Geo-Engineering solutions for stabilization of cut slopes in the Surface Power House area of Luhri Hydroelectric Project Stage-I

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Abstract

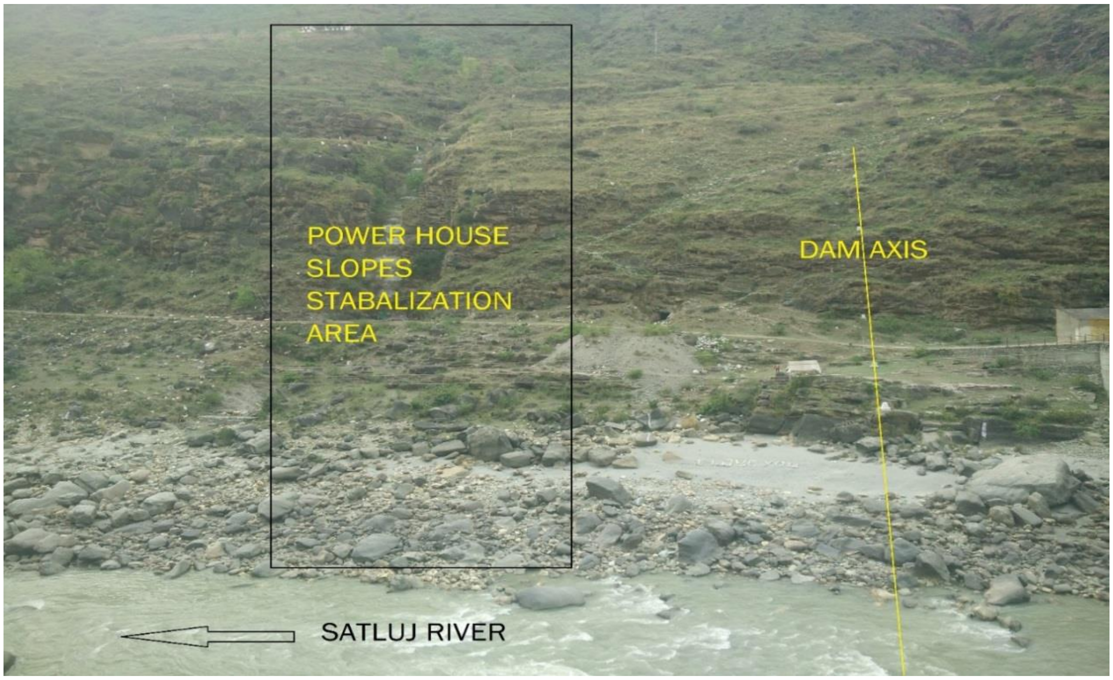
Luhri Hydroelectric Project Stage–I is a run of the river type development to harness the hydel potential of river Satluj. The project is situated on Satluj River near Nirath Village, in Shimla and Kullu Districts of Himachal Pradesh. On the upstream of the project lies the 412 MW Rampur hydroelectric project, which utilizes water discharged from the further upstream 1500 MW Nathpa-Jhakri project. On the downstream of Luhri HEP Stage-I project lies the 800 MW Kol Dam Hydroelectric Project. Luhri HEP Stage-I is having installed capacity of 210 MW. The project envisages construction of a 80m high concrete gravity dam with toe Power House on the right bank. The dam houses six no. low level sluices for passing the floods and periodic flushing of silt. Four no. intakes are also placed in the dam body to feed 4 no. of Kaplan turbines. Geomorphologically the area is located in a young mountain chain, most of the valley slopes are steep. River is confined within narrow V-shaped valleys with little or no flat areas close to the river bed. The project lies in Jutog (Kullu Group) Group of rocks. At project site river is narrow, with steep side slopes. Thus, to accommodate surface powerhouse having size 122m (L) X 50.50 m(W) X 65.50m (H) involves enormous slope stabilization measures covering more than 100 m height apart from local excavation for housing 4 no’s Kaplan turbines. This paper is covering the analysis and stability measures of the cut slopes required for accommodating the surface powerhouse.

1. Introduction:

Luhri Hydroelectric Project Stage–I is a run of the river type development to harness the hydel potential of river Satluj. The project is situated on Satluj River near Nirath Village, in Shimla and Kullu Districts of Himachal Pradesh. On the upstream of the project lies the 412 MW Rampur hydroelectric project, which utilizes water discharged from the further upstream 1500 MW Nathpa-Jhakri project. On the downstream of Luhri HEP Stage-I project lies the 800 MW Kol Dam Hydroelectric Project. Luhri HEP Stage-I is having installed capacity of 210 MW. The project envisages construction of a 80m high concrete gravity dam with toe Power House on the right bank. The dam houses six no. low level sluices for passing the floods and periodic flushing of silt. Four no. intakes are also placed in the dam body to feed 4 no. of Kaplan turbines.

2. Surface Power House:

The proposed Surface toe power house of Luhri Hydro-electric Project Stage-I having size of 122.0 m (long)X 30.5 m (wide) X65.5 m (high) involves slope stabilization for about 120 m high from ± EL 915 m to ± EL 795 m with benches at different levels. To minimize slope cutting powerhouse has been placed in a dry nallah as shown in Photograph 1. This nallah is being diverted /channelized from ± EL 917 m into the reservoir for the safety of the surface power house, refer Figure 1.



Photograph 1 Power House Site of LHEP Stage-1

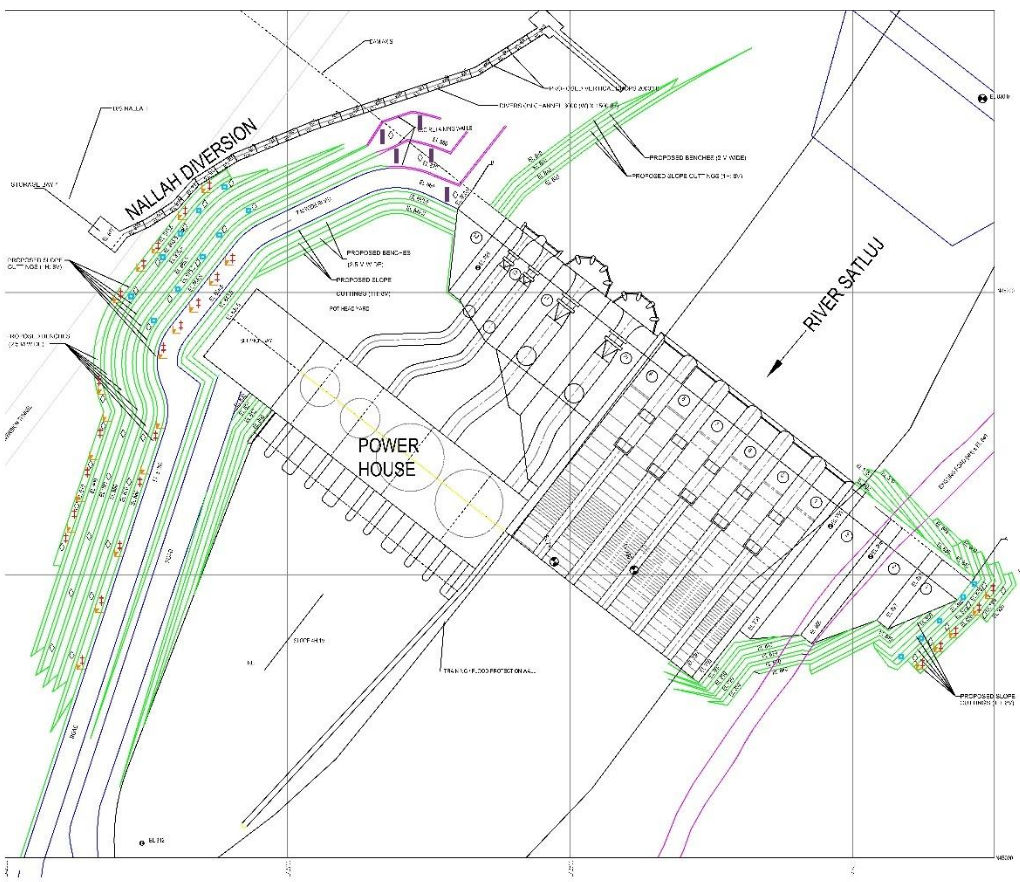


Figure 1 LHEP Stage 1- General Layout

3. Physiography, Geomorphology and Regional Geology:

Luhri hydroelectric project Stage-1 lies in the Inner Lesser Himalaya between the Dhauladhar Range in the south and the Higher Himalayan Range in the north. The Satluj River is the main drainage in the catchment area with headwaters located in the highlands of Tibet. The river flows northwest from Rakshas Lake to Shipki La and is fed by numerous glaciers which include Ganglung Gangri. Entering Himachal Pradesh at Shipki La, it flows in a south-westerly direction where it is joined by the Spiti River and also fed by glaciers originating from near the peak of Leo Pargial. The Satluj crosses the Great Himalaya Range near Kalpa and is subsequently joined by the Baspa River which originates from a glacier. It crosses the Dhauladhar Range through a narrow gorge near Rampur.

In the project area the Satluj is joined by several small streams such as Nogli Gad, Kurpan Gad, Machhad Gad and Ani Gad and, further downstream from the project, where the river flows in a south-east direction, it passes through a narrow valley between Sarahan and Luhri, forming a gorge which cuts across the general trend of the main rock units. And further downstream it cuts through the Shali Range and descends towards Bilaspur. Eventually, after cutting through the Siwalik Ranges, it enters the Indo-Gangetic Plain of Punjab.

The fall of river Satluj from the source in Tibet to the plain is very uniform and averages about 6 m per km. The river bed elevation is 4572 mad at the Rakshas Lake, 3048 mad near Shipki La, 914 mad at Rampur, 813 mad at Neerath, 500 mad at Bilaspur and less than 300 mad where it enters the plains. The total length of the river within Himachal Pradesh is 400 km and the mean annual flow is 16,755 million cubic meters.

Geomorphologically the area is located in a young mountain chain which is characterized by rapid down-cutting. Hence, most of the valley slopes are steep. River is confined within narrow V-shaped valleys with little or no flat areas close to the river bed. The only exception to this is area few kilometers upstream of Neerath where the valley opens out due to more rapid erosion of softer phyllitic rock units, this area is being used as reservoir for this project. Typically most of the slopes have a limited soil covering with rock outcrops common on most slopes except for some area.

The Regional Geological map of the area is enclosed as Plate-1.

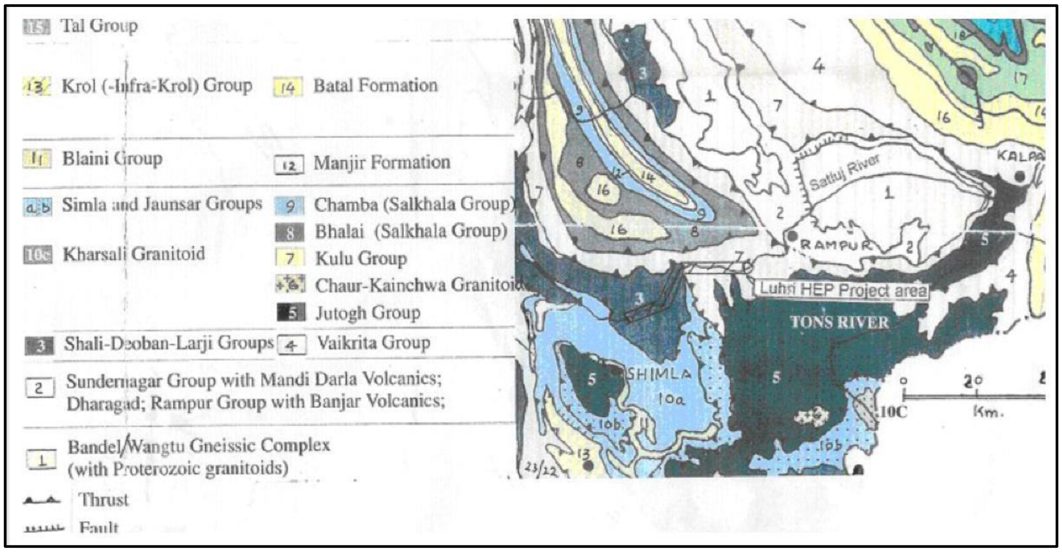


Figure 3 Regional Geological Map of part of Himachal Pradesh showing Project Area

4. Geological & Geotechnical Assessment of Power House:

A geological section passing through the center line of power house has been prepared extending from top of the cut slopes behind the power house up to the river, refer Figure-2. Based on geological data, three sets of joints are present.1st set J-1of joints are mainly foliation joint having Dip direction as 320^0 and dip as 28^0. 2nd set J-2of joints having Dip direction as 210^0 and dip as 70^0. 3rd set of joints J-3, having Dip direction as 120^0 and dip as 60^0.

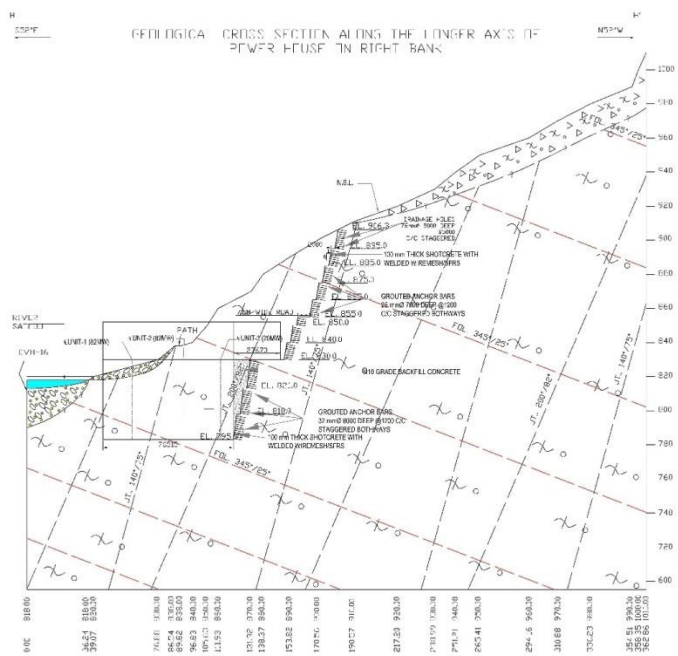


Figure 4 Surface Power House Slope Stabilization

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Cut slopes behind the power house are proposed to be excavated from El. ±915m downwards with an angle of 68°, & height of the bench being 10m up to service bay (830m). Below service bay the cut slopes are proposed to be excavated at an angle of 77° degree. The slopes behind the power house will be excavated in mainly in augen gneiss, fresh to weathered in nature and biotite rich at places. During the excavation of the slopes the foliation joints will be favorably dipping inside the hill. Two valley dipping steeper joints will be encountered on the slopes which can cause instability during excavation. In addition the drill holes have indicated presence of highly jointed/fractured rock zones 3 to 4 in numbers with a thickness of 3 to 4.5m each. These zones are expected to be parallel to the foliation and may not cause any instability. For long term stability these zones needs grouting. Presence of valley dipping joints necessitates concurrent support with the excavation. The details of the support for the proposed cut slopes have been worked out. The service bay will be excavated in hard augen gneiss, biotitic at places with one highly jointed zone of 4.5 to 6.0m thick cutting the service bay diagonally which may need some grouting. The power house foundation (El. 783m) is expected to be excavated in massive to jointed augen gneiss/biotite gneiss. One highly jointed one/fracture zone of thickness 3-6m is expected on the WWN corner of the power house (based on hole no. PH-4, PH-5 & PH-6). Despite this above zone the rock at the foundation of the power house is expected to be Fair to Good in general and is suitable for founding the power house.

4. Slope stability measures in power house area:

The slopes behind power house have been analysed in three zones for stability analysis using SWEDGE. Zone-I starts from the foundation level i.e. EL 795 m up to EL 830.0 m accommodating Machine hall. At EL 830.0 m, a 30 m wide bench has been proposed for service bay. This bench will provide break in continuity & quite substantial relief for slope stabilization measures for upper reach. Zone-II involves slopes cutting from EL 830.0 m to EL 855.5 m. At EL 855.5 m there is a 7 m wide road leading to dam top. This road will provide break in continuity and relief for slope stabilization measures for upper reach. Zone-III covers EL 855.5 m to EL 915.5 m. The various rock parameters have been considered as tabulated in Table 1.

Table 1
Rock Parameters Considered for SWEDGE Analysis

Zone	Elevation		Height of Slope	C & Ø values
	From	To		
I	El.795 m	El.830.0 m	35m	C=0.01 MPa, Ø = 45^0
II	El.830.0 m	El.855.5 m	25m	C=0.01 MPa, Ø = 45^0
III	El.855.5 m	El.915.5 m	60 m	C=0.01 MPa, Ø = 45^0

The value of Cohesion (c) and Internal Friction of angle (Ø) are 0.22 MPa and 45° respectively as per studies done by AECS However, the value of cohesion has been taken as 0.01MPa keeping uncertainties and considering worst case for analysis & design.

Based on geological data, three sets of joints are present as indicated below and tabulated in Table 2:

1) 1st set of joints are mainly foliation joint having Dip direction as 320^0 and dip as 28^0.This joint set has been named as J-1.
2) 2nd set of joints having Dip direction as 210^0 and dip as 70^0.This joint set has been named as J-2.
3) 3rd set of joints having Dip direction as 120^0 and dip as 60^0.This joint set has been named as J-3.

The foliations are dipping into the hill which is quite favorable from slope stabilization point of view. The analysis of slopes has been done on software "SWEDGE". The analysis of power house slopes has been done considering three cut slopes having dip direction 38° (downstream slope), 128° (hill side slope) and 218° (upstream slope).

Table 2
Prominent Discontinuity at Power House

Joint set	Avg. Dip Direction and Dip	Spacing (m)
J-1 (Fol.)	320°/28°	0.3-2
J-2	210°/70°	0.25-1.5
J-3	120°/60°	0.25-1.5

The results of the analysis for Upstream Slope, Power House Hill Slope and Power House Downstream slope are as follows –

Upstream Slope -Upstream slope is having dip direction of 218°. For analysis this slope has been divided into two parts. The first part is from El. 795 to El. 830 and the average cut slope angle in this part is 77°. The 2nd part is from El. 830 to El. 915 and the average cut slope angle in this part is 68°. The findings of the analysis and stabilisation measures in this slope are as below: -

a) El. 795 to El. 830 – There is no wedge formation for Joint Set J1/J3.For Joint set J1/J2 & J2/J3 FOS without support (with seismic load) is 1.73 & 0.892 respectively. To improve the FOS to 3.13100mm thick shotcrete and 25mmø, 6m long @ 2.0m c/c pattern grouted anchor bars are provided.
b) El. 830 to El. 915.5 – There is no wedge formation for Joint Sets J1/J3 &J2/J3. For Joint set J1/J2 FOS without support (with seismic load) is 1.73. To improve the FOS 100mm thick shotcrete and 25mmø, 6m long @ 2.0m c/c pattern grouted anchor bars are provided.

Power House Hill Side Slope - Power House Hill Side Slope is having dip direction of 128°. For analysis this slope has been divided into three parts. The first part is from El. 795 to El. 830 and the average cut slope angle in this part is 77°. The 2nd part is from El. 830 to El.855.5 and the average cut slope angle in this part is 77°. The 3rd part is from El. 855.5 to El. 915.5 and the average cut slope angle in this part is 69.5°. The findings of the analysis and stabilisation measures in this slope are as below: -

a) El. 795 to El. 830 – There is no wedge formation for Joint Sets J1/J3 & J1/J3. For Joint set J2/J3 FOS without support (with seismic load) is 0.633.To improve the FOS to 2.5 100mm thick shotcrete and 32mmø 8m @ 1.5m c/c pattern grouted anchor bars are provided.
b) El. 830 to El. 855.5 – There is no wedge formation for Joint Sets J1/J2& J1/J3. For Joint set J2/J3 FOS without support (with seismic load) is 0.631, to improve the FOS to 2.33 100mm thick shotcrete and 32mmø 8m @ 1.5m c/c pattern grouted anchor bars are provided.
c) El. 855.5 to El. 915.5 – There is no wedge formation for Joint Sets J1/J2 & J1/J3. For Joint set J2/J3 FOS without support (with seismic load) is 0.613. To improve the FOS to 1.84 100mm thick shotcrete and 32mmø 8m @ 1.5m c/c pattern grouted anchor bars are provided.

Power House Downstream Slope - Power House Downstream Slope is having dip direction of 38°. For analysis this slope has been divided into two parts. The first part is from El. 795 to El. 830 and the average cut slope angle in this part is 77°. The 2nd part is from El. 830 to El. 915 and the average cut slope angle in this part is 68°. The findings of the analysis and stabilisation measures in this slope are as below: -

a) El. 795 to El. 830 – There is no wedge formation for Joint Set J1/J2& J2/J3. For Joint set J1/J3 FOS without support (with seismic load) is 3.44.100mm thick shotcrete and 25mmø, 6m long @ 2.0m c/c pattern grouted anchor bars are provided.
b) El. 830 to El. 915.5 – There is no wedge formation for Joint Sets J1/J2 & J2/J3. For Joint set J1/J3 FOS without support (with seismic load) is 3.37. 100mm thick shotcrete and 25mmø, 6m long @ 2.0m c/c pattern grouted anchor bars are provided.

5. Conclusions:

Analysis of Slope stabilization with software supported by Geological exploration plays vital role in development of surface toe power houses and optimization of overall layout of the hydroelectric projects.