GEOTECHNICAL ASSESSMENT OF THE EXCAVATION OF EXPLORATORY DRIFT AT INTEGRATED NYERA AMARI HYDROPOWER PROJECT (I & II)

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Abstract

The integrated Nyera Amari Hydro Power Project - I and Nyera Amari Hydro Power Project-II (442MW) was envisaged one of the projects to be constructed under Power System Master Plan Study. The Project spreads in two districts – Trashigang and Samdrup Jongkhar on the southeastern part of Kingdom of Bhutan.

The underground exploratory work of excavating 1569m length drift at Dam Abutment, Power House Cavern-I and Power House Cavern-II was awarded to Construction Development Corporation Limited by DGPC Ltd during preparation of Detailed Project Report. The exploratory drift excavations exposed large areas of subsurface material thus permitting examination of in-situ subsurface conditions, in-situ testing and evaluation of abnormalities.

This paper deals with the methodology used during the excavation of exploratory drift in different rock condition including weak/sheared rock mass and importance's of subsurface exploration during assessment of site geological conditions and safety evaluation in hydro power project investigation.

1. Introduction

The Dam site of Nyera Amari Hydro Power Project-I (125MW) is located on the upstream of Pangzam in Thrimshing sub-division of Trashigang district whereas the powerhouse is located in sawang village in Gomdar sub-division of Samdrup Jongkhar district.

The dam site of Nyera Amari Hydro Power Project-II (317 MW) is located just downstream of the TRT outlet of NA-I in Gomdar sub-division of Samdrup Jongkhar district while the underground power house is located on the left bank of Nyera Amari river in Martshala village. The location of the two integrated project is shown in the figure-1.

The 4.5m dia and 5.5m dia modified horse shoe shape head race tunnel for NA-I and NA-II respectively is proposed on the left bank of Nyera Amari river with the total length of 26.51km. The power house complex of NA-I comprised of 14m dia circular shape, 92m high underground Surge Shaft, 3m dia circular shape, 296m length Pressure Shaft and underground Cavern measuring 80m (L) x 20m (W) x 45m (H) while the power house complex of NA-II comprised of 14m dia circular shape, 96m

high underground Surge Shaft, 4m dia circular shape, 658m length Pressure Shaft and underground Cavern measuring 105m (L) x 20m (W)x 51m (H).

The 5m dia horse shoe shape and 6m dia horse shoe shape with a total length of 0.76km and 5.2km respectively for NA-I and NA-II will be conducted the water back to the Nyera Amari river.

Figure - 1: Bird eye views of NA-I and NA-II in google earth (DGPC's PFR, NA I & II)

2. Geology of the Project Area

The project area falls within the Lower Bhutan Himalaya having a complex geology. The southern border is defined by Main Boundary Thrust and the northern limit is difficult to trace. The Main Boundary thrust is northward dipping and seems to flatten with depth. The stratigraphically of the project area is given under in the Table - 1:

Table: 1: - Stratigraphy of the project area

Unit	Lithology	Age
Shumar Formation	Phyllite, Quartzite, Schist	Late Precambrian
----------	Shumar Thrust	----------
Baxa	Dolomite, Quartzite, Slate	Lower Paleozoic to Precambrian
Diuri Formation	Pebbly Phyllite, Phyllite, Slate	Permean
Damuda Formation	Sandstone, Shale, Coal	Permo-carboniferous
----------	MBT	----------
Siwaliks Group	Sandstone, Shale, Pebbles beds, Conglomerate	Mid-Miocene to Pliocene

Part of Thrimshing falls under Shumar Formation and the rest of Thrimshing and Gomdar area falls under Baxa group (Baxa Formation by Gansser & Long et al., 2011A) and the area above Phuntshothang falls under Diuri Formation and Damudas Group.

Broadly, the Shumar Formation comprises phyllites which are grey to greenish coloured, fined and well foliated; Quartzite is commonly fine grained, white and thin to medium bedded and well jointed.

The Baxa group consist of pinkish-siltstone, greenish grey to dark grey phyllite and Phyllitic slate, grey to yellowish white dolomite, limestone and basic intrusive and gray to white, medium to thick bedded, medium to coarse grained, locally conglomoratic quartzite exhibiting common trough cross-bedding, inter-bedded with dark gray –green, thin bedded to thinly laminated Phyllite, medium-gray dolostone (locally divided out) (Bhargava, 1995; Tangri 1995a; Long et al., 2011A). The lower contact of the Baxa Group is defined by Main Boundary Thrust (MBT) where it meets the Siwalik Group. The Baxa formations upper contact is for a major part with the Shumar Formation, delimited by the Shumar Thrust. In the project area the Baxa is observed to be underlain by the Diuri and Gondwana which in turn is overly the Siwaliks along the MBT. The northern boundary of the Damuda Group is marked by another thrust bringing the Diuri Formation to rest over it at places.

The base of the Baxa Group consists of flaggy, irregular banded quartzite which is overlain by more massive ferruginous quartzite. The carbonate rocks lying above the quartzite band consist of several dolomitic limestone and thick dolomite layers. The uppermost dark slates are cut off by the thrusts consisting of phyllite and schist belonging to the older Daling-Shumar rocks. Just north of Narphung on the Trashigang-Samdrup Jongkhar highway, the Baxa type dolomite occur between quartzite and phyllites of the Daling-Shumar types (Gansser, 83).

The Diuri Formation is best exposed in north of Deothang, along the Deothang-Trashigang road. Over here, the Diuri Formation consists of poorly sorted conglomorate, white and dark grey quartzite, dolomite, pebbly shales and slates (Gansser, 83; Long et al., 2011A). The Diuri Formation is technically bounded between the Baxa Group in the north and the Damudas/Siwalik Group in the south (Bhargava, 95; Long et al., 2011A). The Damudas, representing the Gondwana are the youngest formation within the Bhutanese Lower Himalaya. It consists of quartzitic sandstones with coal beds, boulder beds, shale, carbonaceous shale, dolomite and limestone (Gansser, 83).

The Gondwana/Damuda Group comprises coal bearing quartzitic sandstones, carbonaceous slates, calcareous slates and shales. The quartzitic sandstone is coarse to medium grained, feldspathic, gritty and micaceous. The flaggy micaceous

sandstone with interbedded slates contains fragmentary plant remains. In the study area the succession of the rocks above the MBT is dull greenish shale, splintery gradually merging into boulder slates. The darks grey carbonaceous slates with boulders and tectonic lenses of quartzitic sandstone and dolomite.

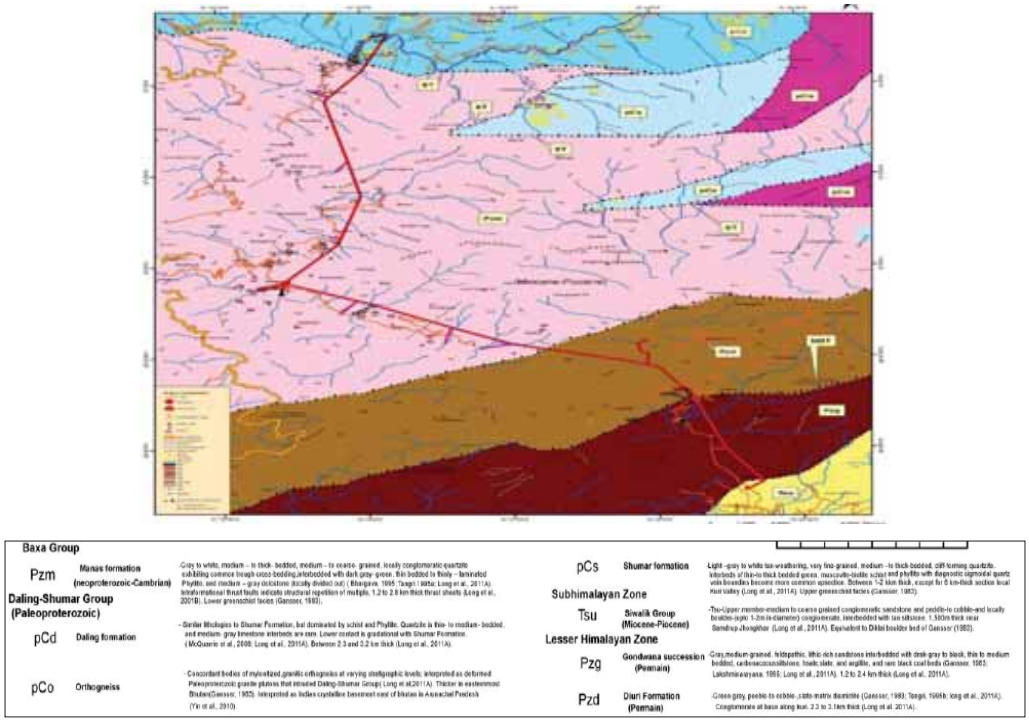

Figure 2: - Geological map of project area (Long et. al., 2011A & DGPC's PFR)

3. Encountered Geology

3.1 Exploratory drift at Dam site

3.1.1 Geology of right and left bank exploratory drift portal area

The exposed rock mass on the right bank exploratory drift comprised un-weathered to slightly weathered, moderately strong to strong, light coloured, fine grain, moderate to highly fractured Quartzite (with occasional seams/ bands of Schist along foliation). Shear seams along foliation (thickness upto few mm) has also been noted at places. Four major discontinuities joint set are recorded in this exposed rock mass. Characteristics of major discontinuities are given in the table provided below.

Table: Characteristics of major discontinuities on the left and right bank drift.

Joint Set	Orientation	Dip Amount	Spacing	Aperture/Infilling	Remarks
S1	320-330°	35-42°	3 to 20cm	Tight to Open (upto 1 cm)/ (Soil/ clay occasionally)	Open joint at surficial only with soil and tree roots intrusion
S2	150-160°	70-80°	20 to 60cm	Tight to Open (upto 1 cm)/ (Soil/ clay occasionally)	Open joint at surficial only with soil and tree roots intrusion
S3	060-080°	68-74°	10 to 40 cm	Tight to Open (upto 1 cm)/ (Soil/ clay occasionally)	Open joint at surficial only with soil and tree roots intrusion
S4	350°	25-30°	20 to 60 cm	Tight to PO (Nil)	

The rock mass at drift exhibit completely dry and un-weathered (occasional surficial staining). The encountered rock mass is strong, moderately fractured and intersected by four major discontinuities. The rock mass rating along the excavated drift at left and right dam abutments has been categories under class III (Fair) rock mass with RMR ranging from 41 – 52.

3.1.2 Failure occurred during excavation, special observations and remedial measures

The excavated drift on the right bank abutment is structurally controlled by two major joint set S1 and S3 whereby S3 plane (strike sub-parallel to the drive direction) cutting S1 plane forming gravity wedge at crown portion.

During the portal development excavation on left bank exploratory drift wedge failure was occurred due to intersection of foliation/bedding plain, S2 joint set and valley dipping S4 joint set. Timber support and steel ribs support of ISMB 125 @ spacing of 100cm were provided as passive support to control the encountered failure. Similar failure was also recorded in certain chainage during the course of excavation in left abutment drift and steel ribs support were provided accordingly.

3.2 Exploratory drift at Power House-I

Exploratory drift at Power House-I is being excavated in Class-III rock mass of Quartzotiferous Slate, Schist with bands of Quartzite rock with RMR ranging from 41 to 54. So far approximately 30% of the total proposed length has been excavated.

Apart from water seepage (in an order of 1L/min to 5L/min), no major geological problem was encountered during the course of excavation.

3.3 Exploratory drift at Power House-II

After excavating ±17.50m the excavations of 2.1m (H) X1.8m (W) exploratory drift for the investigation of underground power cavern of Nyera Amari II was stopped due to encountered poor rock strata and loose fall which result to formed a cavity upto ± 7m apex height, the excavation was stop after evaluation of geological site condition.

Considering the site condition and limited outcrop near the portal area, the drift was re-aligned from Rds ± 11.30m to divert the encountered weak/poor zone. The excavation was carried out till ±9m with drive direction of N290° making an angle of 75° with the first alignment. Further excavation was again stopped after observing the encountered geological condition and furthermore decision was made to again re-align the drive direction from Rds between 5m – 6m of the new alignment. The drift was re-alignment from Rd 5.30m from the new alignment with an initial drive direction of N231° and excavation was carried out till ± 2m manually and control blast.

The exploratory drift was excavated with invert elevation of ±365m from a small rock outcrops, projected toward river valley side. The encountered rock mass around the portal location comprised of fine to medium grain, dark grey to blackish colour, moderately to highly weathered, weak to very weak slate and phyllite rock mass. Occasionally bands of Quartzite rock mass (up to 5cm thick which are strong, compact and unweathered) were also recorded. On the u/s side of the portal location, water seepage (2-3 litre/minute) was also observed. Open join up to (10 to 20cm) with soil and tree root intrusions were also noticed along the join planes. The excavation was carried out with unfavorable drive direction in which the strike of the steeply dipping foliation/bedding plane is sub-parallel to the tunnel alignment.

3.4 pecial Observation along the excavated drift

3.4.1 First alignment

The initial 0-14m of the excavated drift comprised of weak to moderately strong, slightly to moderately weathered, moderately jointed rock mass of carbonaceous Phyllite (Moderately weathered) and slate with occasional bands of medium grain Quartzite.

The RMR ranges from 29 – 33, Class-IV (poor) rock mass. During the course of excavation, a shear/weak zone was encountered between RD 14m – 17.5m RD and a cavity was occurred at RD ±17m forming chimney structure

at crown with an apex height of ±7m. The encountered weak zone/shear zone is characterized by thick gouge matrix, highly to completely weathered carbonaceous Phyllite and few bands of Slate {refer Fig 3 (a) & (b)}.

(a)

(b)

Figure 3: (a) Photograph showing weak/shear zone at ±16 RD, (b) Photograph showing contact between moderately strong slate and weak/shear zone at ±14m RD

The tunnel is damp to wet in condition with few dripping point at certain places. Continuous loose fall were occurred between RD 14m to 17.5m. Excavations were carried out manually without drilling/blasting. Timber support and steel ribs support of ISMB 125 were provided at the spacing of 75cm to 100cm.

3.4.2 Second alignment

The encountered rock mass at Rd 0m – 6.5m comprised of weak to moderately strong, slightly to moderately weathered, moderately jointed rock mass of carbonaceous Phyllite (Moderately weathered) and slate with occasional bands of medium grain Quartzite. From ±6.5m – ±9.00m chainage the encountered rock mass comprised of moderately to highly weathered rock mass of carbonaceous Phyllite. In between highly weathered carbonaceous rock, rock blocks of slightly weathered quartzite and Slate of variable size (cobble, pebble, boulders) were also recorded. A cavity upto ± 1.5m has occurred at crown and left crown between Rd 7m - 9m. The drift is damp to wet in condition and the prevailing rock conditions and highly disturbed features also shows the possibility of presences of geological features like fault, fold etc around this area. The increase in degree of weathering in rock mass may also be the result of low cover zone toward the nala depression on the downstream side of the portal location. Excavations were carried out manually and control blasting. Timber support and steel ribs support of ISMB 125 were provided at the spacing of 75cm to 100cm.

3.4.3 Third alignment

Similar excavation methodology and support measures were adopted to excavate the third alignment from 5.30m Rds of second alignment with initial drive direction of N231°. Encountered rock comprised of moderately weathered to highly weathered Phyllite with bands of slightly weathered Slate and Quartzite (refer Fig 4). Steeply dipping foliation with strike parallel to drive direction makes the excavation very unfavorable resulting continuous over break/cavity at crown in this weak and weathered rock mass. A cavity of ±2.5m has occurred at the junction of this new alignment. Toppling from right wall and left wall were also recorded in this new aligned drift due to steeply dipping foliation joint with strike parallel to drive direction. The heterogeneous nature of the encountered rock mass (slightly weathered, moderately strong Quartzite, Slate and moderate to highly weathered carbonaceous Phyllite) with wet ground water condition created detachment of individual rock blocks creating risk working condition to the work force team.

Figure 4: Photograph showing highly weathered/weak rock mass at 0.60m Rd of 3rd alignment.

3.5 Shifting of the exploratory drift location

Considering the multiple tunnel opening within this highly weather small rock outcrops and cavity at many places of the excavated drift and all the three faces, excavation and further face advancement became very risky and therefore, shifting of the portal location was opted after proper assessment, considering the available geological data (sub surface mapping and exploratory drilling) and location of the upcoming appurtenant structures, tunnel alignment etc. of construction phases. Timely rectification of the site location concurrent to the pertaining poor geology and decision to change the site/structural location not only enable to achieve the target of excavation schedule but also provide the safety and economic working condition.

Presently the excavation in the new location has achieved 155m progress which is approximately 18% of the total length of the proposed drift. The encountered

geology comprises of strong to very strong, un-weathered rock mass class- II and class-III rock mass of Diamitite which is comparatively better geological strata than the earlier location.

4. Conclusion

The principle function of exploratory drift is an exploratory device which permits detailed examination of the sub surface geology such as rock structures like joints, fractures, fault/shear zones and provide the adequate assessment aspects of underground structures. It also identifies the factors which critically affect the safe performance of the appurtenant structures. It also refines the overall picture obtained from surface geological mapping and acquired specific design parameter and enable economic designed to be prepared. Although a slower in investigatory approach, excavation of exploratory drift should be used when other methods do not supply adequate information.

References

1. US Army Corps of Engineers, "Geological Investigation". EM1110-1-1804, Feb 1984
2. Unpublished Report: DGPC's PFR on integrated Nyera Amari Power Project (I & II).

Author's Profile

Krishna Laishram completed his M.Sc in Geology (Hons.) from Center of Advance Study in Himalayan Geology, Panjab University, Chandigarh in the year 2008. He joined Energy Infratech Pvt. Ltd. in 2008 as Trainee Geologist and subsequently elevated to Sr. Geologist. He was involved in construction activities of Teesta III (1200 MW) and Mangdechhhu Hydro-Electric Project (720MW). He was also involved in investigation of several projects in India and Bhutan viz. Demwe Lower and Demwe Upper (3000 MW), Kholongchu HEP (600 MW) and Kynshi HEP (300 MW). Presently he is working as Sr. Geologist in Construction Development Corporation Limited (CDCL), Bhutan and looking after geo-technical aspects of ongoing excavation of exploratory drift at Integrated Nyera Amari Hydropower Project.