International Journal of Applied Research 2018; 4(11): 11-20

ISSN Print: 2394-7500
ISSN Online: 2394-5869
Impact Factor: 5.2
IJAR 2018; 4(11): 11-20
www.allresearchjournal.com
Received: 08-09-2018
Accepted: 10-10-2018

Champak Babu Silwal
Central Campus of Technology, Dharan-14, Hattisar, Sunsari, Nepal

Kabi Raj Paudyal
Central Department of Geology, Tribhuvan University, Kirtipur, Kathmandu, Nepal

Correspondence
Champak Babu Silwal
Central Campus of Technology, Dharan-14, Hattisar, Sunsari, Nepal

Geological, engineering geological and geophysical study of the proposed Dotigad hydropower project area of Dadeldhura district, far western Nepal

Champak Babu Silwal and Kabi Raj Paudyal

Abstract
Geological, engineering geological and subsurface investigation was carried out in the Bagarkot area, with the aim of site selection for the hydropower development (5.78 MW Run-of-River (RoR) type project) from the Dotigad River in the Lesser Himalayan succession. Lithology of the area is divided into: the Schist and the Gneiss formations. Schist is distributed as finger like pattern within the gneiss mass. Petrographic analysis of representative rock samples reveals fresh rocks free from adverse micro-cracks. The proposed weir axis has well exposed bedrock on both banks, the desander and powerhouse area lies on the alluvium deposit of Dotigad, the area between the intake and powerhouse has mostly residual soil cover and the penstock alignment lies on the colluvium. The rock of the area has three plus random joint sets. The RMR and Q-value ranges from 68-57 and 24.4-9.266, respectively categorized as fair to good.
In subsurface study, 2D ERT survey was conducted using dipole-dipole array to access the depth of bedrock and other sub-surface geological condition. The result was verified by the drilling method in the key project areas. Falling head field permeability test was conducted and the coefficient of permeability was found to lie between the ranges $1.25\times10^{-5} – 7.06\times10^{-7}$ m/s indicating permeable to semipermeable soil. Analysis of geo-technical parameters of rock mass was done using the data from the field and their empirical relations. Average in-situ deformation modulus ranges between 33.51-19.09 Gpa. The in-situ horizontal and vertical stress ranges from 14.89-8.70 Mpa and 8.22-2.08 Mpa respectively, where their ratio (k) ranges from 4.9-1.79. The Damage Index of the rock mass along HRT ranges from 0.19-0.11, which indicates that stress induced damage does not occur. On the basis of overall study, the area is found to be feasible and suitable site in the context of folded and thrusted mountain belts of Himalaya.

Keywords: Engineering geology, 2D ERT survey, geotechnical, Dotigad hydropower

Introduction
Geological and engineering geological studies are very essential to assess the suitability of the site condition for various civil engineering projects. It gives details about the rock and soil, their classification, geological structure, stability of slope and many other stability related geological features which are very essential for the engineering purpose. The thickness of soil, depth of bed rock, weak zone and ground water condition are identified by using geophysical and geotechnical tools. Rock mass classification is one of the major tasks for engineering geology. Rock types, weathering condition, conditions of joints and ground water condition are studied to assess the stability condition of the rocks at and below the ground. Another factor of the engineering geology is the study of soil. Soil type, soil depth, its permeability and porosity, bearing capacity, shear strength, etc. play a vital role to design the load bearing structures on the surface.
The study was carried out with the aim of the geological, engineering geological, geotechnical and subsurface investigations in the area of Dotigad from Bagarkot to Khullakhet. The catchment of the Dotigad lies within the Mahakali River Basin with an area of 93.306 km^2 at proposed intake site. The gross head available for the design is 140 m and the design discharge is 2.816 m^3/s. The river is rainwater feed on the monsoon period. The Dotigad Hydropower Project (DHP) is the Run-of-River (RoR) type project. The proposed install capacity of project is 5.78 MW with the design discharge of 4.93 m^3/s and designed gross head of 140 m from amsl (above mean sea level).

Materials and Methodology

The geological and engineering geological mapping was done using the topographical maps (2980 10D and 2980 11C) at 1:25000 scale published by Department of Survey (1998), Government of Nepal. Geological field traverse along with the engineering geological field was done extensively in the area. Geological map was prepared and the rock sample collected during the field study was analyzed in the laboratory for petrographic study. For the Engineering geological mapping, the traverse was made on and around the major construction sites. The engineering properties of the rock and soil were noted. On the rocky outcrop, the rock type, discontinuities, infilling materials, weathering condition, strength and seepage conditions were the major properties of concern. The geo-morphological features, types of surface deposits and their depth were also noted in the field.

During soil survey, the field identification of soil was conducted. The soil was classified according to their origin and geologic features i.e. alluvium, colluviums and residual soil. Exposure of rocks was also depicted in the same map. The permeability of soil was also measured by using falling head field permeability test.

For the geotechnical study of rock mass Rock Mass Rating (RMR) (Bieniawski 1989) [2] and Q-system (Barton *et al*. 1974) [3] was adopted. The rock mass classification was done for the rock mass along the alignment of Headrace tunnel. Geo-mechanical classification using RMR system and Tunneling Quality (Q) (Stillborg 1994) [4] for the jointed rock mass has been carried out and the rock mass along the tunnel has been classified based on these standard classifications proposed by Bieniawski (1989) [2] and Stillborg (1994) [4]. The stress analysis along the HRT includes the in-situ deformation modulus (Em), In-situ stress condition, elastic and plastic behavior of the earth material and failure criteria.

In-situ deformation modulus (Em) of a rock mass in GPA can be determined empirically using the relations of RMR and Q-values along The HRT. The relation are, [$Em = 2RMR - 100$ for $55< RMR< 90$ (Bieniawski 1978)] [5], [$Em = 10(RMR-10)/40$ for $30<RMR<55$ (Serafim and Pereira 1983)] [6] and [$Em = 25 \log10Q$, for $Q>1$ (Grimstand and Barton 1993)] [7].

The analysis using rock cover is a very simple approximation and a more elaborate to analysis in-situ stresses. The vertical stress (σv) acting on a tunnel is estimated using [$\sigma v = \gamma z$] Where, γ is the unit weight of the overlying rock body and z is the depth below surface. Horizontal stress (σh) acting on the tunnel at a depth z below a surface can be estimated as, [$\sigma h = k\, \sigma v$] Where, k is the ratio of horizontal to vertical stress. The relation has the limitation in the Himalaya in which the additional horizontal stress due to the collision of Indian and Eurasian plate has to be considered.

For the estimation of Damage index (Di) the relation [$Di = \sigma max / \sigma c$] is used where σmax is maximum tangential boundary stress and σc is the unconfined compressive strength of the rock mass. The σmax Can be calculated as [$\sigma max = \sigma v\ (3k-1)$].

For the subsurface investigation using geophysical technique, the equipment Terrameter SAS 300C was used. The dipole-dipole array was used to measure the resistivity of the subsurface materials. The pseudo-section was produced from the data collected during 2D ERT survey and was converted to geological cross section. Based on the output of geophysical survey core drilling in different locations were recommended and conducted for the validation and assurance. Rotary core drill rig named Koken drill rig KL-2D was used for the drilling purpose. The litholog of the drillings were then compared with the geological cross section produced from the geophysical survey.

Result

Geology

The lithology of the area can be divided into to lithostratigraphic units (the Schist Unit and the Gneiss Unit) (Figure 1). The Schist Unit consists of grey to dark grey, medium-coarse grained, well-foliated schists (quartz-schist, two-micaceous schist, and intercalation of psammatic and pelitic schists in equal proportion). Quartz-schist is faintly to well laminated (lamina= 2 mm to 1.5 cm). Mostly, the outcrops of schist are crossed by a number of few millimeters to few centimeter thick pegmatitic and/or granitic veins, sills and dikes (Photograph 1(a)). Some of the intrusions are parallel to the foliation while the others are oblique or even perpendicular to the foliation (Photograph 1(b)). The most noteworthy feature is that some schist layers abruptly disappears within the gneissic bodies indicating magmatic digestion during its intrusion (Photograph 1(c)). At the contact aureoles, well developed hornfels are also noted (Photograph 1 (d)). These are the indicators of contact metamorphism.

There is limited distribution of schist in the project area (≈10% by distribution). It is found in the left bank of Dotigad at intake area, Junala area and around the power house area, in the right bank of the Dotigad (Figure 1). The general strike of foliation is NE-SW dipping towards north with 30º to 65º dip amounts.

The Gneiss Unit is widely distributed (about 90% by area) in the proposed project site (Figure 1). It consists of monotonous succession of coarse to very coarse augen gneiss (Photograph 1 (d,e)). Milky white colored plagioclase feldspar has formed the augen (max. diameter= 2.5cm) in the gneissic rocks. The average mineral composition of gneiss is visually estimated as feldspar (mostly plagioclase) ~50%, quartz~40%, and micaceous minerals~10%.

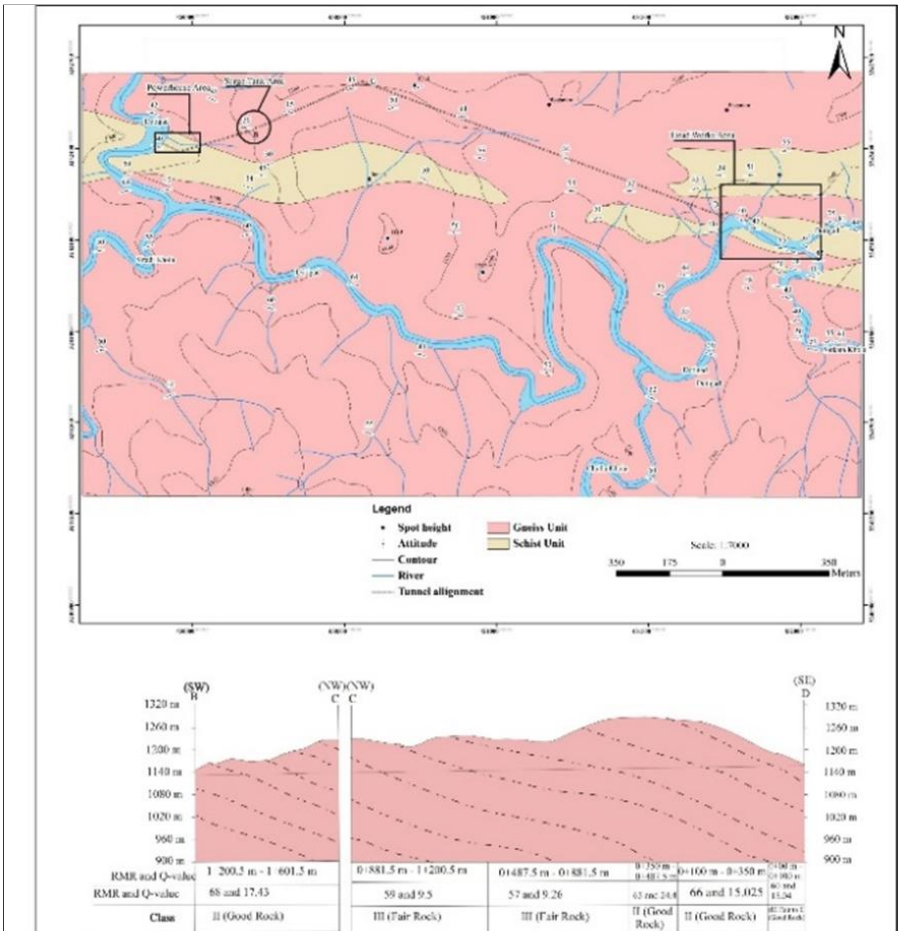
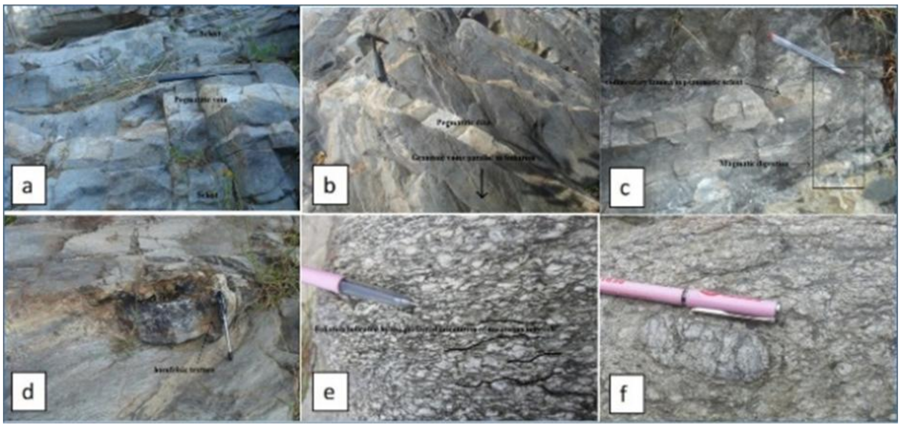


Fig 1: Geological map and Geological Cross-section along the tunnel Alignment.

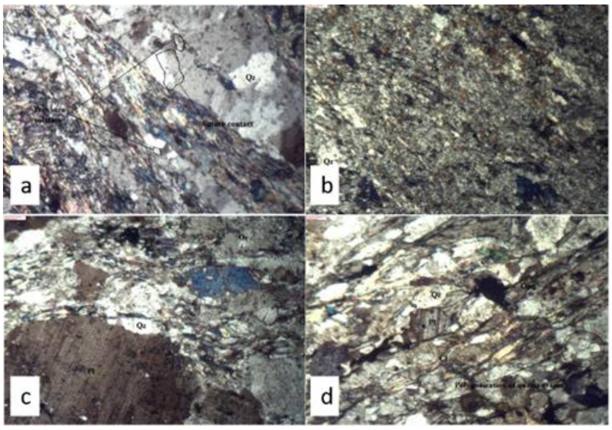
Some outcrops consist of quartz rich augen gneiss. Some anhedral to sub-hedral quartz are found abundantly in the gneiss. These quartz might be the secondary relict from the host rock quartzite as magma intruded in such rocks and could not digest it completely (Photograph 1 (f)). The diameter of these fragments ranges from few millimeters to few centimeters. The rock behaves like quartzite as it gives metallic sound while hammering, gives fringes of fires on struck, and shows hardness 7 and conchoidal fracture on breaking, however, the texture and structure justifies the gneiss. Gneiss is faintly to deeply weathered in hill slopes and ridges with dry and fragmentary soil development; however, in river side and road cut sections fresh outcrops are commonly found. Structurally the area consists of homoclinal rocks. No sign of major fold, fault and thrust were observed during the study. However, some mesoscale folds (tight to open) and some outcrop scale faults are observed.



Photograph 1: a) Outcrop of schist crossed by pegmatitic/granitic veins and dikes, b) Field photograph of pegmatite/granite dike/vein observed both parallel and oblique to the foliation c) Field photograph showing the abrupt cross cutting by augen gneiss to the laminated psammatic schist (indicator of magmatic digestion) d) Outcrop of hornfels developed at the contact between the pegmatitic/granitic dikes and schist. e) Outcrop view of well foliated augen gneiss (size of augen 2.5 cm in its longest axis) f) Relict quartzite (xenolith) within the gneiss

Petrographical Study

The petrological study of the representative rock samples was done for detail mineralogical composition, texture and many other optical and deformational properties, preparing thin sections.



Photograph 2: Photomicrograph of a) augen gneiss, b) hornfelsic quartzite with strong recrystallization of quartz grains, c) augen gneiss, d) quartzo-feldspathic gneiss Scale: 1 cm = 15 nm. Magnification: 10x4.

The augen gneiss sample (Photograph 2 (a)) shows that the rock is well foliated and medium grade with quartz grains showing the re-crystallization features. Pressure solution and suture contacts among the grains justifies medium to high-grade metamorphism of the rock under considerable pressure. The size of mineral grains supports the fact further. Quartz is strongly wavy. Pelitic minerals are slightly bent and some irregular micro-cracks are also noticed.

Hornfelsic quartzite (Photograph 2 (b)) shows Coarse to very coarse-grained, equigranular, granoblastic mass with bimodal distribution of quartz grains within the rock. Rocks in overall mass shows granoblastic texture. However, it has abundant non-aligned crystals with platy and prismatic habits. Two sets of highly disturbed foliation are marked by the preferred orientation of platy minerals. Though the grains are smaller, grain contacts is sharp and irregular which is the strong evidence of hornfelsic texture. The quartz grains have re-crystallization features. Indented and suture contacts among the grains justifies medium to high-grade metamorphism. Inclusions and micro-fractures are abundant. These cracks are filled with secondary mineralization as seen opaque under microscope.

Augen gneiss (Photograph 2 (c)) shows Plagioclase feldspar with well-developed augen shaped structures. Orthoclase is found altered to secondary chlorite/sericite and unidentified clay minerals. Secondary chlorites are found at the rims of the biotite crystals and shows isotropic behavior under cross-nicols. Mineralogical composition and texture clearly indicates its origin from the granite. Quartz grain shows the re-crystallization features. Pressure solution and amoidal contacts among the grains justify high-grade metamorphism of the rock. Quartz is strongly wavy and deformational lamellae are seen commonly. Biotite and muscovite books are widespread and deformed irregularly. Weathering is quite severe in these feldspars.

Quartzo-feldspathic schist (Photograph 2 (d)) shows Plagioclase feldspar as well-developed porphyroblast. Orthoclase is found altered to secondary chlorite/sericite and unidentified clay minerals. Quartz grain shows the re-crystallization features. Both indented and suture contacts are remarkable among the grains that justify high grade metamorphism. Quartz is strongly wavy and deformational bands are seen commonly. Some of the quartz grains show polygonization. Ground mass is re-crystallized and cemented by silica. Some randomly oriented micro-joints and fractures are noticed within the grains of the plagioclase.

Metamorphism

Presence of biotite in both gneiss and schist as an index mineral suggest that the area lies in the medium grade metamorphic zone with biotite isograde zone.

The area has gone two types of metamorphism. The presence of hornfels in the contact of granitic veins and schist indicate the contact metamorphism, whereas the gneiss which is the metamorphic product of granite (from petrographic study and field evidence) is evident of regional metamorphism. Mostly two sets of foliation indicate the rocks have undergone polymetamorphism in two different deformational events. Also, the secondary chlorites around the biotites indicate retrograde metamorphism.

Engineering geological study

In the present study, the detail engineering geological investigation was carried out in the scale of 1:7000 for the project area (Figure 2). The detail information of engineering geological investigation is presented in the following headings.

Weir Axis

Both banks of river along the proposed weir axis consist of bedrocks. Left bank consist of rocky hill slope while the right bank consists of gentle slope with bedrock (mainly schist) at the river bank followed by alluvium and colluviums in the higher parts (Figure 2). The trend of the river is almost parallel to the strike of bedrocks with alluvium not more than 5 m at the right bank. Based on joint condition, RMR and Q values of the rock are 55 and 8.5 respectively. The rock belongs to class III (fair rock).

In the right bank the alluvium is composed of sandy clay with few gravels and boulders. The composition of soil is visually estimated as >50% coarse material, 40% medium to coarse and remaining 10% fine clay, the soil is named as silty gravel. The soil mass consists of the sub-angular to sub-rounded clasts of gneisses and schists.

Desander Area

It lies in the paleo-channel or flood plain deposit followed by the colluviums in up slope section. The depth of bed rocks can be considered at the depth of ~5 m based on the nearby exposures. In between the river and desander, rock succession consists of schist with abundant quartz and granitic veins. The RMR and Q values of these bed rocks are found as 61 and 15.2 respectively with good rock of class II.

Soil is composed of 60% coarse materials (sand and gravel) and 40 % fine sand and clay. The soil is classified as sandy clay with little gravel. The uphill section of the desander basin is covered by the sparsely mixed vegetation. Some rock outcrops (weathered gneiss) are also observed. Present geomorphology (eg. concave landscape, scar slope etc.) indicates the presence of past landslides.

Tunnel Inlet Portal

The tunnel inlet portal is located at the right bank of the Dotigad about 280 m downstream from the confluence of the Dotigad and the Satkata Khola. Inlet starts from the moderate to steep rocky hill (65˚) with thin cover (about 0.5 m) of residual soil. The inlet portal consists of massive blocks of gneissic rocks (~UCS >150 Mpa). Value of RMR and Q of the rocks in this area is calculated as 60 and 15.04 respectively. The rock is described as good in class II. The hill slope is facing NE. Under visual estimation the soil is greyish brown, coarse grained sandy soil with angular fragments of gneiss. The inclination of the trees is towards the bottom of hill indicates creeping of surface soil over the slope.

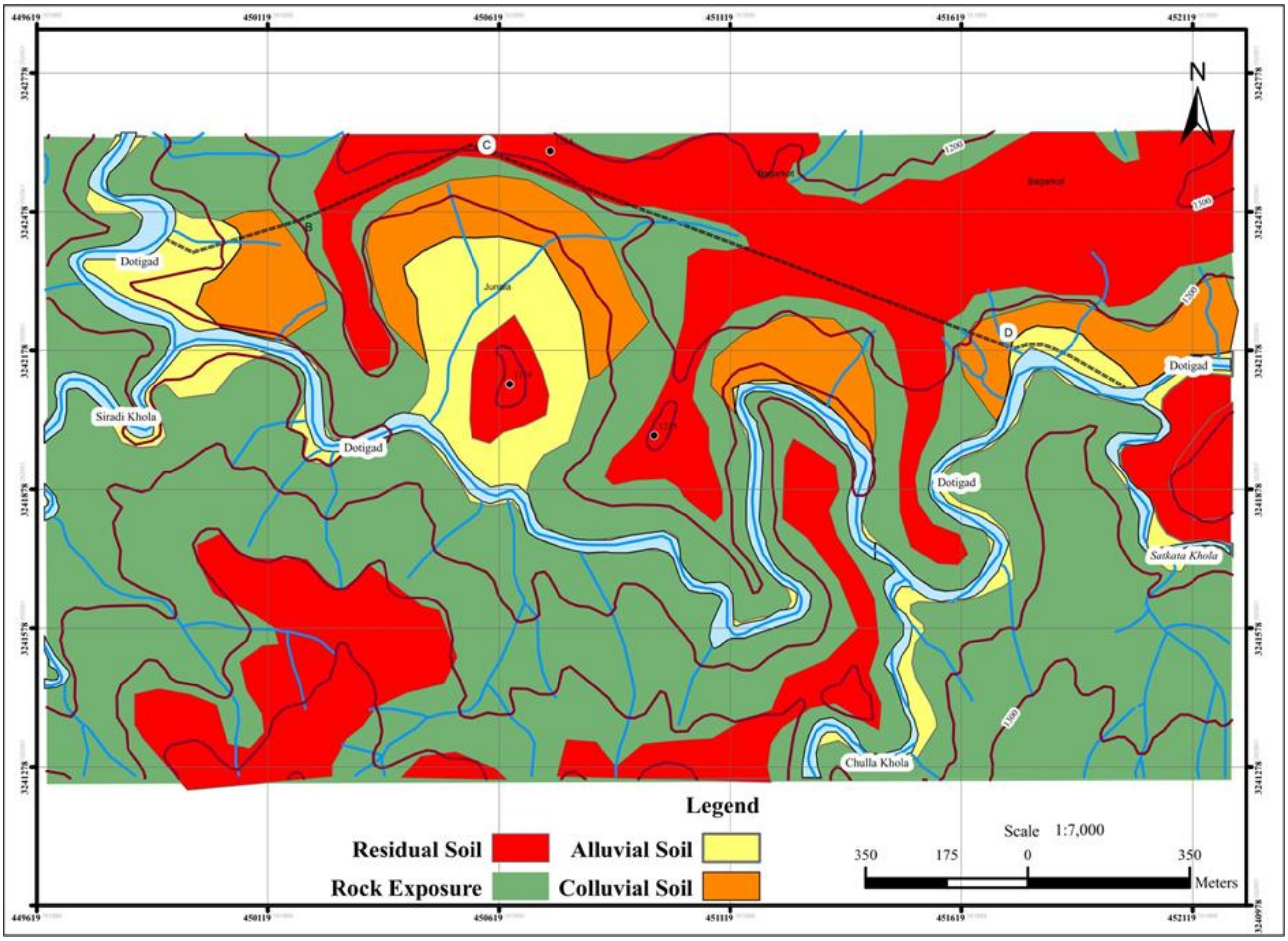


Fig 2: Engineering geological map of the area

Headrace Tunnel

The field mapping shows about 1601.5m long tunnel alignment with the diameter of 2.5m. In the tunnel alignment, monotonous succession of augen gneiss is observed (*Figure 1*). The rocks on the ridges and hill slopes are moderate to deeply weathered with soil (sandy soil) development. However, at the depth of tunnel axis, the rocks are considered as the faintly weathered to fresh. The average value of RMR in headrace tunnel area is found 53-68 and Q value of the rocks varies from 16-24 (*Figure 1*).

Tunnel Outlet Portal/Surge Tank

The location lies on steep slope (60º - 65º) with moderately weathered and fractured monotonous succession of augen gneiss. The RMR and Q values of these rocks are found to be 70 and 17.44 respectively (good rock -class II)**.** The steep slope and scar indicates the existence of old landslides in this area. The area is covered with thin cover (~0.5 m) of residual soil.

Penstock alignment

It forms the steep slope composed of gneiss (RMR=70 & Q=17.5) in the upper part and intercalation of schist and meta-sandstone with injected granitic-gneiss in the lower part (surface of which is covered with a layer of colluvium soils of about 4-5 m thick).

Powerhouse Area

It is proposed on the right bank of the Dotigad at Khullakhet, which is about 300 m downstream from the confluence of the Dotigad and the Siradi Khola. The altitude of the powerhouse site is 995 m. It lies at the alluvium deposit not less than 5 m depth followed by the colluviums in higher levels. The soil type of the power house area is clayey gravel to sandy clay. The gravel consists of fragments of schist, gneisses and meta-sandstones. Some boulders of few meters in diameter are also observed within the area. The exposure of bed rocks exists near the power house, at the right bank. The value of RMR and Q are found as 55 and 14.25 respectively. The rocks can be categorized under the fair to good.

Falling head field permeability Test

The field permeability test has been conducted in five different locations (Figure 8) by using falling head method. The litho-log and permeability values are presented in Figure 3.

The result of coefficient of permeability 'k', indicates the soil of the area as permeable to semipermeable soil ($k = 1.25\times10^{-5} – 7.06\times10^{-7}$ m/s).

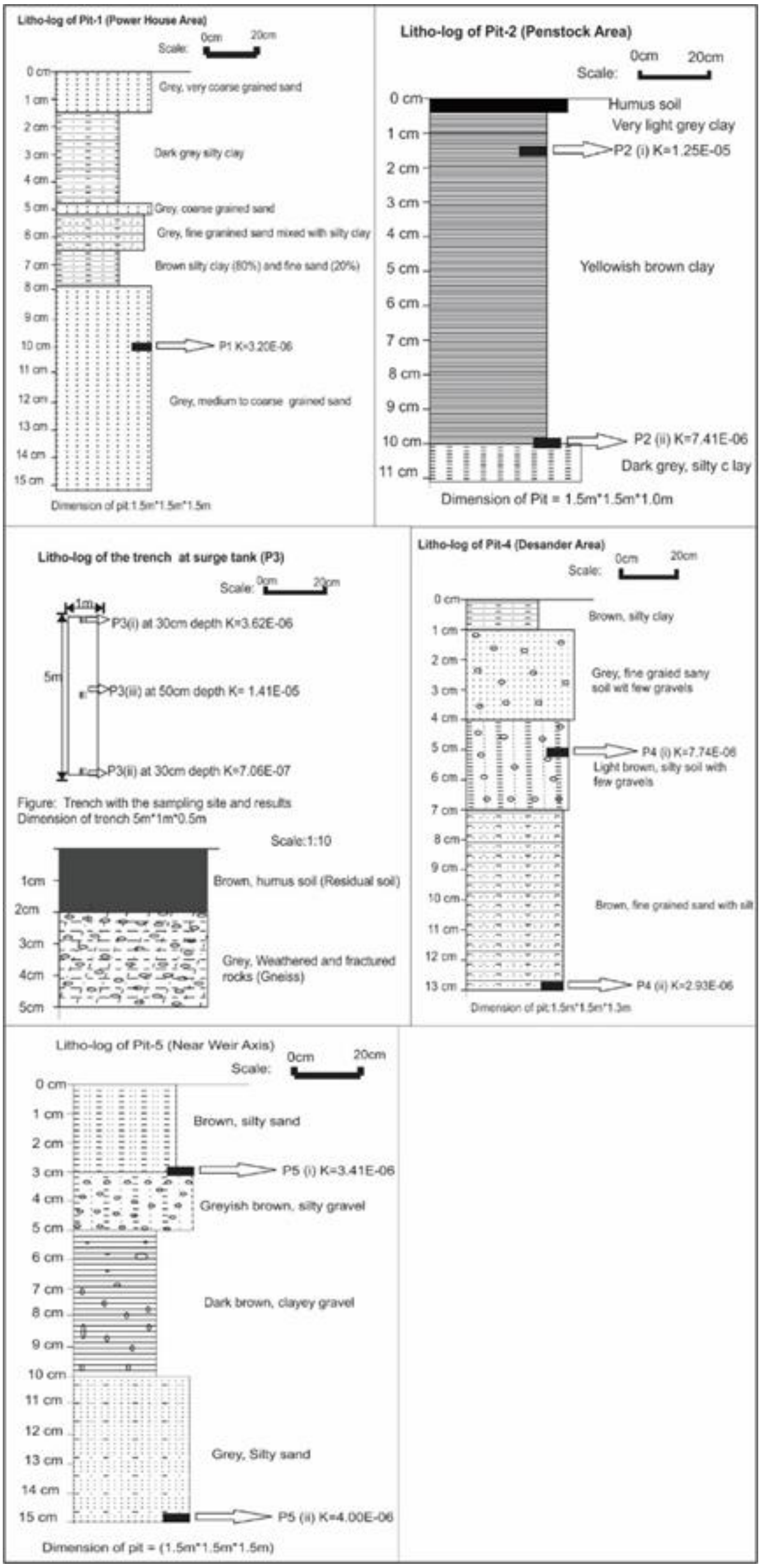


Fig 3: Litho-logs at the pit/ trench locations

Geotechnical study of HRT

Geotechnical studies include preliminary stress analysis and rock excavation support design along the headrace tunnel.

Estimation of in-situ deformation modulus

In-situ deformation modulus (E_m) along the proposed headrace tunnel is calculated using Rock Mass Rating (RMR) and Q- values. Average in-situ deformation modulus obtained along the headrace tunnel is shown in Table 1.

In-situ stress anaysis

The study area lies on the Lesser Himalayan Zone, there is variation of height within short distances. For a reliable result, in-situ vertical and in-situ horizontal stress as well as horizontal to vertical stress ratio (k) along the underground structures is calculated at the different interval (chainage) in the headrace tunnel which are presented on Table 1. Distribution of in-situ vertical and in-situ horizontal stresses are shown in Figure 2. The maximum rock cover for the underground structures (z), unit weight of the overlying rock (γ) which is assumed as 0.026MN/m^3 and deformation modulus E_m is used from Table 1, for the estimation of k. normally the value of k is less than 2 for the depth up to 1000 m. In the present study, their value ranges from 1.78 to 4.83. The maximum value, i.e. 4.83 lies between chainage1+200.5 m and 1+601.25 m and minimum value i.e. 1.78 lies between chainage 0+350 m and 0+487.5 m (Figure 4).

Table 1: Detail Calculations using empirical relation for geotechnical study

Location Chainage	RQD%	RMR	Q	E_m= 2RMR-100Gpa	E_m= $25\log_{10}Q$	Average deformation modulus E_m	Overbu-rden, Z(m)	unit weight(γ)	Vertical stress, σ_v	K=0.25+ $7E_m(0.001 + 1/z)$	Horizontal stress, σ_h=k σ_v	σ_{max}= $\sigma_v(3k-1)$	Di = σ_{max}/σ_c
0+00-0+100	69-73	60	15.04	20	29.4312	24.7156	40	0.026	2.08	4.7482	9.8763	27.5490	0.1377
0+100-0+350	54-58	66	15.025	32	29.4204	30.7102	140	0.026	7.28	2.0005	14.5635	36.4105	0.1820
0+350-0+487.5	71-75	63	24.4	26	34.6847	30.3424	160	0.026	8.32	1.7899	14.8918	36.3553	0.1818
0+487.5-0+881.5	53-57	57	9.266	14	24.1723	19.0861	88	0.026	4.576	1.9018	8.7027	21.5322	0.1077
0+881.5-1+200.5	55-59	59	9.5	18	24.4431	21.2215	79	0.026	4.108	2.2789	9.3619	23.9777	0.1199
1+200.5-1+601.25	50-54	63	15.23	26	29.5675	27.7837	54	0.026	2.808	4.0461	11.3614	37.8752	0.1894

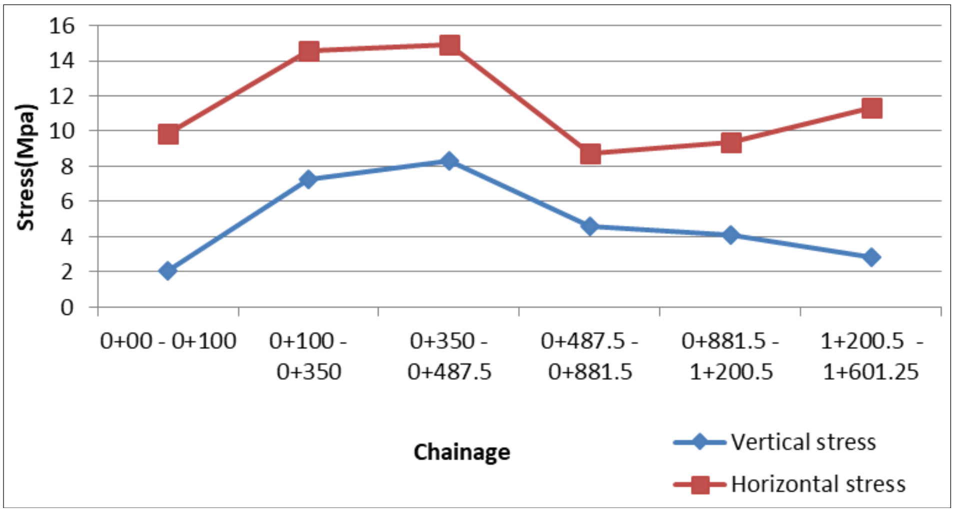


Fig 4: Distribution of vertical and horizontal stress along tunnel alignment

Elastic and plastic behaviour of rock using stress parameters

The damage index estimated for underground structure is presented in Figure 5 and is shown in Table 1. In the present study, the calculated value of Di along the underground structure ranges from 0.14 – 0.25 which is Di less than 0.4. Hence rock mass behaves as elastic behavior, no visible damage will occur along the tunnel length.

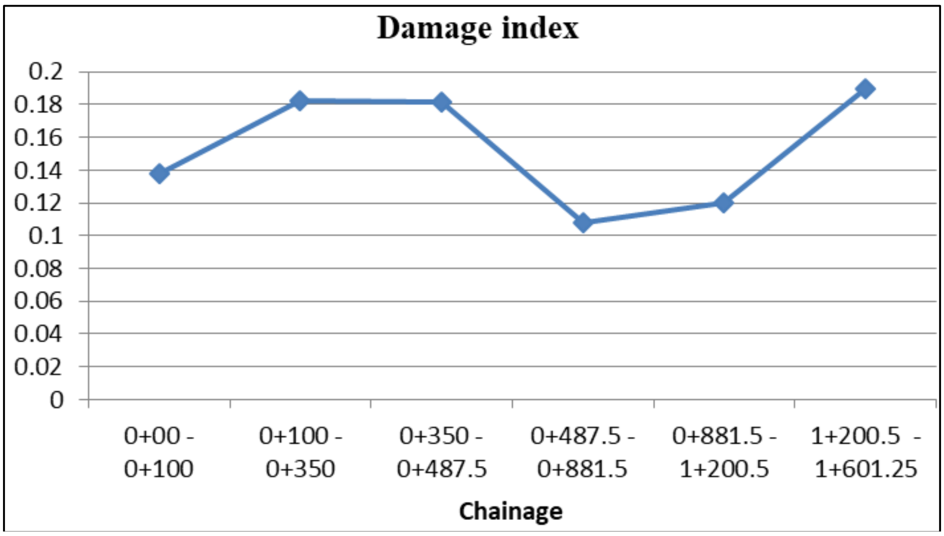


Fig 5: Distribution of damage index along the tunnel alignment.

Rock mass classification

The calculated RQD, RMR and Q value along the tunnel alignment is shown in Figure 6.

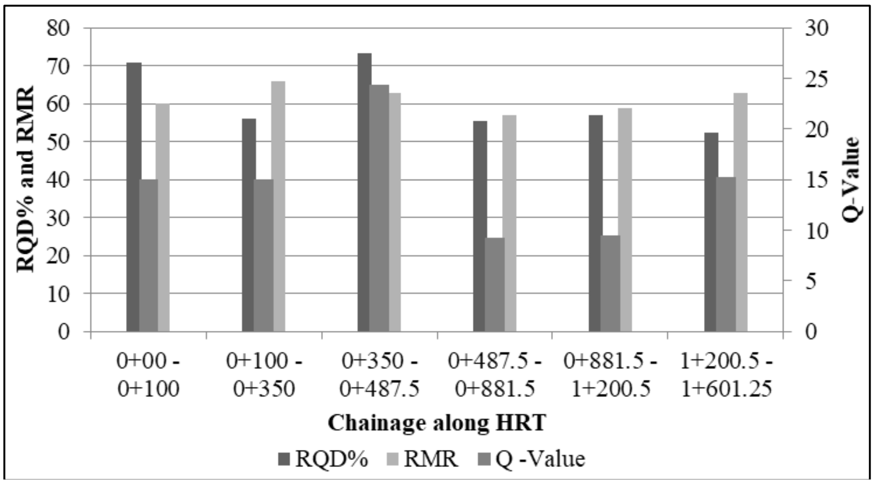


Fig 6: Distribution of different rock mass classification along the tunnel alignment.

Subsurface investigation

Altogether 16 profiles (total length 3090 m) has been surveyed in the investigation. The 2D electrical resistivity survey was conducted along five profile lines at the intake site, four around powerhouse, two along the penstock and other five along tunnel axis.

The geological materials are classified according to their resistivity values. Better quality bedrocks, moderately fresh normal bedrocks and semi-weathered to moderately weathered rocks with little fractures have resistivity value greater than 4000 Ωm, 2100 Ωm to 5000 Ωm, and 500 to 2600 Ωm, respectively. Weathered to semi weathered and partially saturated rocks with minor fractures or graphitic schist have resistivity value 200 Ωm to 500 Ωm, while highly weathered and saturated rocks having resistivity value range from 100 to 200 Ω m.

The rocks having resistivity value less than 700 Ωm are suspected as ground water bearing formation or saturated debris or sand or high graphite-bearing rocks. The materials on the top of the resistivity sections with irregular patterns of resistivity distribution having low to high value resistivity are considered as overburdens. The high resistivity value formations on the surface layer are possible to be some dislodged bedrocks or big boulders.

From the electrical resistivity tomography profiles, the subsurface materials were identified. The representative profile from the 16 different profiles is presented in Figure 7. This profile is 210 m long along the right bank at power house area and is parallel to the river flow direction. The tomogram is presented in Figure 7.

The section shows low resistivity layer (<1000 Ωm) that is observed all along the profile length. It is alluvial/colluvial soil that extends up to about 35 m at chainage 120 m. Intermediate resistivity layer (1000 to 2000 Ωm) is possibly weathered bedrock or dry alluvium. Fresh bedrock is present approximately below 35 m only. The bedrock has high resistivity which could be gneiss.

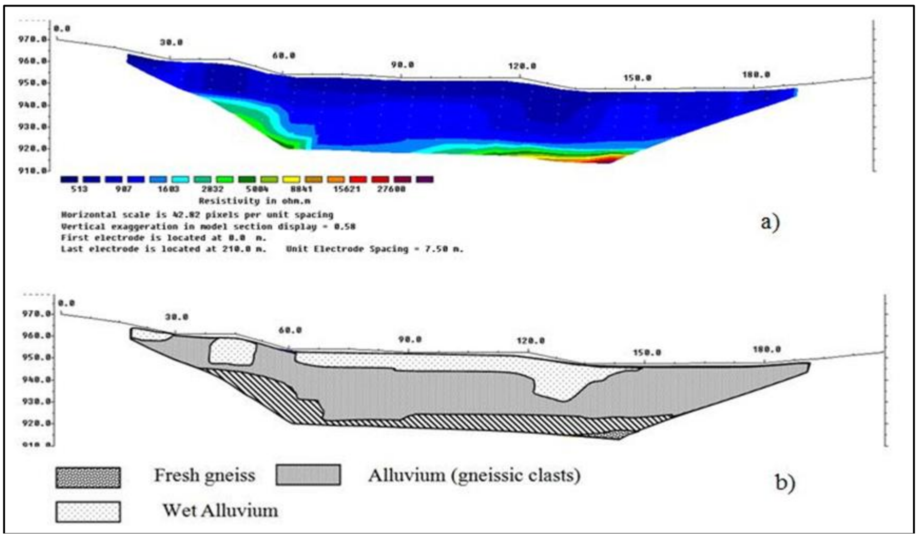


Fig 7: Inverse model resistivity section (a) and geo cross section (b) along profile 6.

The numbers, location and depth of drill hole were determined based on the geological mapping and geophysical result interpretation. The holes were mainly done where the major project components are located (Figure 8) to know the foundation material, overburden depth (rock head) and rock mass quality and shear /weak zones.

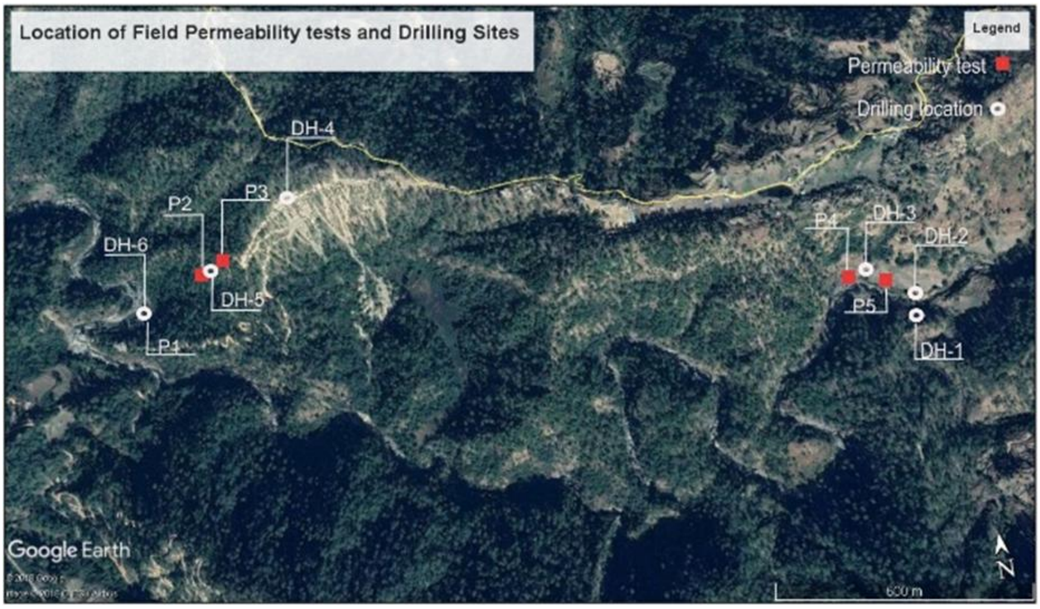


Fig 8: Location of permeability test (P) and drill holes (DH) around the study area.

It also confirms the doubt arises during geological and geophysical exploration. Despite the importance of core drilling, the total length of drilling was limited to the weir, forebay, surge tank, powerhouse area and the zone of probable weakness.

Comparison has been in all the lithologs from the drill holes and the geo-cross section produced by ERT survey. The representative comparison is shown in *Figure 9*.

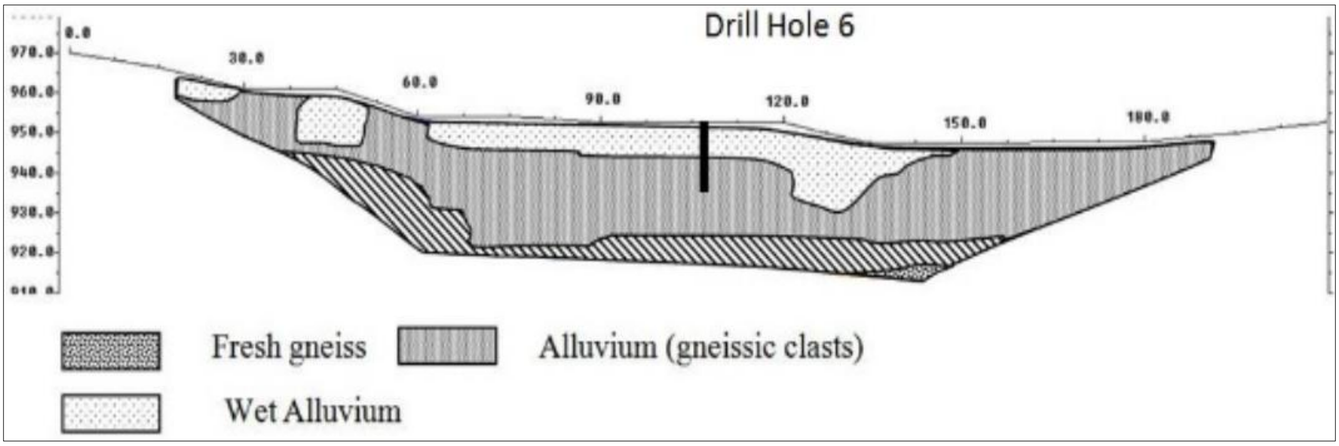


Fig 9: Geo-cross section of ERT profile-6 showing location of DH–6.

In drill hole DH-6 the lithology suggests 0-8.5 m alluvium soil followed by bedrock of gneiss whereas, the 2D-ERT profile -6 indicate about 10 m alluvium followed by fresh gneiss bedrock.

Discussion and Conclusion

The rocks of the Dotigad Hydropower Project (DHP) area has been mapped into two local lithostratigraphic units as the Schist Unit and the Gneiss Unit. The Schist Unit comprises the succession of pelitic and psammatic schist of biotite grade with occasional intercalation of meta-sandstones. The Gneiss Unit consists of the monotonous succession of augen gneiss. The rocks of the Schist Unit are highly intersected by veins and dikes of granitic and pegmatitic intrusions. At the contact with these magmatic intrusions with host rocks (schist and meta-sandstone), spotted hornfels are developed. Except for some small scale folds and faults, no large folds and faults are found in the proposed project area.

On the basis of engineering geological study, the thickness of alluvial soil is found less than 10 m in the intake and desander area while it is not more than 15 m in power house area. The residual soil cover on the ridge is supposed not to be more than 10 m depth. Few small to medium landslides are observed in the hill and ridge areas. One prominent landslide is observed in the area from where the tunnel axis passes. Rocks exposed in the banks of the river beds and lower reaches of the ridges are faintly weathered while it is moderate to high in the hill slopes and ridges.

From geological and engineering point of view, the intake area is found most suitable for weir axis and desandar basin for proposed hydropower development. The intake portal area and adjacent hill would be stable after some engineering maintenance. The headrace tunnel alignment is also suitable for the proposed tunnel axis. The surge tank and penstock area, however, situated in the steep land with moderately fractured and weathered rocks.

Geomorphology indicates the presence of old landslide scars in the penstock area, which may reactivate again in future. Precaution should be made before or during hydro-power development. The power house area is located geologically in the sound and suitable area.

Support design for the construction of the underground structures based on RMR, Q and RQD suggests systematic rock bolts and shotcrete.

On the basis of overall geological and engineering geological investigation, the site is found feasible for the project and in context of rugged and fold-and-thrust belt of Nepal Himalaya; the area is the most suitable one from its geological stability point of view.

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