pegmatite & Garnet intrusion.	
(QBG)	F-20°-30° (Rough Undulating)	
FractureZone	Fracture to highly fractured with highly weathered zoneat places	0.2-28
Shear Zone	Crushed rock, sandy sludge with Clay gouge at places	1.4 - 32.4

The four main layers are repeating at different depth in different location of boring logs. In total 18 layers have been identified for the database construction. The sequence of the layers is QBG-1, fracture-1, shear zone-1, QBG-2, fracture-2, QBG-3, fracture-3, shear zone-2, QBG-4, fracture-4, shear zone-3, QBG-5, fracture-5, shear zone-4, QBG-6, fracture-6 & QBG-7. Fromthe constructed database, 2D and 3D cross-sections can be generated in any direction which is very convenient for the users.

Identification of critical slip surface

The cross-section generated from the Rockwork software is superimposed with the inclinometer readings and boring logs to identify the slip surface as illustrated in Fig. 4. The shear zone and fractured rock layer indicated by boring logs and the shearing plane indicated by the inclinometers conform to each other. The best way to describe the failure mechanism isthat due to the presence of very weak shear zone layer with highly fractured rock mass dipping valleyward resulted in development of progressive failure. In addition, excavation at the toe of dam approximately at El.1,130 m to El.1,140 m led to daylighting of shear zone (Sz1) which caused the movement in July 2013.

Different intensities of fractures are present on this slope and same is represented in cross- section along the dam. The main shear zone (Sz1) dips at an average angle of 26^{o} and Sz2 has average dipping angle of 16^{o} whereas the face slope has average dipping angle of 36^{o} (Fig. 4).Since the upper shear zone got daylighted towards face slope, it satisfies one condition of the planar failure criteria. Another criterion for planar failure mode is, dip angle of face slope should be greater than sliding plane which was also satisfied.

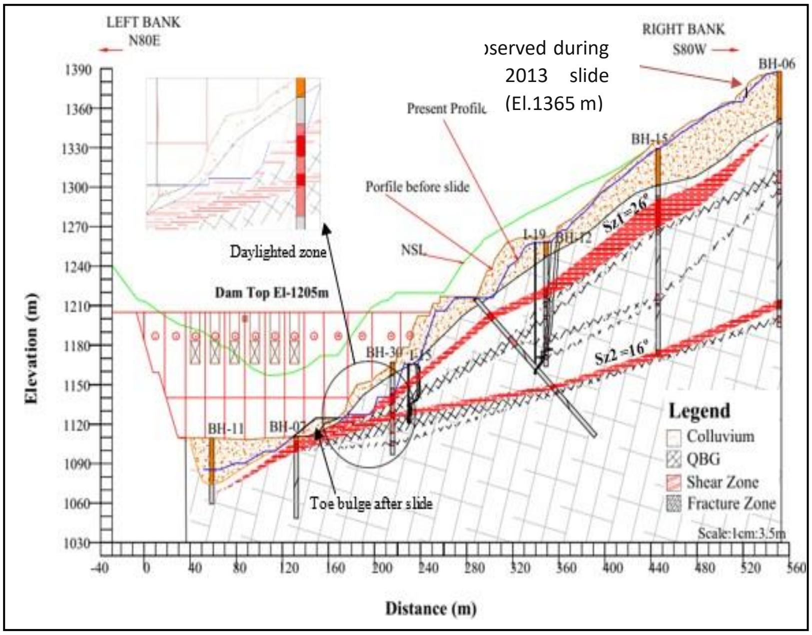

Fig. 4 2D Cross-section along Dam Axis (A-A')

Bulging of toe area as illustrated in Fig. 4 is one of the significant indications of planar failure that occurred during 2013. With all the conditions mentioned above, the mechanism of failure is planar failure along persistent discontinuity which is upper shear zone (Sz1).

Conclusion & Recommendations

PHPA-I has been facing challenges in arresting the slope movement of right bank of the dam, with the major slide happened in 2013. From the geotechnical investigation, rock mass on right bank consists of quartzo feldspathic gneiss with S-type folding & foliations with very thick colluvium (up to 34 m). Different intensities and thickness of shear zone and fractured zones were observed from the subsurface profile, with two prominent shear zones detected along the dam axis. Upper shear zone got daylighted towards face slope with its dip angle greater than sliding plane, thus concluded as planar failure along persistent discontinuity. The subsurface profile once constructed can be used for identifying the critical slip surface, modeling for slope stability analysis and generation of database for future use. Further excavation can be carried out after proper treatment of the shear zones.

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About the author

Ms Rinchen Lhamo did her Bachelors from College of Science & Technology inCivil Engineering in 2010. She then started her professional career as an assistant engineer at Druk Green Power Corporation limited (DGPC). During her tenure as engineer, she was largely involved in looking after the civil capital works and running & maintenance works of Chhukha Hydropower Plant. Before pursuing her masters, she also served at 720 MW Mangdechhu Hydroelectric Project Authority for one year, which was then under construction, on secondment from DGPC. While at MHPA, she was involved in supervision of Underground Powerhouse Complex and Pothead Yard. She completed her Masters of Engineering in Geotechnical & Earth Resource Engineering from Asian Institute of Technology, Thailand (2019). Currently she is working under Centre of Excellence for Civil & Geotechnical Engineering under Hydropower Research & DevelopmentCentre. Her current research interest includes geotechnical investigation & geotechnical instrumentation & monitoring.