GEOMORPHOLOGICAL & GEOLOGICAL STUDY OF HALAIPANI SMALL HYDRO ELECTRIC PROJECT (16 MW)

ANJAW DISTRICT, ARUNACHAL PRADESH

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This Geomorphological & Geological Studies report prepared by Grej Engineers Pvt. Ltd. is for development of Halaipani Small Hydroelectric Project (16 MW). All the information and details given here are based on survey & site visit carried out and related research work done in the past by some researchers. However we don't make any representation of any kind, express or implied, regarding the accuracy, adequacy, validity, reliability, availability or completeness of any information given in this report.

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GEOMORPHOLOGICAL & GEOLOGICAL STUDY

OF

HALAIPANI HYDRO ELECTRIC PROJECT

16 MW (4 x 4.0 MW)

ANJAW DISTRICT, ARUNACHAL PRADESH

1.0 INTRODUCTION

Halaipani Small Hydro Electric Project is a run of the river scheme proposed on the Halai River, a tributary of the Lohit River, known as Tellu River in upper reaches & Brahmaputra in Assam. The project envisaged construction of a Barrage at latitude 27°58'45.05"N; longitude 96°43'27.53"E, already constructed 2 km long water conductor System (Feeder Channel, D-Tank and Power Channel, Forebay Tank) and a surface powerhouse proposed at latitude 27°58'12.08"N; longitude 96°42'48.33"E to be located on the right bank of the river with 1.30m dia & 174m long, 04 Nos. of Penstock Pipe to utilize the net head of about 95m and design discharge of 21.57 cumecs to generate 16 MW of power. The project area is covered under the SOI Toposheet No. 91D/12, 91D/16, 90A/9.

2.0 TOPOGRAPHY

Arunachal Pradesh state depicts highly undulating and rugged topography characterized by the typical features of Lower and higher Himalayan belt having numbers of ridges (Fig. 1). The region is highly precipitous, rough having moderate to steep slopes and covered with densely forested valleys. The Himalayan belt rises abruptly from the plains and comprises a rugged mountainous and forested terrain with conspicuous NW-SE ridges having altitudes above 3000m in its middle reaches. The average elevation in the project area lies between 700m to 1000m. Ridges are trending nearly NE- SW forming high to moderate hill slope and numbers of rills and nalas joining Halai River constitutes catchment area of about 280 sqkm. The river originates at an elevation of about El. 4500m msl flowing towards South in its initial reach and takes multiple kink to follow Southwest and finally joins Tellu River near Chamukh Village. The high mountains in the upper catchment area (northeast) remains snow clad almost throughout the year rendering them almost inaccessible.

Fig. 1 A view rugged topography & forested valley in the area

3.0 GEOMORPHOLOGY

Regionally, Arunachal Pradesh has been divided into four physiographic segments having distinct stratigraphy and structures viz. Himalayan Ranges, Mishmi Hills, Naga-Patkoi ranges, Brahmaputra plains. Out of them Himalayan Ranges in Arunachal Pradesh can again be subdivided into Tethys / Tibetan Himalaya in the north, Higher Himalaya, Lesser / Lower Himalaya and Sub Himalaya in the south. The major geomorphic unit in the project area depicts structural hills consisting of rocks of Himalayan Belt & Mishmi Hills.

The area constitutes Siwalik Range in the South which is merged into Brahmaputra Plains and the hills & mountains associated with valley and intermontane plateaus. The area comprises Lesser Himalayan rocks, the Mishmi Crystallines, the Tidding Suture Zone and the Lohit Plutonic Complex. The Mishmi Thrust underlies the Lesser Himalayan unit, while the Mishmi Crystallines are thrust over the Lesser Himalayan unit. Along the Main Central Thrust (MCT), the rocks of the Tidding Suture Zone, thrust over the Mishmi Crystallines, which in turn are over thrust by the Lohit Plutonic Complex (LGC or Lohit Granitoid Complex) along the Lohit Thrust. Major thrusts of Mishmi Hills like Lohit Thrust and Tidding Thrust are prominent on the longitudinal profile of the river like Tidding and Dav River. The area has a complex geological and tectonic setting due to triple junction of Indian Plate, Eurasian Plate and Myanmar Plate. In this region, high degree of crustal shortening is observed. Tethyan Himalaya part is missing and Siwaliks has been eroded completely.

Geomorphologically, the landform in the area is structural origin where most of the project area represents mountainous with high hills and narrow valleys, gently sloping hill terraces constitutes cultivation terrace with thickly covered debris. Dense vegetation and slope wash materials observed throughout the hill slope while traversing through channel alignment.

Cultivation terrace made up of debris deposit modified by jhum cultivation are also prominent near the settlements/village area noted in the vicinity of project area. The area is in young stage and the erosion is comparatively rapid. Due to landslide /cloudburst in the past leads to heavy deposition in river bed in the upper catchment area. The source of the Halai River is snow-capped mountains. Due to some neotectonic activities, the river takes a sharp bend and changes its original path as it can be clearly seen in the satellite image (Fig. 2). A major landslide has been observed in upper area of Halai River which changes and obstructs the path of River. Surface of hill slopes are generally covered by either residual soil or slope debris materials consisting of in-situ rock boulder mixed with soil. Satellite image is depicted here which shows the terrain characteristics with major project component and geomorphological features of the area (Fig. 3).

Fig. 2 Satellite image shows project location & geomorphic features of the area

Fig. 3 Image showing topography and surface features near the project area

4.0 GEO-STRUCTURES

The neotectonic activities in the project catchment area have forced the streams and rivers to turn abruptly in the direction of demarcating faults. This has happened at multiple locations of the tributaries of Lohit River and its confluence where the Lohit River takes a sharp southwesterly turn along the active Brahmakund Fault from its persistently southerly course near Parasuram Kund. Massive volume of unsorted debris forms fluvial terraces in a wide channel of Lohit indicate that the river has changed its course due to tectonic uplift, straightness in NW-SE direction of small streams joining the Lohit River indicate the existence of NW-SE trending fault.

Along the tectonic contact there is abrupt change in stream direction and rise in mountainous from flat terrace of Brahmaputra Alluviums. The contact between flat terrace and mountain is almost straight. Movements along with the fault planes not only displaced the boundary thrusts but also trigger fresh/recent landslides, subsidence of roads, ponding of streams and damage to other infrastructures. The crucial active faults in the area have been discussed herein and also shown in figure (Fig. 4). An abrupt change in flow of Halai River shows the presence of fault line in catchment area which triggered recent landslide and flash flood like situation in Halai River (Fig. 2).

Lohitpur Fault:

The Lohitpur Fault trends NE-SW and dips about 70°-80° towards NW. It extends over a distance of about 30 km from Lohitpur in the northeast to Lohit/Digaru river confluence in the southwest. The alluvial silty terrace (Tezu Terrace) has been uplifted by 20 m along the fault.

Tezu Khola Fault:

The Tezu Khola fault runs along Tezu Khola and extends over a distance of about 8 km. This fault has NE-SW trend and is responsible for dextral displacement of Mishmi Thrust.

Delai River Fault:

The NE-SW trending Delai River Fault extends over a distance of about 7 km and has caused 2 Km dextral displacement of Mishmi Thrust in Lohit valley.

Brahmakund Fault:

The NE-SW trending Brahmakund Fault extends over a distance of about 18 km. It is well expressed in the form of straight and linear course of river Lohit.

Tidding Fault:

The Tidding Fault, runs along the Tidding River and extends from Tidding Tuwi in the northwest to east of Lalpani in the southeast in the Lohit valley over a distance of about 30 Km. The fault lies in the Lohit Plutonic Complex of Trans Himalaya and has NW-SE trend. Movement along this active fault are evident from abrupt narrowing down of wide channel of Lohit to a gorge at Tidding river confluence, series of landslide scars in a straight-line trending NW-SE.

Hayuliang Fault:

The Hayuliang Fault trends NW-SE from Tidding in the northwest to Changwinti in the southeast over a distance of about 75 km in the Lohit valley. At Hayuliang there are two prominent levels of the river terraces. The older one has been raised by 70 m, and the younger by 20 m with respect to Lohit River bed. This fault has caused north-westward deflection for about 40 km of Lohit River from its persistently south-westerly course.

Walong Fault:

In the extreme eastern comer of Eastern Syntaxical Belt (ESB), this NNE-SSW trending fault is very prominent and extends from Kandun in the north to Samdul and further south over a distance of about 55 km. Two levels of uplifted fluvial terraces, have been observed along the western side of the fault which is in present on the eastern side. This indicates that the western (Walong side) block across the fault has lifted up 100 m more than the eastern block. The existence of hot water spring on the right bank of river Lohit at Tilam indicates that the fault is of deep-seated nature. Recent movements along the Walong Fault is also evident by deeply dissected narrow Y-shaped valley of Lohit with steep slopes and occurrence of unfurrowed fresh landslides devoid of vegetation.

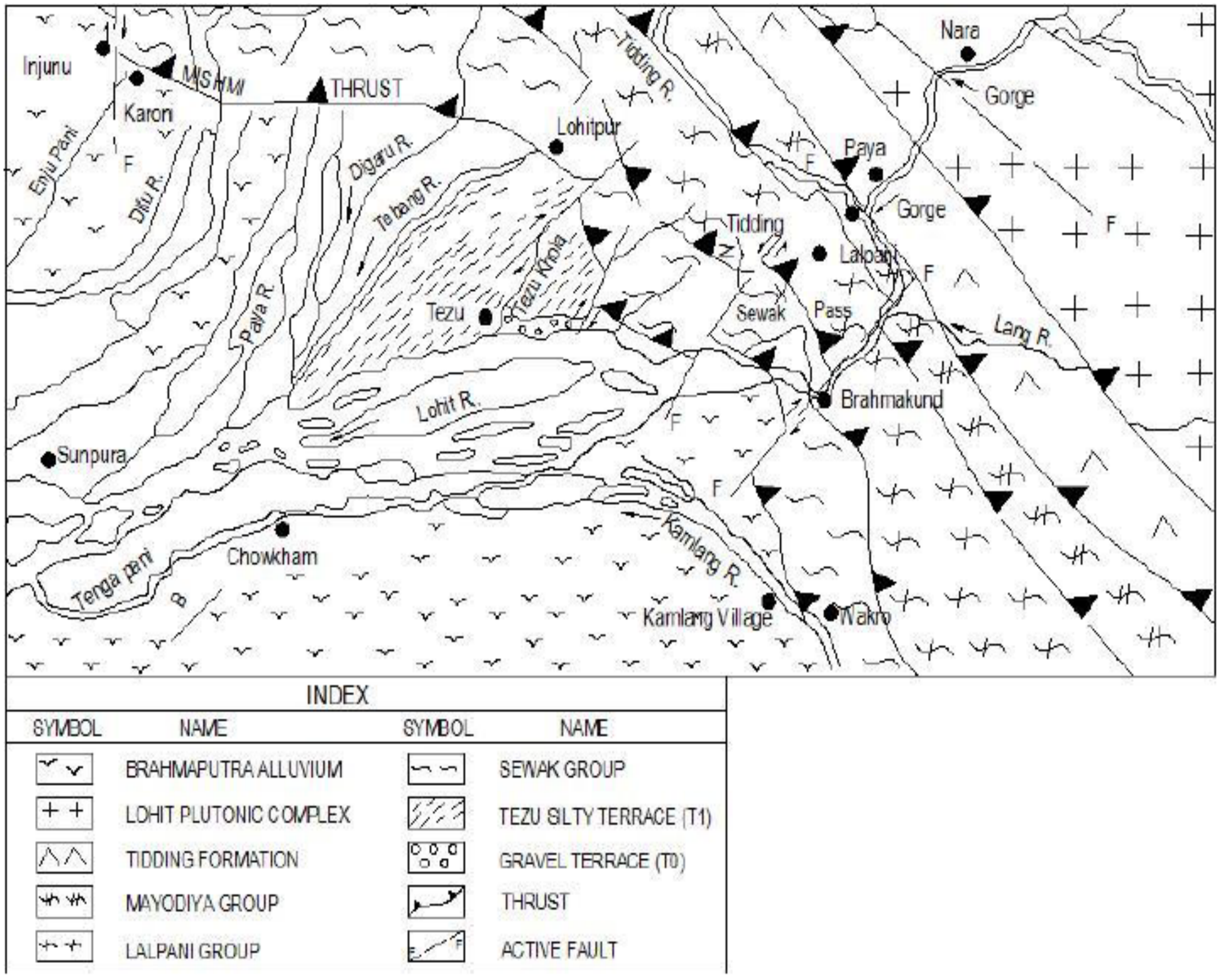

Fig. 4 Image showing major thrust/fault zone in the regional area

5.0 DRAINAGE

The rivers like Lohit River, Dibang River, Siang River, Subhansiri River, etc. of Arunachal Pradesh are the major tributaries of the Brahmaputra River. Mostly rivers run southerly direction and joins Brahmaputra in Assam. The Lohit River enters into India near Kahoo Village (easternmost inhabitant First village of India) and surge through wide valley at Walong to Narrowing near Parasuram Kund for about 200km before draining itself in the plains of Assam. Major part of Anjaw District drain into Lohit River which originates from Zayal Chu ranges in eastern Tibet. Lohit River has multiple tributaries like Tidding River, Dav River, Halai River, Dong River etc mostly originates itself in Anjaw District and joins Lohit. Halai River is one of the important tributaries of Lohit River having the catchment area up to the proposed diversion site is 270 sq km. The slope of the Halai River is about 10 m in 1 km. The river network is trellis type, and its tributaries are sub-parallel in nature which shows presence of structural control and flows the geomorphological trends of the hills and mountains. The river bed is full of river borne materials like boulders, gravels, pebbles, sand and silt. The drainage pattern of the Halai River is dendritic type and sub parallel.

6.0 REGIONAL GEOLOGY

Various workers have described the geology of the eastern Arunachal Pradesh (Gansser, 1964, Nandy, 1973, Karunakaran, 1974, Stoneley, 1974, Jain et al., 1974, Valdiya, 1976, Thakur, 1986, Acharyya, 1987, Kumar, 1997).

In the recent past, various organizations such as Geological survey of India, Department of Geology, National Mineral Development Cooperation and Power developers have been carrying out systematic geological mapping to understand the geological history and tectonics of the area in detail. The lithologic assemblage and tectonic set up of the regional area has been reported by many workers of different Government and non-government organizations. The regional litho-stratigraphic sequence is given in the table 1 and geological map of the regional area is given in the figure (Fig. 5).

Table 1: Litho-stratigraphic succession & rock types around the regional area

Stratigraphy equivalent	**Group/Formation**	**Lithological Description**
Trans Himalaya	Lohit Granitoid Complex (LGC)	Granites, Garnetiferrous Gneiss, leucogranite, Diorites, migmetites and pegmatites, Mica schist with minor quartzites
~~ Walong Thrust ~~~~~~		
	Etalin Formation	Garnet-kyanite gneiss, amphibolite, schist, quartzite, marble
~~ Lohit Thrust ~~~~~~		

Higher Himalaya	Tidding Formation	Chlorite schist, serpentinites, intrusive granodiorite, quartzite, crystalline limestone, graphitic phyllite / schist
~~ Tidding Thrust ~~~~~~		
Higher Himalaya Lesser Himalaya	Mayodiya Group/ Yang Sang Chu Formation Lalpani Group	Chlorite-phyllite lenses of serpentinite garnet, sillimanite, graphite schist, quartz-muscovite, schist, garnetiferous amphibolite Garnet-biotite schist and gneiss, augen gneiss, banded gneiss, carbonaceous schist, micaceous quartzite, crystalline limestone and amphibolite
~~ Lalpani Thrust ~~~~~~		
Lesser Himalaya	Sewak Group	Sericite-chlorite puckered phyllite, foliated sericitic, quartzite, quartz porphyry, mylonitic augen gneiss and Schist, Gneiss & Crystalline Limestone
~~ Mishmi Thrust ~~~~~~		
Recent Deposits	Brahmaputra Alluviums	Alluviums, Sand, Silt and Flood deposits

The Lohit Valley section comprises four major NW–SE trending lithotectonic units: the Lesser Himalayan rocks, the Mishmi Crystallines, the Tidding Suture Zone and the Lohit Plutonic Complex. The geology of the Lohit Himalaya is quite different from that of the area in the west. It contains the NW-SE tendering metamorphic belt (comprising quartzsericite schist, augen gneiss, kyanite schist, chlorite-actinolite schist with crystalline limestone and serpentinite) between Brahmaputra alluvium (Mishimi Thrust) and Lohit Thrust and is continuing into metamorphic of Siang – district across Siang fracture to the NW. The metamorphic belt is overridden along NW-SE Lohit Thrust by Diorite-Granodiorite Complex of Mishimi block and terminates along Siang fracture. Garnetiferous amphibolites are also been reported as small bands within the main Diorite-Granodiorite Complex of Mishimi block. Syntectonic diorite-gneiss, late-tectonic hornblende granodiorite and biotite leucogranodiorite, hornblende schist, amphibolite, metadolerite and few bands of crystalline limestone are also observed.

6.1 LOHIT GRANITOID COMPLEX (LGC)

The LGC forms the most conspicuous unit in the eastern Arunachal Pradesh extending from Namcha Baruwa in the northwest to Dapha Bum Range in southeast abutting against the Naga-Patkai ranges along Mishmi Thrust. It consists of varieties of plutonic rocks with high grade metasediments which include diorite, granodiorite, tonalite, hornblende-biotite granite and leucogranite. The detailed characteristics of this group have been discussed below.

Granitoids of Lohit Valley:

The NW-SE trending Granitoid complex is made up of diorite, tonalite, granodiorite, hornblende granite, leucogranite, apelites, tourmaline bearing pegmatites, biotite rich gametiferous gneiss, banded gneiss, schist and marble bands. Diorite is the most dominant rock units observed in the Lohit valley. In general, the rock is mesocratic and foliated with variable proportion of felsic and mafic constituents. Several outcrops of metanorite within the diorite are encountered between Kongra and Changreilang in Lohit valley (Kumar et.al, 2000).

The granodiorite of the LGC is mostly gneissic with alternate bands of the quartzo-feldspathic and ferromagnesian minerals. The mineral assemblage is represented by plagioclase, K-feldspar, quartz, biotite, muscovite, hornblende, pyroxene, chlorite and epidote.

The youngest plutonic phase of the LGC is represented by coarse to very coarse leucogranitic granite exposed at places pegmatic around Walong and further north in the

Lohit valley, the rock is often pegmatitic. Mineralogically, it comprises quartz, K-feldspar, plagioclase, muscovite and biotite. Minor occurrences of tourmaline-epidote granite and tourmaline pegmatite are noticed near Nayul and Kamlang bridge, respectively (Kumar et.al, 2000).

Etalin Formation

A sequence of high grade metasediments, associated with the LGC exposed around Etalin in Dibang valley has been designated as Etalin Formation. The metasediments are represented by inter banded sequence of migmatitic gneiss, calc-silicate gneiss, marble, quartzite kyanite gneiss, mica-schist and amphibolite. The sequence shows general increase in metamorphic grade as well as proportion of amphibolite towards the north. In Lohit valley the Etalin Formation is exposed in several localities and mostly occupies the zone from south (diorite) to north (leucogranite). Amphibolite is one of the major constituents of the Etalin Formation. Strongly schistose to gneissose bands are exposed near Hayuliang and between Pranji and Halai in Lohit valley. The amphibolites often contain garnet porphyroblasts of lilac colour.

6.2 TIDDING FORMATION

The Tidding Formation comprises meta-volcanics showing varying degree of alteration to chlorite-phyllite or chlorite-actinolite-phyllite associated with thin crystalline limestone and carbonaceous phyllite. It is made up of basic volcanics, chlorite schist, serpentinised peridotites, crystalline limestone, foliated quartzite, grey marble with epidote and intrusive leucogranite. The ophiolitic melange sequence of Tidding Formation tectonically lies above the high grade rocks of the Mayodiya Group along the Tidding Thrust, which passes through north of Pyunli in Dibang valley and east of Tidding in Lohit valley. In the vicinity of the thrust zone, the basic volcanics of the Tidding Formation have been altered to chlorite schist and the interbedded quartzite shows development of mylonitic foliation.

The contact between the Tidding Formation and the LGC has been interpreted as a thrust (Lohit Thrust) by Nandy and Basak (1966-67), According to Kumar, et. al, 2000 the contact is tectonic in the Siang and Dibang valleys but in the Lohit valley the tectonic nature of the contact is not clearly discernible and minor intrusive bodies of diorite are frequently found. Minor intrusions of granodiorite are also recorded, particularly in the vicinity of the LGC. The ultramafics show alteration to serpentinite which are well exposed at Tidding and also mapped near Myodia Pass, Mayi hills (Babu and Das, 1990), north of Tuting and Rayalli (Kumar, 2000). The serpentinite is composed of antigorite, lizardite and epidote.

6.3 YANG SANG CHU FORMATION:

This unit comprising mostly by graphitic metapelite is best developed in the Yang Sang Chu valley (Singh and Malhotra, 1983b). In Dibang valley area it has also been described as Myodia Formation. The YSC Formation consists of garnetiferous graphitic phyllite, schist and schistose amphibolite. Development of staurolite and sillimanite are noted in the lower part of the sequence and one of the characteristics of the YSC Formation is that it displays upward decrease in grade of metamorphism (Kumar, et.al, 2000). Minor occurrences of garnetiferous amphibolite showing weakly developed gneissosity are found in the Siang river section (Kumar, et.al, op .cit.) and south of Salangam in Lohit valley section.

Mayodiya Fm.

The extensive succession of the high-grade metamorphics constituting kyanite-sillimanite bearing garnet-biotite schist and gneiss, psammitic gneiss, streaky gneiss, foliated quartzite, amphibolite and dolerite dyke well exposed around Mayodiya Pass on Roing-Anini road in Dibang valley. It tectonically rests over the medium grade metamorphics of the Lalpani Group along the Main Central Thrust (MCT) which passes through the south of Mayodiya Pass in Dibang Valley and east of Lalpani in Lohit valley. The MCT demarcates the plane of abrupt change in grade of metamorphism and composition of lithology. The coarse grained kyanite-sillimanite bearing schist and gneiss of the unit is tectonically underlain by the fine grained garnet-biotite schist and gneiss of the Lalpani Group. It may be interesting to note that throughout the extension of the MCT in the Lohit and Dibang valley, the kyanite-sillimanite bearing schist and gneiss are highly sheared and mylonitized while the underlying fine grained foliated micaceous quartzite and carbonaceous schist of the Lalpani Group is highly sericitized and crushed.

6.4 THE LALPANI GROUP

Lalpani Group mainly consists of garnet-biotite schist and gneiss, augen gneiss, banded gneiss, carbonaceous schist, foliated micaceous quartzite, crystalline limestone and amphibolites. The medium-grade metamorphics exposed around the village Lalpani on the Tezu-Walong road in the Lohit valley has been named as the Lalpani Group. It tectonically rests on the low-grade metamorphics of the Sewak Group along the Lalpani Thrust which passes through north of Tiwari Gaon in Dibang valley and east of Sewak Pass in Lohit valley. The Lalpani Thrust demarcates the plane of abrupt change of grade of metamorphism. The rocks of the Sewak Group representing green schist facies of metamorphism, in contrast to the Lalpani Group rocks showing amphibolite facies and inverted metamorphism. A major 5 km wide slump zone has been observed within the crushed carbonaceous schist of Lalpani Group at Lalpani in the Lohit valley referred as Lalpani Slump Zone which has caused subsidence as well as· slumping of road within 3 to 4 km stretch from Lalpani towards Tidding. This slump zone is very crucial and important because it could be related with the reactivation of Lalpani Thrust

6.5 SEWAK GROUP

The rocks of Sewak Group consist of sericitic-chlorite, mylonitic augen gneiss foliated sericitic quartzite, porphyry of quartz, phyllonite, crystalline limestone, schistose muscovite chlorite-quartzite phyllite, metavolcanics. mylonitized gneiss, crystalline marble, impure marble and greywacke. The rock units are exposed as a thrust sheet above Mishmi thrust to the south and as a tectonic window beneath Lalpani Group near Hunli Village known as Hunli Window. The chlorite-biotite grade metamorphics is thrusted along the Mishmi thrust above Quaternary alluvium of the Brahmaputra River. The rocks of Sewak Group belongs to low grade greenschist facies metamorphics.

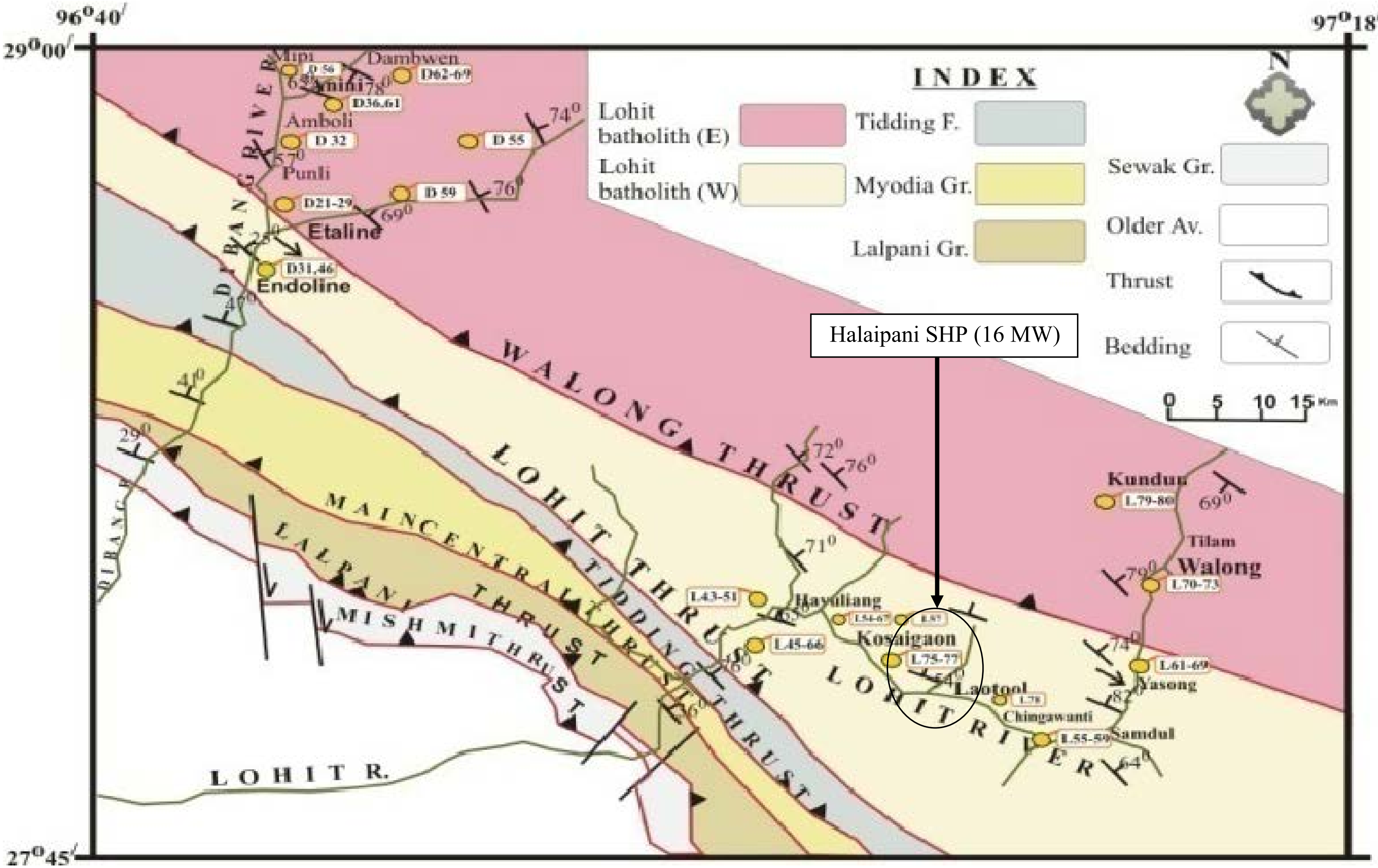

Fig. 5 Regional Geological Map of Eastern Arunachal Pradesh (Lohit Valley)

7.0 GEOLOGY OF THE PROJECT AREA

Geologically the area belongs to Lohit Granitoid Complex and geological survey has been carried out for all project components. Rocks throughout the area are very hard and massive Granitoid constituting diorite, granite, leucogranite and different grade of gneiss. Hill slopes are generally covered with debris deposit consisting in-situ rock boulders mixed with gritty soil and gravels.

As per the geological survey, following sequence of geological formations is encountered in the project area.

Recent Sediments	River Born Material	Boulders, Cobble, pebbles, Sand & Silt
	Debris Deposit	In situ rock boulders, gravels, pebbles, mixed with grit soil
Lohit Granitoid Complex (LGC)		Granodiorite, garnetiferrous gneiss, Granitic Gneiss & minor marble bands

River born materials are kind of loose large boulders, cobbles, pebbles, sand and silt found in the river bed as well as along the banks of the Halai River (Fig. 6 & 7). These materials are continuously modified during floods and in case of cloudburst or landslide. The large boulders and cobbles are observed throughout the river bed. These boulders are mostly made up of granite, diorite, gneiss and other volcanic rock. The size of these boulders may -vary from few cm to 7-10m.

Debris Deposit constitutes sandy, gritty soil as heterogeneous mixture having large numbers of huge boulders, gravels and pebbles generally angular to sub-angular gravel and finer sandy-silty matrix (Fig. 8 & 9). Rock boulders are mainly of granite, diorite, gneiss and amphibolite, schist mixed with insitu soil. Areas having these deposits are fairly stable and have forest cover with large tracts of cultivated slopes. The general slope of hill face made up of debris throughout the area is about 40°- 60°. In general, thickness of this deposit may vary as 3-5m in depth whereas in the slide portion exposure depth increases upto 7-10m.

Fig. 6 A view of river born sediments at Barrage Location

Fig. 7 A view of river born materials near Power House Location

Fig. 8 View showing the debris deposit noted near the Penstock Alignment

Fig. 9 A View of landslide beside the Anchor/Saddle block for penstock

Rock exposures of LGC members are observed throughout the left bank of River section. The area has dense vegetation as observed while traversing from Forebay Tank to Barrage, outcrop of rocks are noticed at few locations. The rock exposures are limited as the water conductor channel lies over the hill slope made up of such bed rock. Rocks are very hard, massive, medium to coarse grained and grayish in colour.

The main rock unit observed in the project area is diorite, leucogranite and granitic gneiss which are very hard, solid, jointed along foliation plane (Fig. 10). Mineralogically, these are composed of quartz, Feldspar, plagioclase, hornblende, tourmaline and biotite. Intrusions of diorite and Pegmatite veins are also noted in the Granitoid body on the right bank of Halai River near Barrage area (Fig. 11). There are three sets of joint are noted in the area which are closely spaced and persist for substantial distance (Fig. 12).

The rocks are moderately dipping in northward direction striking parallel to the river and the litho-stratigraphic succession is nearly uniform. Rocks are well foliated and highly jointed in nature. One Joint set are generally rough and filled with weathered material while another joint sets are closed and tight. The detail of Joint sets has been given below in Table 2. Surficial weathering is prominent along open joints and assumed to be fresh rock at shallow depth.

Table. 2 : Prominent Sets of Joint

Sets	Strike	Dip	Direction	Spacing	Persistence	Nature
J1	N 250° – N 70°	58°- 62°	N340°- N345°	2-2.5m	35-40m	Closed with 2-3mm aperture size
J2	N 070° – N 250°	55°- 60°	N 160°-N 170°	5mm - 10cm	45-50m	Prominent, Open, fractured & clay infillings
J3	N 180° – N 0°	76°- 80°	N 270°-N 275°	4-10cm	10-15m	Closed and tight

Fig. 10 A View of gneissic rock exposed below the Intake which is hard and solid

Fig. 11 A View showing rock exposure on the (a) Right Bank (b) Left Bank

Fig. 12 A View of jointed granodiorite on the left bank of Halai River

8.0 GEOLOGICAL APPRAISAL OF PROJECT AREA

8.1 BARRAGE SITE

At proposed Barrage site, Halai River is quite narrow flows through a span of 12-15m in the direction of N 190^0 E i.e. SW directions (Fig. 13). The proposed Barrage area (upstream & downstream) is having large sized boulders and cobbles which must be removed by blasting. River bed is full of river born materials mainly consist of loose boulders, cobbles of granite, granodiorite, gneiss & and damaged RCC block of Barrage. The Left abutment of the Barrage is having steep rocky slope compared to right abutment.

On the Left bank of Halai River, bed rock consists of granodiorite and augen gneiss, banded gneiss is found exposed. Rocks are hard, compact, and massive and jointed in nature. The left abutment slope is about 65°-70° with the presence of thick vegetation. From river bed to about 30m the sound rock is exposed which is very hard, strong and massive. The surface is slightly weathered and jointed. Three sets of Joints are noted in which the general trend of the rock is dipping towards the river bed at 55°- 60° in N 160°- N 170° direction.

The right bank hill slope along the Halai River at Barrage axis is made up of Diorite, gneissic rock which is very hard and massive in nature. The gneissic rock shows different degree of metamorphism. The surface of hill slope is covered with thick slope wash materials/debris deposit observed near the intake area. The right abutment area slope may vary as 50°-60° and is having massive rock which is mostly strong to very strong medium grained diorite up to height of 30-35m thereafter the rock slope is covered with slope debris. The litho unit of the right bank is represented by Granitoid body which is slightly weathered and pegmatite veins are prominent.

A major landslide has been observed at the right bank of the barrage axis which seems to be the main cause of intake damage (Fig. 14). The slide area is having loose in-situ rock boulders mixed with grit soil. The depth may vary as 7-8m towards hill or may be high.

The Left abutment of Barrage site is safe but right abutment shows some kind of slope failure as there is a landslide noticed over hill slope.

The Intake has been constructed on the right bank and partially damaged in flood (Fig. 15). The base of the intake area has washed away as that area constitutes debris deposit/river born materials along the flank of river.

It is suggested to do 02 nos. of boreholes at abutment location and slide zone to identify the depth of debris deposit for safer design and construction. The sediment carrying capacity of the river is very high and huge sediments have been observed in upstream area due to previous flood and cloudburst. The barrage structure design should be done on considering 1 in 100 years flood and free from scouring of river. Large boulders must be removed from river bed and foundation shall be done over hard rock formation. Grouting/shotcreting will be required at the abutment to seal open joint and loose sediments. The Barrage axis can be shifted 30-35m downstream side but it will lead to increase the height of Barrage. To work with the same axis, Slope protection measures must be carried out to protect the right abutment slope.

Fig. 13 A view showing the location of proposed Barrage site

Fig. 14 Views showing the slide at right abutment of Barrage Axis

Fig. 15 View showing the existing Intake structure

8.2 CHANNEL ALIGNMENT

Existing Channel passes through hill slope made up of Granodiorite rocks of Lohit Granitoid complex and debris deposit. The rocks are fresh, hard and massive in nature. The exposures are limited as the entire area has thick vegetation and already construction done over such rock (Fig. 16). The measured length of channel alignment is about 1944m (405m- Feeder Channel & 1539m- Power Channel) which crosses through few minor gully and seasonal Nala. Due to heavy rain some nalas/ gullys fed by heavy sediments in to channel at few places. That locations need to be covered with RCC. At places, The channel has been filled with muck and partially damaged. Moreover Channel is safe and minor repair and cleaning is required. Geological assessment states that the alignment is safe and passes over stable slope.

Fig. 16 A view showing the existing channel filled with sand/silt

8.3 DESILTING TANK

The 63m x 18m Desilting tank has been constructed over a gentle to low hill slope made up of consolidated debris and hard rock (Fig. 17). The area has dense vegetation and bushes cover. Outcrop of bed rock is observed at the back slope of D-tank which belongs is assumed that the structure has been kept over strong foundation.

The entry point of tank is damaged and subsidence noticed due to scouring of river. It has been observed that the foundation has been kept over consolidated debris which may eroded in heavy flood (Fig. 18). The main structure is safe and doesn’t show any movement which confer that the tank position has been kept over solid and hard rock.

Fig. 17 A view showing the existing D- Tank

Fig. 18 Another view showing damaged portion of D-Tank

8.4 FOREBAY TANK

The 66m x 10m forebay tank is constructed over a gentle hill slope made up of consolidated debris deposit (Fig. 19). The area has dense vegetation and bushes cover. Outcrop of bed rock is not observed in the area as the entire forebay area has been constructed. The structure is safe and in good condition. Only cleaning is required as the entry point has been filled with small quantity of slope debris. The tank location is geologically safe and stable.

Fig. 19 Views showing the existing Forebay Tank area

8.5 PENSTOCK ALIGNMENT

Four Nos., 1.3m dia and 174m long penstock pipe has been proposed over gentle to moderate hill slope. Penstock alignment traverses over hill slope made up of debris deposit which is partially consolidated (Fig. 20). A slide zone has been developed beside the alignment which shows the subsurface geology is made up of loose debris made up of rock boulders mixed with soil. Some Saddle/Anchor block has been eroded near road side due to loose nature of deposit. The slope angle is moderate about 45°-50° at its initial reach then it will drop at high angle about 70° and will cross NH 113 before it reaches to Power house.

It is suggested to have detailed slope stability assessment of alignment slope for the safe alignment under global failure condition. Also need to calculate safe bearing capacity at location of Anchor/Saddle block to examine the foundation failure at these critical structures.

Fig. 20 A view showing the hill slope for Penstock Alignment

8.6 POWERHOUSE SITE

A surface Power house has been proposed on the right bank of the Halai River. The proposed area has flat terrace made up of flood deposits such as river born sediments (Fig. 21). The back slope of the site has cut and fills materials and needs slope protection work. Exposure of bed rock is not observed as the entire area is having loose debris and flood deposit (Fig. 22). Few large boulders of variable size are noted at the proposed location. The access to the power house should be above from the HFL of the Halai River.

It is suggested to do 02 nos. boreholes at proposed PH site to assess the flood deposit thickness and depth of bed rock. The site also requires river training works for at least 1 in 100 years flood condition throughout the length from bridge to Power house complex for safe and suitable.

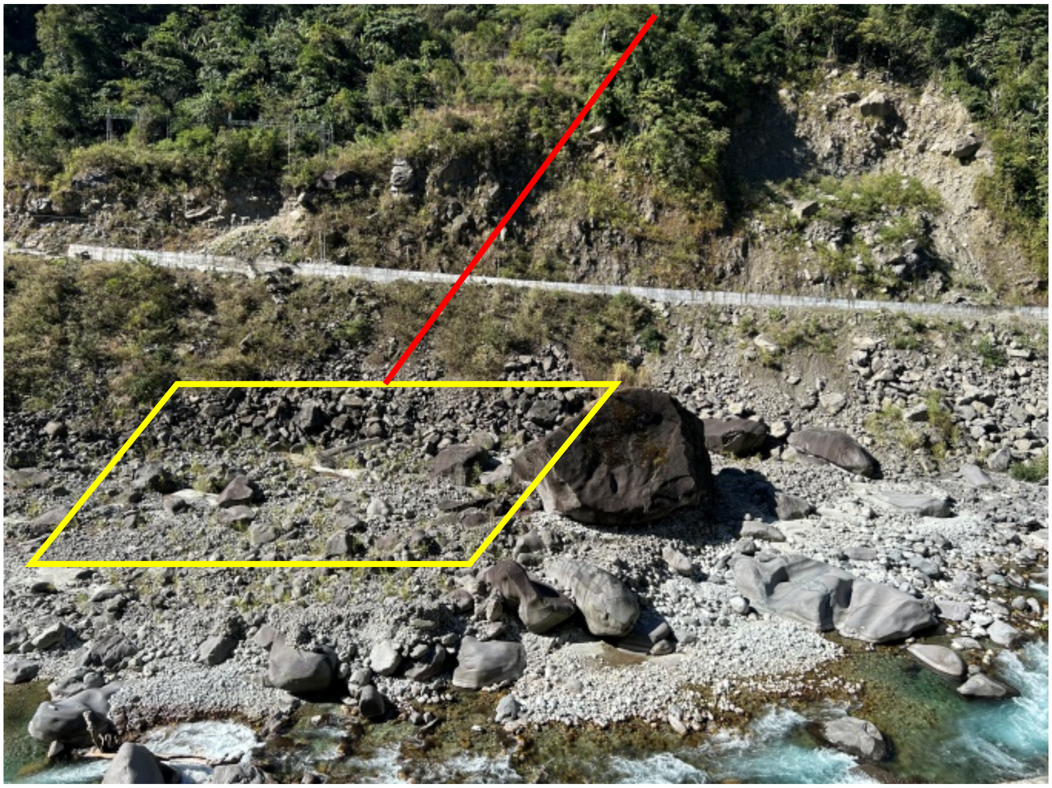

Fig. 21 A view showing the flood terrace where Power House is proposed

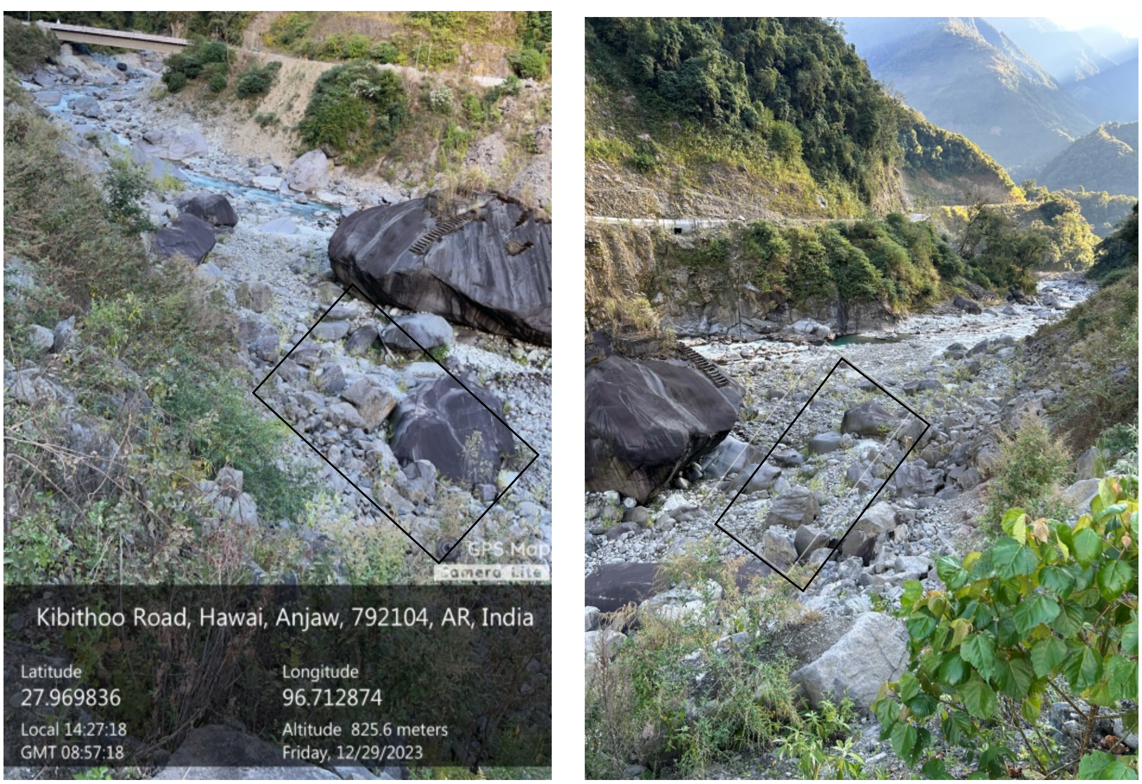

Fig. 22 Another views showing proposed PH site

8.7 SWITCHYARD SITE

Existing Switchyard site has been damaged due to slide occurred at the bottom (Fig. 23). It was planned over hill slope made up of partially consolidated debris deposit as it can be seen from roadside. Geologically the site is neither safe nor stable as this area is having loose sediments.

It is suggested to shift at another location which is identified on the right bank of Halai River beside National Highway NH 113 (Fig. 24). The site seems to be a dumping yard used for road construction which is more favorable as compared to previous site. Recommended two nos. borehole at the location for the safe design and strong foundation. The bottom/base of the slope must be protected by construction of a retaining wall which will prevent from scouring.

Fig. 23 A view showing damaged Switchyard

Fig. 24 A view showing the alternate location of proposed switchyard

9.0 SEISMICITY

The area falls under seismic Zone–V as per Seismic Zoning Map of the India as adumbrated in the Indian Standard Criteria for Earthquake Resistant Design of structures IS: 1893-Part I, 2002 (Fig. 25). Seismo-techtonically, Arunachal Pradesh comprises four geotectonic blocks viz., 1) The Himalaya, 2) The Mishmi Hills, 3) Naga-Patkai ranges of the Arakan Yoma Mountain and 4) The Brahmaputra Plains separated from each other by major tectonic fabric, characterized by distinct stratigraphy with different orogenic episodes and geological history.

Due to the collision of Eurasian Plate and Indian tectonic plates, the Brahmaputra valley and its adjoining hill ranges are seismically very unstable. In fact, the region's active seismicity has a significant impact on the hydro-geomorphic regime of the Brahmaputra system of rivers, causing landslides that result in the natural damming of rivers, flash floods due to the bursting of landslide-induced temporary dams, raising of riverbeds by siltation, fissuring and sand venting, elevation of existing river and lake bottoms and margins, creation of new water bodies and waterfalls due to faulting.

Arunachal Pradesh is the cordon sanitaire between the Indian and the Eurasian plates in North-eastern India. Dozens of earthquakes are recorded in this region every year. The earthquake activity in this region is due to the Indian plate diving (thrusting) beneath the Eurasian plate. This process can trigger powerful earthquakes. Earthquakes here are generally shallow but in the Naga hills some intermediate focus events have also occurred. All districts of the state of Arunachal Pradesh lies in Zone-V. Since the earthquake database in India is still incomplete, especially with regards to earthquakes prior to the historical period (before 1800 AD), these zones offer a rough guide of the earthquake hazard in any particular region and need to be regularly updated. According to GSHAP data, the state of Arunachal Pradesh falls in a region of high to very high seismic hazard (Fig. 26).

As already mentioned above, seismically the area constitutes one of the most active domains and high damage risk zone of the North East Himalayas. Keeping in view the geotectonic set up and active nature of seismicity, the area has been kept in highest active seismic zone. Other than the seismicity, the area is also vulnerable to landslides, cloud burst, high rainfall, etc. Therefore, the components/ structures have to be designed for the seismic load commensurate to Zone-V in addition to other static and dynamic loads. A seismic co-efficient of 0.15 g may have to be adopted on account of the thrust/fault zones and cross lineaments which are considered to be capable of generating earthquakes of magnitude 7 and above.

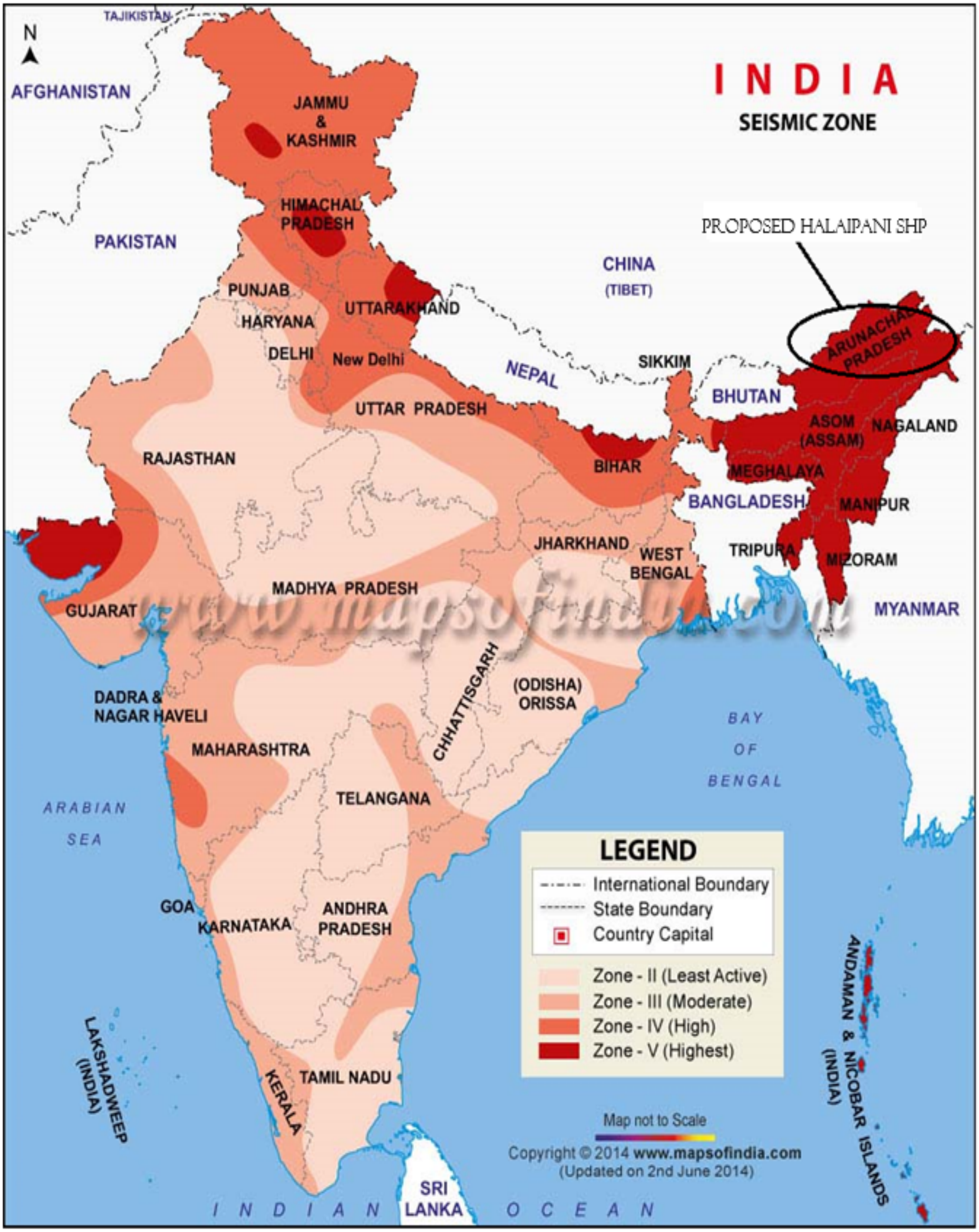

Fig. 25 Seismic Zonation Map of India

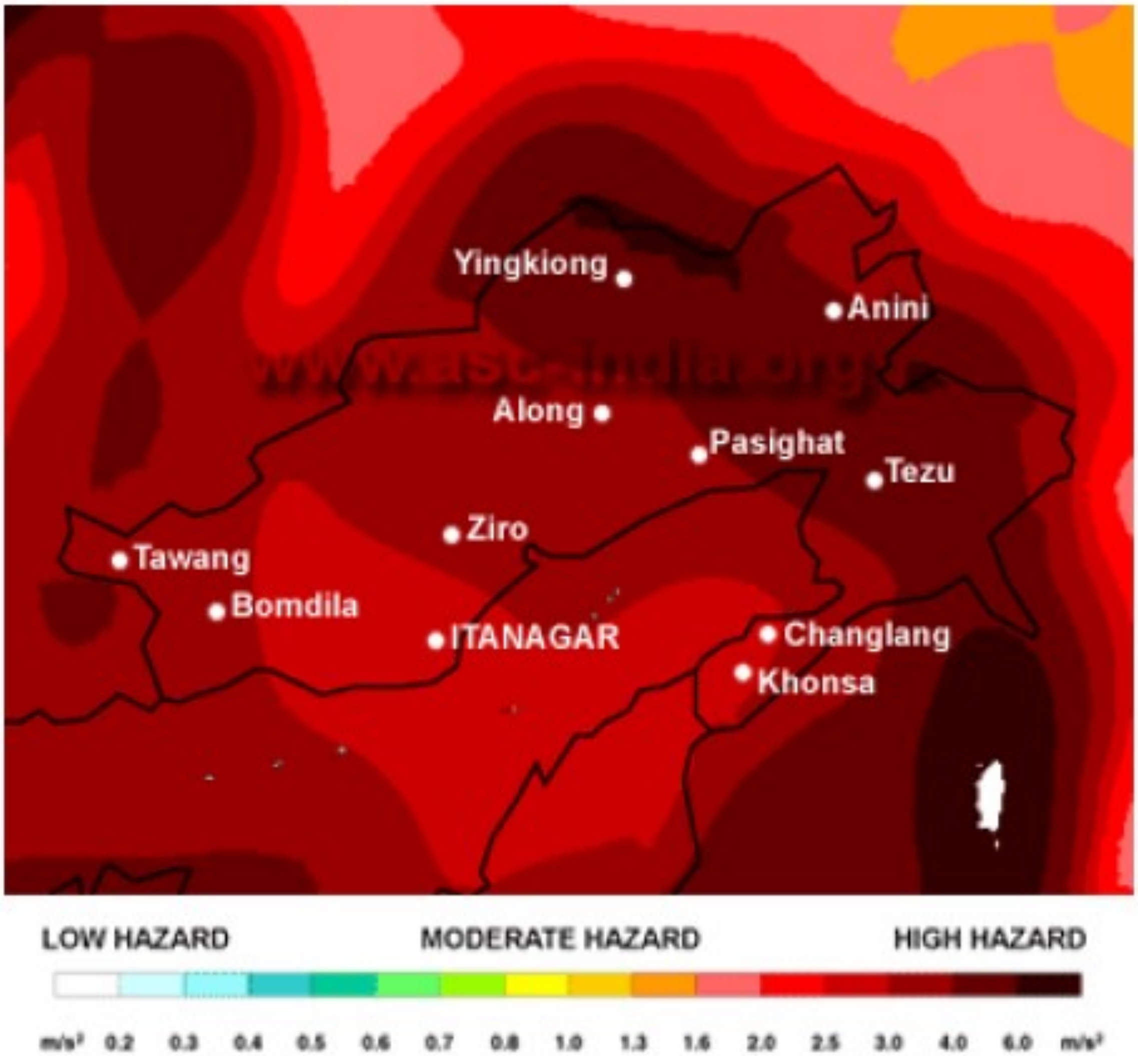

Fig. 26 Seismic Hazard Zone Map of Arunachal Pradesh

10.0 CONCLUSION

The geological features especially the lithology of rocks favor the development of the project. The geological appraisals are based on the survey done on 29.12.2023 and related research work. The detailed geotechnical investigation is very much essential as recommended in the geological appraisal section before taking up the project during construction or execution. Few places require slope protection work and detailed studies for safe and good construction.