Geological and Geotechnical Evaluation of Cut Slope of Diversion Channel of Nimoo Bazgo Hydroelectric Project, Leh, J&K

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Abstract

The Nimoo Bazgo Hydroelectric Project *(45MW)*, a run of river scheme is located near village Alchi, in the northern side of Greater Himalaya *(Ladakh Himalaya)*, in Leh district of Jammu and Kashmir on the river Indus.

Geologically, the project is located in the thick pile of monotonous, syntectonics sedimentaries, namely sandstone and shale, constituting the Indus flysch of Ladakh region, belonging to Cretaceous age.

The project comprises a 372m long diversion channel on the left bank, 48m height concrete gravity dam, three independent intakes directly from the dam blocks, and a surface power house on right bank at the toe of the dam.

As per the detailed project report, prepared during the investigation stage, the diversion channel was proposed on the left bank, in moderately jointed bedrock of sandstone and shale.

The discontinuities play a significant role on the strength and deformability of rock mass. As per the anticipated structural stability of the cut slope for diversion channel, bedding joint strike sub parallel to the diversion channel alignment and is hill dipping, hence possibility of this set leading to structural instability was lesser. However, it was presumed that, during the progressive excavation of cut slope the valley dipping joints requires suitable treatments, to avoid unstable blocks on the left bank.

The present paper deals with the geological and geotechnical evaluation of rock mass of the cut slope of the diversion channel.

Keywords: *Ladakh Himalaya, Syntectonics Sedimentaries, Indus Flysch, Diversion Channel, Cut Slope.*

Introduction

Nimoo Bazgo H.E. Project is located in Leh District of Jammu and Kashmir. Dam site is located about 1km upstream of Alchi village, (refer vicinity map fig: 1).

The project is a run-off-river scheme, to generate 239.3MU in a 90% dependable year having installed capacity of 45MW (3x15MW), utilizing a net head of approximately 34m, developed by construction of a 48m high concrete gravity dam above deepest foundation level across river Indus, and a surface power house, (refer layout plan of the project fig: 2).

The project has the following components: -

- Concrete Gravity Dam 48m high, above deepest foundation level.
- 372m long Diversion Channel, having 20m base width.
- 3 nos. penstock intake.

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- 3 nos. of penstocks of 3.3m dia.
- Surface Power House with installed capacity of 45MW (3x15MW).
- A tail race channel.
- Cellular wall.
- Transformer Yard.
- Switchyard.

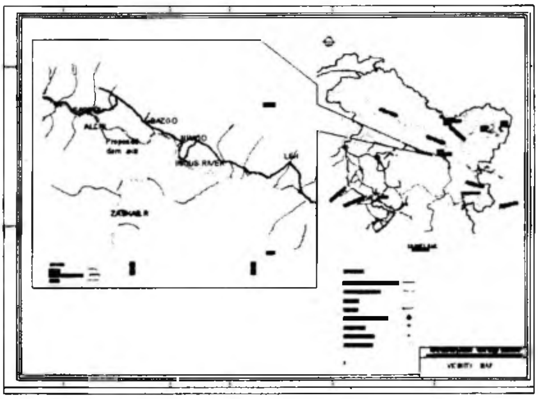

Fig 1: Vicinity Map; Showing Project Location

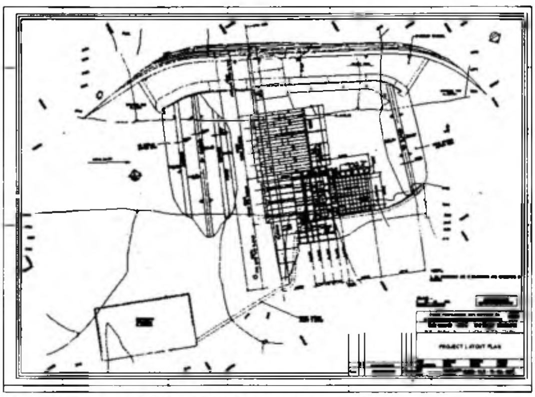

Fig 2: Layout Plan of Project

The climate of the Ladakh region is of a cold desert. The minimum temperature goes down to nearly –28.6^{0}C during winter and during this period construction activity cannot be taken up owing to inclement weather and prevailing cold climate, also road communications to the area are cut off almost for 6 months. Considering these conditions full season diversion was planned, so that work in the dam and powerhouse may be continued in the summer month, which is also the high flood season for the river. The flood of 25 years return period, which works out to 2060 cumecs for river diversion works was taken into the consideration during the planning stage, but after the flood of year-2006, the design flood of diversion channel was modified to 2200 cumecs.

Topographical and geological conditions at dam site were not found suitable for locating a diversion tunnel. Moreover for such a high flood, tunnel diameter and height of coffer dams are found to be prohibitively expensive. Accordingly, a diversion channel on the left bank was proposed for diversion of the river during construction period.

Geological Environment and Previous Investigation: - The project is located on Indus Formation of Ladakh Himalaya on river Indus, which includes turbidites, ophiolitic mélanges with seamounts and calc-alkaline volcanics. It is also referred as Indus Suture Zone and is represented all along its length by the obducted materials of the Neo-Tethyan oceanic crust, together with deep marine Triassic to Eocene sediments. The Indus Suture Zone is sandwiched between the Ladakh Granitic Complex in the north and Phanerozoic sedimentary belts in the south; (refer regional geological map fig: 3)

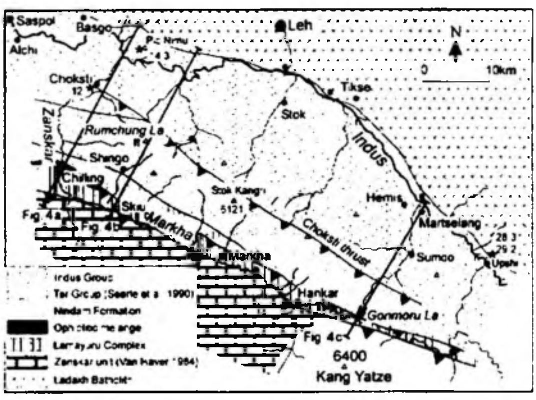

Fig 3: Regional Geological Map of the Project Area
Source: *Sinclair, H. D.,* Jaffey, N. (2001)

Detailed geological mapping of various project components were carried out during the investigation stage. In general, the bedrock is constituted by an alternating sequence of light greenish grey sandstone and dark grey

Table 1: Discontinuities Details

Sr. No.	Set No.	Orientation	Spacing	Aperture	Remarks
1.	S1	223/56°	<6cm	1mm –5mm	Bedding
2.	S2	105 / 62°	< 6–20cm	2mm–3000mm	Joint
3.	S3	025 / 56°	< 6-20cm	5mm – 15mm	Joint
4.	S4	350/58°	20-60cm	10mm-50mm	Joint

shale. The sandstone is of medium strong to strong nature, whereas the shale is moderately weak, splintery and fragmented on weathered surface, (refer geological map of the project area fig: 4). The shale appears to disintegrate on exposure during course of time. The bed rock dips with an angle of 55° to 60° towards N215° to N220° from right to left bank in the dam area with its strike extension sub-parallel to the river course. Broadly, four major sets of discontinuities as tabulated in Table: 1 have been observed.

In order to determine engineering properties of the rock types constituting the Indus Flysch, core samples of sandstones and shales were tested in the laboratory for determination of compressive strength, cohesion and angle of friction. Besides this, in-situ rock mechanic testing at dam site drift was also got conducted for plate load and rock to concrete shear test. The results of laboratory test in respect of sandstone and shale indicates UCS value of 34.9MPa and 3.77MPa respectively in saturated condition.

In general, strike of the sequence is sub parallel to flow direction of the river. Hence, the linear extension of weak zones such as splintery shale bands and fractured zones, along the bedding was expected to be intercepted for longer length from upstream to downstream direction of any structure.

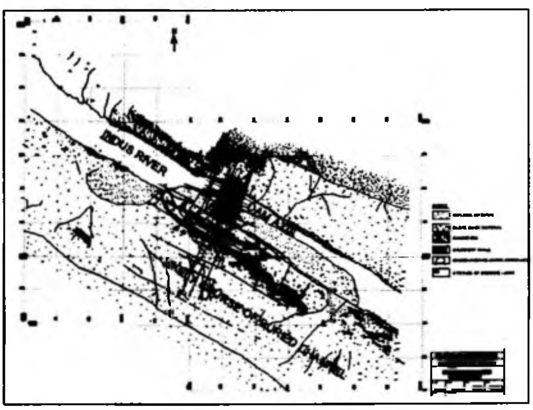

Fig. 4: Geological Map of the Project Area

The 372m long diversion channel with base width of 20m was proposed to be excavated, in the left bank in closely to moderately jointed bedrock of sandstone and shale. In general, bedding joint strike sub-parallel to the diversion channel alignment, (refer geological L-section fig: 5 and typical geological cross section of diversion channel fig: 6).

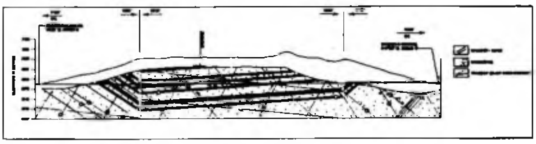

Fig. 5: Geological L-Section of Diversion Channel

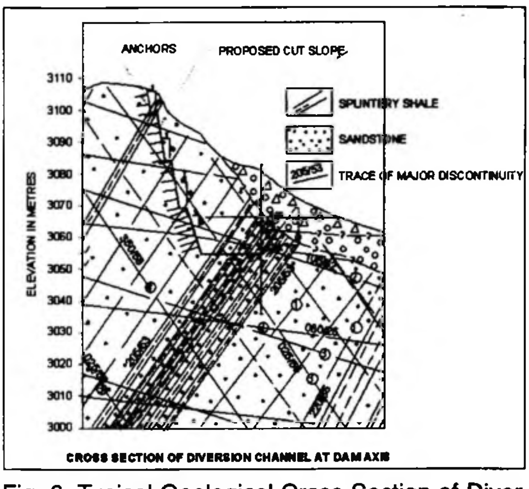

Fig. 6: Typical Geological Cross Section of Diversion Channel

Diversion Channel Construction Design:- The 372m long, 20m bottom width, trapezoidal shaped diversion channel is located on left bank of Indus River. The channel has been designed for 2200 cumecs flood discharge.

Invert level of channel at inlet is 3054.70m and at outlet is 3052.88m with a slope of 1V: 198H.

The design drawings showing plan and sections of diversion channel involve 10 sections (P, A, B, C, D, E, F, G, H, Q). In each section excavation procedure was explained with help of drawing. In general, excavation in left bank hill side follows from top level to El: 3069m in 6:1 slope providing 2m berm at intermediate levels. From El: 3069m to El 3054.7m i.e. upto bottom of diversion channel excavation follows 3:1 slope. Providing 20m width in bottom, excavation follows 0.75:1 slope towards right bank and lock wall was placed on suitable foundation in right wall, (refer typical design cross section of diversion channel fig: 7).

Further, in order to ensure transient flow conditions and improve the channel hydraulics' model analysis was also undertaken at CWPRS, Pune, simulating the different discharge at inlet and outlet of the channel.

During the progressive excavation support in form of rock bolts, shotcrete was provided in the design drawing for stability of cut slope.

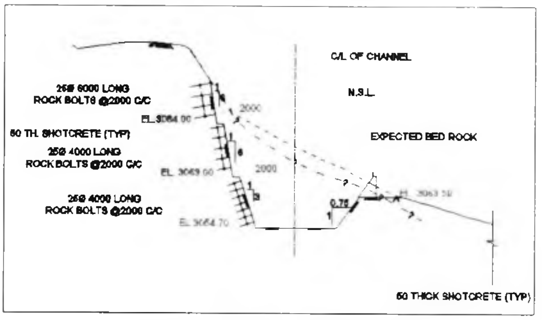

Fig. 7: Typical design Cross Section of Diversion Channel

Geological/Geotechnical evaluation during the progressive excavation: - To understand the effect of the geological conditions on overall slope configuration, geological plan showing the overburden-bedrock interface, superimposed over construction drawing and geological information's as encountered during the progressive excavation were depicted in each design sections. Giving due consideration to these information, assessment was made, where wedge formations were primarily associated with geological conditions such as adversely oriented joints, vis-à-vis slope angle.

In the initial stage of excavation of cut slope, for accommodating the open diversion channel, as per the design drawings there were appreciable undulations/valley formation in the top berm extending down to El: ±3080m, which necessitated a marginal shift towards hill side for ensuring stability of top berm. It is also pointed out here that, this area being exposed to the atmosphere, was subjected to considerable weathering and manifested by dissected joints.

During the progressive excavation of diversion channel, when the cut slope has reached to an El: 3064m (an average), distressed zone in form of tension cracks along the strike of slope was observed between section D to F at the El: 3104m, no manifestation of this discontinuity/distress on the excavated surface of the cut slope was observed. The development of crack has forced the project to evaluate the slope stability, based on the strength and the deformability of rock mass.

The tension crack observed as mentioned above, was in the overburden and the area in the vicinity passes through a buried channel.

Fig. 8: Photograph showing the disposition of slip plane along the cut slope.

After the removal of the overburden it was seen that the RBM and fluvial glacial material was filled along the tension crack zone, dipping towards the valley i.e. towards the cut slope and formed a huge wedge. The entire area around the crack zone was examined, and found that 4-6 inches aperture of crack has been developed almost along the strike of slope. Movement across the crack plane was also noticed in the initial phase, (refer photograph showing disposition of slip plane along the cut slope fig: 8).

As the toe of the hidden slip plane got day lighted during the excavation, causing slide/ collapse along the potential slip plane filling the diversion channel area with its debris.

To understand the failure mechanism in present case, following assumptions were made.

1. **Discontinuity related failure, related to the orientation of slope and discontinuity: -** Stability of slope related to discontinuity in the rock mass and slope, i.e. related to the orientation of the discontinuity and the slope orientation (orientation dependent stability). The rock mass in the influence area dissected by four sets of discontinuity viz. 230/52-62; 040/68-70; 315-340/54-62; 150/55, out of these four sets, two sets plays a major role for the stability of cut slope namely 040/68-70; 315-340/54-62, these two joins are valley dipping and clay filled at some places, (refer photograph showing slip plane after failure fig: 9).

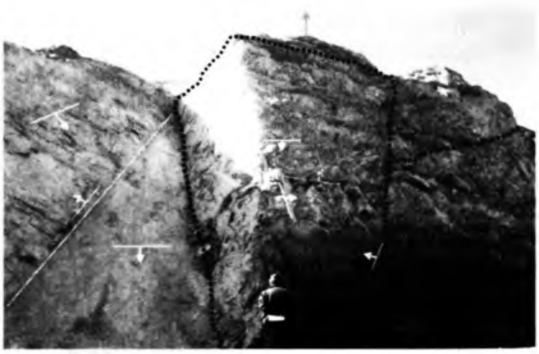

Fig. 9: Photograph showing slip plane after failure

Anticipation

(i) In present case, as per the slope mass rating, difference of joint dip direction of valley dipping joint ($\acute{a}_j$) and slope dip direction ($\acute{a}_s$) was less than 5^0, and consequently planar failure occurred.

(ii) Dip amount of slip plane varies from top to bottom, when dip amount of the slip plane was plotted for examination of slope stability, the slip plane extended upto the bottom of cut slope, but during the progressive excavation slip plane got day lighted and planar failure occurred along the identified slip plane.

2. **Breaking of intact rock under the influence of stresses in the slope: -** Stability of slope in relation to the strength of the rock mass in which the slope is excavated, i.e. independent of the orientation of the discontinuity and of the slope. The rock mass in the influence area comprises of sandstone and rock mass was fresh to slightly weathered. The slope mass rating of the rock mass around the failure area evaluated to determine the strength of rock mass in correlation with slope stability, and it was unfavorable for valley dipping joints, also the static load on the top of cut slope acted as catalyst for sliding of rock mass along the clearly identified slip plane.

After the occurrence of wedge failure along the clearly identified slip plane, adjacent block started moving, which was not only critical from slope stability point of view, but also for the diversion of river. To understand further failure, and stabilized the block, geological cross sections were examined, and conclusion was drawn that toe support in form of reinforced concrete should be provided at the earliest to stop/minimize the movement of adjacent block.

After providing the toe support and cement grouting, from the top of the cut slope along the slip plane, the movement of block got stabilized.

Result and Conclusions

Slope failure involves the sliding of rock mass along two or more surfaces, by virtue of different forces acting on them. The 'V' shaped wedge slided along the weathered slip plain, along which no cohesion between the adjacent rocks mass was observed. The rock mass in influence area comprises of sandstone with intermittent bands of shale. The area also dissected by frequent shear seams.

After failures of cut slope, following steps were taken to stabilize the adjacent rock mass and restore the pace of diversion work:-

1. Cement grouting from top of cut slope at regular intervals, through 6m to 10m holes of 45mm diameter.
2. Additional rock bolting from the concrete surface into rock, at 3m to 7m above the bottom of cut slope.
3. Slush grouting along the cut slope, mainly along the identified weak planes, to provide cohesion between adjacent rock mass.

Fig. 10: Photograph showing full phase diversion

Meanwhile, monitoring of cut slope was made through topographical markers, established at top along the cut slope. After ensuring the stability of the cut slope, diversion was successfully achieved on due date, (refer photograph showing the full phase diversion Fig. 10).

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References:

1. Detailed Project Report (2003) : Site Investigation and Geology (Volume-IV): Nimoo Bazgo (Alchi) H.E. Project, NHPC.
2. Sinclair, H. D., Jaffey, N. (2001) : Sedimentology of the Indus Group, Ladakh, northern India: implications for the timing of initiation of the palaeo-Indus river. Journal of Geological Society, London, Vol: 158.
3. Kovari, K., Fritz, P. (1978) : Slope Stability with Plane, Wedge and Polygonal Sliding Surfaces. Proc. Symp. Rock Mechanics related to Dam Foundations, Rio de Janeiro, Brazil.
4. Kovari, K., Fritz, P. (1984) : Recent Development in the Analysis and Monitoring of Rock Slopes. Proc. IV Int. Symp. On Landslides, Toronto, Canada.
5. Kovari, K., Fritz, P. : A Unified Approach to Rock Slope Stability Analysis.