DAM MASS RATING, A GEOMECHANICS CLASSIFICATION, OF THE ROCK MASS OF DHAP DAM SITE, SHIVAPURI-NAGARJUN NATIONAL PARK, CENTRAL NEPAL

A Dissertation Submitted to the

CENTRAL DEPARTMENT OF GEOLOGY
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In Partial Fulfillment of the Requirement for the Award of Degree of Master of Science in Engineering Geology

By

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RECOMMENDATION

Under my supervision, this dissertation entitled **“DAM MASS RATING, A GEOMECHANICS CLASSIFICATION, OF THE ROCK MASS OF DHAP DAM SITE, SHIVAPURI-NAGARJUN NATIONAL PARK, CENTRAL NEPAL”** of Mr. Sunil Man Singh is approved for the examination and is submitted to Tribhuvan University in partial fulfillment of the requirements of M.Sc. Degree in Engineering Geology.

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On the recommendation of the Supervisor and Associate Professor Dr. Naresh Kazi Tamrakar this dissertation work of Mr. Sunil Man Singh is approved for the examination and is submitted to Tribhuvan University in partial fulfillment of the requirements of M.Sc. Degree in Engineering Geology.

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The dissertation work of Mr. Sunil Man Singh entitled **“DAM MASS RATING, A GEOMECHANICS CLASSIFICATION, OF THE ROCK MASS OF DHAP DAM SITE, SHIVAPURI-NAGARJUN NATIONAL PARK, CENTRAL NEPAL”** was examined by the following board of examiners and was accepted for the partial fulfillment of the requirements of M.Sc. Degree in Engineering Geology.

BOARD OF THE EXAMINERS

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(Internal Examiner)

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Sunil Man Singh
February, 2020

ABSTRACT

Design and build of Dhap Dam has been proposed to impound the monsoon rain upstream the dam to allow the adequate flow in the Bagmati River during the dry seasons. The dam is proposed of 24 m height with top length of 172.7 m which is supposed to raise the water of existing Chisapani Lake to 850,000 m^3. This research was carried out to identify the rock mass condition of the foundation footprint which the dam would rest upon. The geological and engineering geological investigations were based solely upon surface observation and were limited to the foundation footprint of 132 m × 90 m dimensions. Throughout the footprint the rock mass was banded gneiss of Sheopuri Formation, an extension of Higher Himalayan Crystallines, varying from Fresh to Residual grade of weathering. Two systems of rock mass classification were adopted: RMR and DMR. The RMR placed the rock mass of the study into Poor rock to Good rock and into Fair rock to Good rock at the left and at the right respectively from the streamflow, whereas the DMR classed five of the observation points into 'Concern' category with respect to the Degree of Safety of the dam against sliding demanding engineering remedy.

Keywords – Bagmati, Dhap, RMR, DMR, foundation, dam

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ABBREVIATIONS

BGC – Basic Geotechnical Classification
BRBIP – Bagmati River Basin Improvement Project
CDG – Central Department of Geology CF – Correction Factor
CFRD – Concrete Face Rockfill Dam
DMG – Department of Mines and Geology
DMR – Dam Mass Rating
DMR_{STA} – Dam Mass Rating for dam Stability
GCN – Gosainkund Crystalline Nappe
GERD – Great Ethiopian Renaissance Dam
GSI – Geological Strength Index
HHC – Higher Himalayan Crystallines
KCN – Kathmandu Crystalline Nappe
LH – Lesser Himalaya
MCT – Main Central Thrust
MT – Mahabharat Thrust
NATM – New Austrian Tunneling Method
pH – potentiality of Hydrogen
RMI – Rock Mass Index
RMR – Rock Mass Rating
RMR_{B} – Basic Rock Mass Rating
RMR_{BD} – Basic Dry Rock Mass Rating
RQD – Rock Quality Designation
RSR – Rock Structure Rating
R_{STA} – Rating of adjusting factor for dam Stability
STDS – South Tibetan Detachment Systems
UCS – Unconfined Compressive Strength

CHAPTER I

INTRODUCTION

1.1. Background

Following is a research carried out to classify the rock mass of the foundation footprint of Dhap dam, Chisapani, Shivapuri-Nagarjun National Park, in order to identify safety of the dam against sliding regarding the outcrop scenario of the footprint and then to propose an engineering remedy in case the identification is found to be alarming.

A dam is desired to impound water for any of several reasons: flood control, water supply for human or livestock, irrigation, energy generation, recreation, or pollution control. Moreover, a dam must retain water, have enough safety against sliding and adjust itself to the terrain deformations without too much cracking in service (Romana, 2003b). And there are various types of dam.

Dhap dam is a proposed Concrete Faced Rock Fill Dam (CFRD) which is aimed to impound the stream flow upstream and raise the existing Chisapani Lake to store 850,000 m^3 of water. It is aimed to collect the monsoon rain and discharge the outflow to maintain adequate flow in the Bagmati River during dry seasons (BRBIP, 2013). Table 1 gives the salient features of Dhap Dam.

However, because the purpose of a dam is to retain water effectively and safely, its water retention ability is of prime importance. “Guidelines for Operation and Maintenance of Dams in Texas” stresses that water may pass from the reservoir to the downstream side of a dam by:

1. Seeping through the dam
2. Seeping through the abutment
3. Seeping under the dam
4. Overtopping the dam
5. Passing through the outlet works
6. Passing through or over a service (primary) spillway
7. Passing over an emergency spillway.

Of the mentioned seven discharge modes of water from upstream – dam – downstream, seeping under the dam is a prime factor to invite the sliding of the dam which in turn causes the dam failure, to mar the downstream life and property with complete annihilation. To identify this sliding chances of the dam, if there is any, is the prime impetus of this research.

Table 1.Salient Features of Dhap Dam (Main Dam Design Report, revision 3, 2018)

Item	Description
Dam type	Concrete Face Rockfill dam
Dam height (D/S toe to crest)	24.00 m
Dam top Length	172.7 m
Dam crest elevation	2090.14 m asl
Upstream slope inclination	1V: 1.7H
Downstream slope inclination	1V: 1.7H
Crest width	8 m
Concrete face thickness	300 mm
Dam volume	53000 m3 (Tentative)
Normal Water Level (NWL)	2087.14 m asl
Freeboard (measured from the dam crest)	3 m

1.2. Location

1.2.1. Geographical Setting

The intersection of the longitudes 27º48'36"N to 27º48'50"N with the latitudes 85º27'18"E to 85º27'30"E at approximately 2090 m above sea level situates the study area of Dhap dam foundation footprint. The area is placed on almost the top of Shivapuri Hill in Shivapuri – Nagarjun National Park, Sundarijal at the North East border of Kathmandu, adjoined with Sindhupalchok to the East and with Nuwakot to the Northwest North region of the dam site. The dam site is 3 km southward and downward from a famous tourist retreat – Chisapani Bazar. The study area is about 350 m downstream of existing 3.5 m low dam constructed by Shivapuri-Nagarjun National Park some 27 years ago for the wildlife therein (Figures 1, 2, 3).

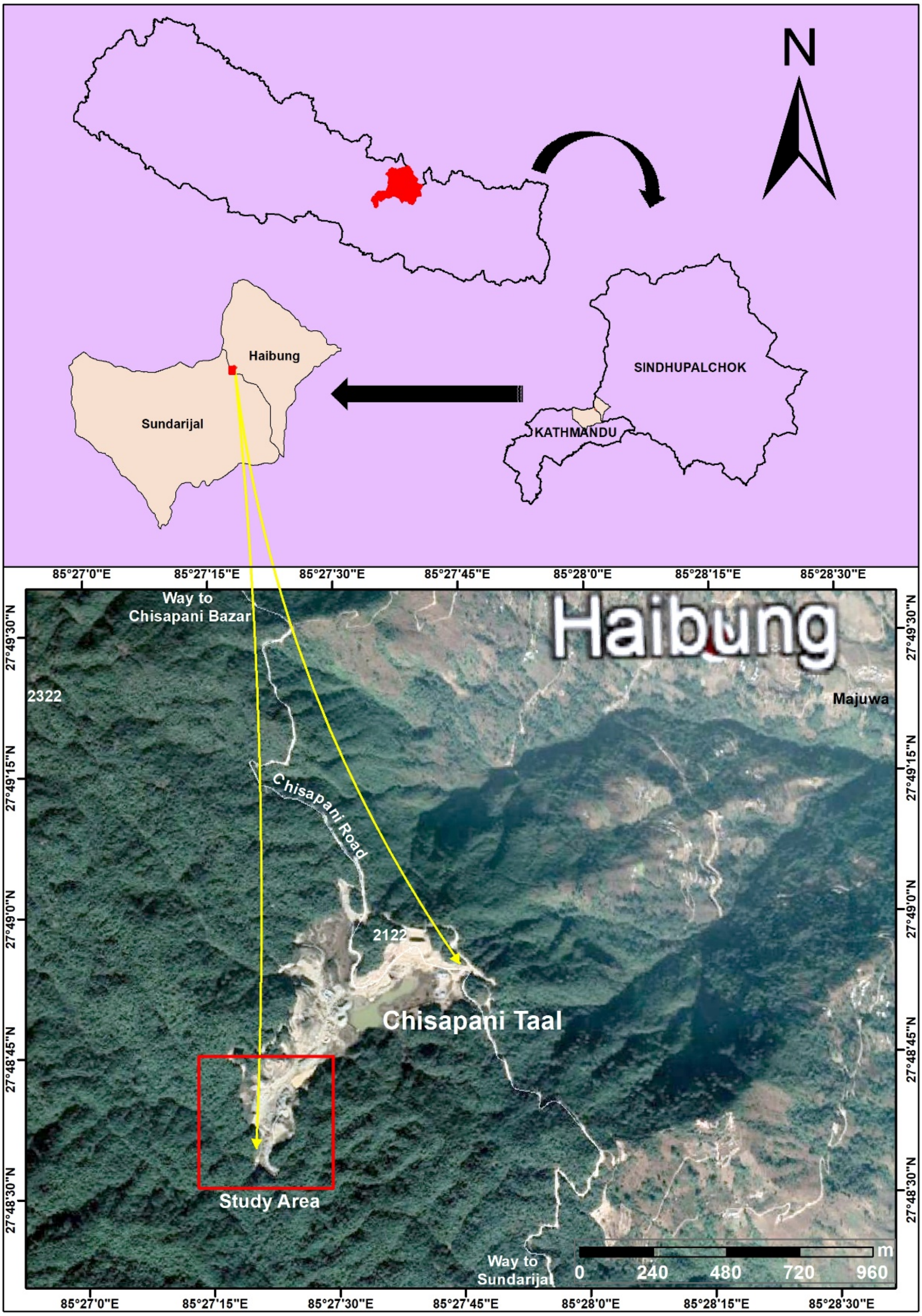


Figure 1. Location map of the study area.

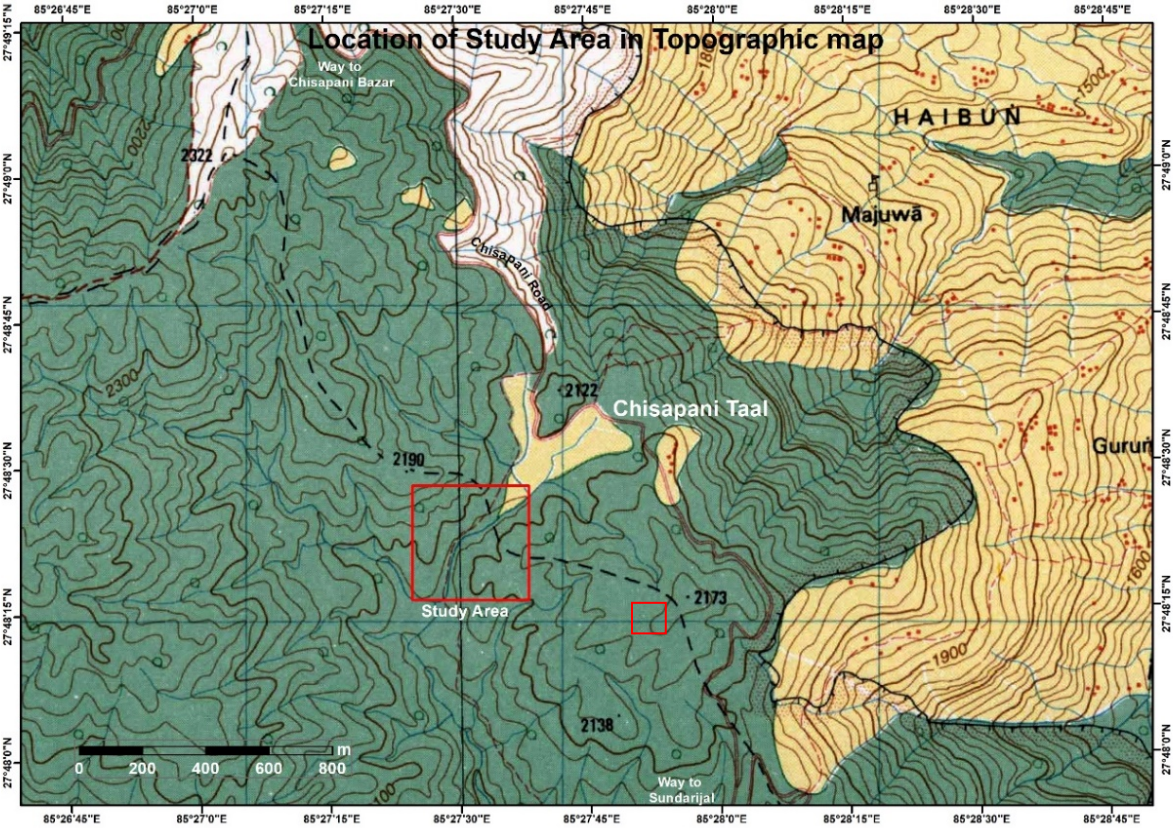


Figure 2. Study area in topographic map (sheet no. 2785 02D, Sundarijal)

1.2.2. Geological Setting

Based on the "Engineering and Environmental Geological map of the Kathmandu Valley", scaled to 1:50,000, published by the DMG, the geology of the Dhap Dam falls within the Sheopuri Gneiss Formation of Precambrian rocks. Regional geologically the dam site is located within strongly metamorphosed basement rocks of the Higher Himalayan Tectonic Zone. Physiographically, the region lies within the Fore Himalayan Geomorphic Unit. The main rock type in the dam construction site is gneiss. Tectonically, the zone is very active and is uplifting at a high rate due to the collision of the Indian and Eurasian tectonic plates owing to the development of major thrust faults. The major tectonic feature Main Central Thrust (MCT) lies north to the dam site about 5 km at about Patibhanjyang saddle. It is a part of an active seismic zone as in the other part of the Himalayan seismicity. The impacts of the 2015 Earthquake in Chisapani and adjoining areas is an example of the high seismicity in the region (Ghimire, 2018).

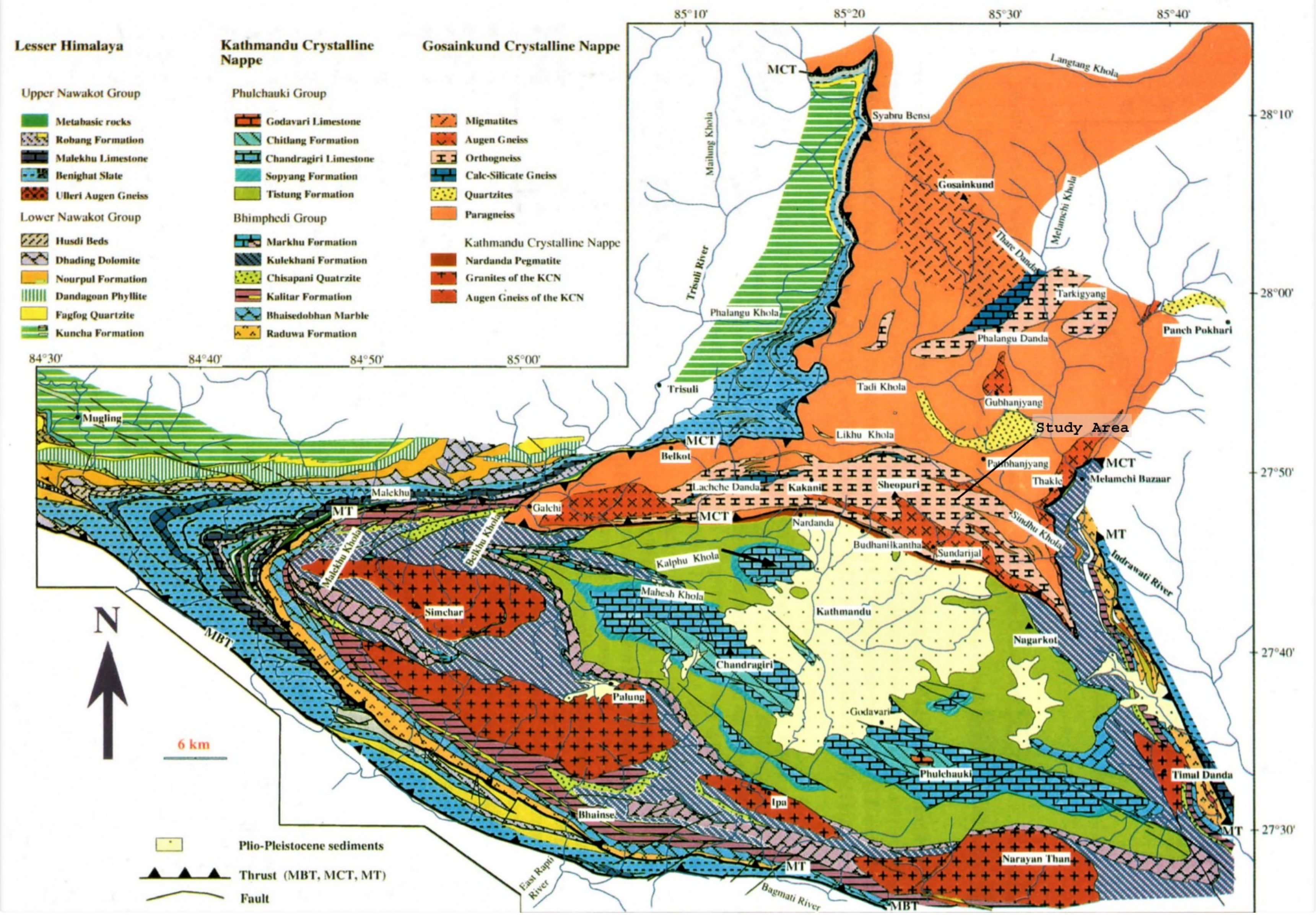


Figure 3. Study area in the geological map of central Nepal (modified after Rai, 2001)

Moreover, the amphibolite to granulite facies rocks of the Gosainkund Crystalline Nappe in the Gosainkund – Sheopuri region correspond to the rocks of the Higher Himalayan Crystalline (Rai, 2003).

1.3. Accessibility

The study area can be accessed through three roadways:

First there is an existing village road from Sundarijal via Mulkharka, Jhule, Bhanjyang and Dhap. The road is narrow though, only suitable to small vehicles.

Next there is the project road, which is the developed National Park – road through the forest that goes Sundarijal – Mulkharka – Jhule – Bhanjyang – Dhap, about 18 km.

And there is a road from Sankhu–Bajrayoginee–Ghumarichok–Manichood– Jhule–Bhanjyang to Dhap, about 23 km.

1.4. Topography and Drainage

The topography of the site is relatively rolling around small lake (the existing Chisapani Lake) which is surrounded by small hilltops reaching upto 2090 m asl, covered by slightly dense forest. There are about four valley streams contributing to the reservoir. The outflows of the existing lake serve as the headwaters of the Nagmati River, which then confluences to the Bagmati River. The dam site lies immediately downstream of the open grassy, swampy wetland within a hilltop valley surrounded by low forest covered hills. Immediately to the northeast of the catchment boundary and beyond the existing access road, the land falls away very steeply into the deep valley of the Sindhu Khola watershed towards NE and to Nuwakot in the NW.

1.5. Climate

The study area experiences warm temperate climate. The temperature ranges from 3°C in January to 30°C in June. Rainfall is caused mainly due to the Monsoon coming from the Bay of Bengal. The monsoon season falls during mid-July to mid-September. The maximum mean monthly rainfall of 607.4 mm has been observed in the month of July and the minimum mean monthly rainfall of 7.2 mm in December has been observed, based on 1994 – 2010 period, recorded at the confluence of Bagmati and Nagmati by Department of Hydrology and Meteorology. For Dhap, estimated catchment mean annual rainfall is 3,000 mm approximately. The study area also observes occasional snowfall in the month of January-February.

1.6. Objectives

i. To prepare Engineering Geological Map of Dhap dam foundation
ii. To prepare Structural Map of Dhap dam foundation
iii. To place the rock mass of the Dhap dam foundation into geomechanics classification system
iv. To check and propose an engineering remedy to the chances of the sliding of dam, if any

1.7. Justification of the Study

The study area lies in tectonically active zone, for the fact that MCT passes at about Patibhanjyang just 5 km northward. The impact of the thrust is also clear from the 2015 Earthquake. The Rock Mass Rating (RMR) system of Geomechanics Classification alone may not be enough to classify the rock mass therein because it takes into consideration no account of the impact of discontinuity orientation with respect to the dam axis. Therefore, this research tries to do the rock mass classification of the dam foundation footprint through Dam Mass Rating, a new geomechanics classification adapted from RMR, to check the chances of dam sliding influenced by discontinuity orientation and to give an engineering solution in case the chances are identified.

1.8. Limitation

i. The "Giraffe" technique (Rinaldi et al., ?), a digital close range photogrammetric approach could speed up and improve the quality of collected data for mapping but the research was limited to mobile photography, Brunton compass, metric tape, hammer and hand lens.
ii. Unconfined Compressive Strength (UCS) of the intact rock was determined in-situ using empirical field test and available tables, rather than the standard instruments.

iii. Weathering grade of rock mass was determined in-situ via empirical field test and available tables.

iv. To reduce time, effort and risk areas with steep cut slopes, and thick-vegetation were discarded.

v. The narrow time squeezed between foundation clearance and construction work which was all demanding and its overlapping with the institutional academic time saved very few favorable time.

CHAPTER II
LITERATURE REVIEW

Literature relevant, recent and reliable have been studied to tarnish the knowledge on the research theme. Published and unpublished journal, articles, papers, books, abstracts, maps, have been reviewed.

2.1. On Setting of the Study Area

"Engineering and Environmental Geological map of the Kathmandu Valley", in scale 1:50000, published by the Department of Mines and Geology (DMG), places the geology of the Dhap dam site within Sheopuri Gneiss Formation of Precambrian rocks, within strongly metamorphosed basement rocks of the Higher Himalayan Tectonic Zone.

Rai (2003) corresponds the amphibolites to granulite facies rocks of the Gosainkund Crystalline Nappe in the Gosainkund-Sheopuri region to the rocks of the Higher Himalayan Crystallines which thrust over the greenschist–lower amphibolites facies rocks of the Lesser Himalaya (LH) along the Main Central Thrust (MCT).

The greenschist–to granulite–facies rocks in the Kathmandu and Gosainkund regions are divided into three tectonic units on the basis of structure, lithology and metamorphism. The Gosainkund Crystalline Nappe (GCN) corresponds to the southward extension of the Higher Himalayan Crystallines (HHC), which thrusts over the Kathmandu Crystalline Nappe (KCN) along the main Central Thrust (MCT). The GCN an KCN thrust over the Lesser Himalaya (LH) along the MCT and the Mahabharat Thrust (MT), respectively (Rai et. al., 2004)

2.2. On The Higher Himalayan Zone

The Higher Himalaya extends from Main Central Thrust (MCT) to the Tibetan–Tethys Zone and runs throughout the country. This zone mainly consists of almost 10 km thick succession of crystalline rocks. Accroding to Bordet et al. (1972), this sequence can be divided into four main units: Kyanite–Silimanite gneisses, Pyroxene–Marble gneisses, Banded gneisses and Augen gneisses.

The Higher Himalayan Crystallines (HHC) are mainly composed of Kyanite – Silimanite grade gneisses intruded by High Himalayan Leucogranites as structurally higher levels (Upreti, 1999). Throughout much of the range, the unit is divided into three formations (Pecher and Le Fort, 1986). In Central Nepal, the Upper Formation III consists of augen orthogneiss, whereas the. Middle Formation II is calcsilicate gneisses and marble, and the Basal Formation I is Kyanite–and–Silimanite bearing metapelites, gneisses and metagraywacke with abundant quartzites.

The northern part is marked by South Tibetan Detachment System (STDS). The protolith of the Higher Himalayan Crystalline is interpreted to be late Proterozoic clastic sedimentary rocks deposited on the northern Indian margin (Parrish and Hodge, 1996).

2.3. On the Lesser Himalaya

In central Nepal, the LH is divided into two groups: the Lower Lesser Himalaya and the Upper Lesser Himalaya (Le Fort, 1975; Pecher, 1978; CoIchen et al., 1980, 1986) or the Lower Nawakot Group and the Upper Nawakot Group (Stocklin and Bhattarai, 1977; Stocklin, 1980). This unit is composed of late Precambrian to Paleozoic? sedimentary and metasedimentary rocks such as limestone, dolomite, gritstone, conglomerate, slate, phyllite, schist, metasandstone, quartzite, augen gneiss (Ulleri augen gneiss) and amphibolite. These rocks are exposed around the Kathmandu valley (Rai, 2001). The upper section of the Upper Lesser Himalaya along the Mailung Khola in the vicinity of the MCT has undergone strong deformation, and metamorphosed to amphibolite facies producing garnet and/or kyanite related to the movement along the MCT (Le Fort, 1975, Pecher, 1978, 1989), while only greenschist facies rocks can be observed at the proximity of the MT (Rai, 2001).

2.4. On Kathmandu Crystalline Nappe

This nappe is composed of the rocks of the Kathmandu Complex, Which is divided into the Bhimphedi and the PhuIchauki groups (Stocklin and Bhattarai, 1977; Stocklin, 1980). The Bhimphedi Group is the lower unit and is composed of amphibolite-facies rocks (phyllite, schist, metasandstone, quartzite, and marble of Precambrian age). The metamorphic rocks of the Bhimphedi Group gradually pass upward to a low-grade to non-metamorphosed fossiliferous Lower Paleozoic sequence of Tethyan affinity belonging to the Phulchauki Group which is composed of limestone, slate, metasandstone, phyllite, calc-phyllite and marble. The rocks of the Kathmandu Complex are also intruded by several Cambro-Ordovician peraluminous granitic plutons (Le Fort et al., 198l, 1983; Scharer and Allegre, 1983) in the south, the east and the west of the Kathmandu Valley. Small augen gneiss bodies of granitic origin are found in the Bhimphedi Group exposed along the Mahesh Khola, Malekhu Khola, Belkhu Khola and the Bagmati River. AIong Malekhu Khola incipient development of kyanite in this gneiss is also observed. A 15 km long E-W running narrow pegmatite body named the Nardanda Pegmatite is exposed at the northern edge of the Kathmandu Valley. It has a maximum exposed thickness of 300 m at the middle part (Rai, 2001).

2.5. On Gosainkund Crystalline Nappe

The Gosainkund Crystalline Nappe (GCN) lies to the north of the Kathmandu Valley and consists of the amphibolite to granulite-facies rocks. The nappe reaches to the northern edge of the Kathmandu Valley, and extends upto Nagarkot in the east and to Galchi in the west (Rai, 2001). The high-grade metamorphic rocks of the GCN include varieties of paragneiss and orthogneiss (augen gneiss, granitic gneiss), micaschist, migmatite, calc-silicate gneiss, marble and quartzite. The gneisses exposed along the higher part of the Sheopuri Range such as at Thakle, SW of Melamchi Bazaar and in the Gosainkund Range contain abundant sillimanite (Rai 1998). The lower sections of the GCN exposed along the Likhu Khola and Tadi Khola lying to the north of the Sheopuri Range contain kyanite-garnet bearing rocks, whereas sillimanite occurs at a higher section on both sides of these rivers.

2.6. On Rock Mass Rating (RMR)

Palmstrom (2000) tabulates rock mass classification systems as Terzaghi Rock Load Classification, Lauffer's stand up Time Classification, New Austrian Tunneling Method (NATM), Rock Classification for Rock Mechanical Purposes, Unified Classification of Soils and Rocks, Rock Quality Designation (RQD), Size-Strength Classification, Rock Structure Rating (RSR), Rock Mass Rating (RMR), Q – Classification System, Unified Rock Classification System, Basic Geotechnical Classification (BGC), Geological Strength Index (GSI), and Rock Mass Index (RMI).

Rock Mass Rating (RMR), also known as Geomechanics Classificaiton System, was originally proposed by Bieniawaki in 1973 for use in tunnels, slopes and foundation. However, it has gone several evolutions through the years 1974, 1975, 1976 and 1989, amending the rating assigned to different parameters, namely, Unconfined (uniaxial) Compressive Strength (UCS), Rock Quality Designation (RQD), Spacing of Discontinuities, Condition of Discontinuities, Groundwater Condition and Orientation of Discountinuities (for tunnels).

The UCS can be indirectly evaluated by means of Point Load Test and by correlations with the Schmidt Hammer Rebound Value, or directly by unconfined compression test. However, when laboratory tests are not possible Hoek and Brown (1997) has given a table for the estimated value of UCS, which further has been in modified form in Marinos and Hoek (2000). On deciding the value of UCS for foliated rocks Hoek and Broun (1997) suggests that the maximum value should be used for hard, well interlocked rocks masses such as good quality slates and the lowest value for tectonically disturbed, poor quality rock masses such as the graphitic phyllite.

The RQD was initially proposed by Deere (1963), and it has since then been the topic of various assessments (Deere et al., 1967, Deere and Deere, 1988; Deere, 1989), mainly for civil engineering projects. Its application has also been quickly extended to other areas of rock mechanics, and it has become a fundamental parameter in geotechnical engineering (Hoek & Brown, 1980; Hoek and Bray, 1981). Many researchers have done studies on this relationship: Palmstrom, 2005; Choi and Park, 2004; Zhang et al., 2012. However, Pells et al. (2017) warns, as RQD is a rating in RMR, that ±30% error in RQD results typically in <6% error in RMR, and hence only in extreme cases with high water pressures, unfavourable joint orientations, and a 30% underestimate of an already low RQD does the error reach about 20%.

Joint set spacing is the distance between individual joints within a joint set. Palmstrom (2001) distincts joint spacing from average joint spacing stressing that the reciprocal of latter is the sum of the reciprocals of each joint set spacing.

Palmstrom (2001) stresses that the knowledge of the type of the frequency of the joints and fissures are often more important than the types of rocks involved, as the engineering properties of a rock mass depend often far more on the system of geological defects within the rock mass than of the strength of the rock itself. The condition of discontinuity is hence significant.

Hoek et al., (2000) refers the presence of groundwater in a rock slope as a critical factor in any assessment of the stability of that slope. Water pressure, acting within discontinuities in the rock mass, reduces effective stresses with a consequent reduction of shear strength.

Hoek and Brown (1997) states that for very poor quality rock masses the value of RMR is very difficult to estimate and the balance between the ratings no longer gives a reliable basis for estimating rock mass strength.

2.7. On Dam Mass Rating (DMR)

Romana (2003, a & b) reviews the difficulties in RMR use for dam foundations deriving from several points: consideration of water pressure is very doubtful (the pore pressure ratio varies along the dam foundation, dams must operate with changing water levels ….), there is no good rules for quantifying the adjusting factor for the joint orientation (which must allow for the safety against total failure by horizontal shear, for local failure, for water leakage through the joints …), there are changes in properties of both the rock and the joints induced by watering changes (saturation, desiccation, flow along the joints …). Thus, proposed has been a new Geomechanics classification system – DMR (Dam Mass Rating), as an adaptation of RMR, giving guidelines for several practical aspects in dam engineering and in appraisal of dam foundation.

2.8. On Weathering

Selby (1993) described weathering as 'the process of alteration and breakdown of soil and rock materials at and near the Earth's surface by physical, chemical and biotic processes’.

Esaki and Jiang (1999) stress that the ultimate effect of physical weathering is reflected in increase of porosity, and that the degree of chemical weathering increases the water in the internal structure of minerals, (H_2O^+).

Weathering intensity in rocks results in mineralogical modification of the primary minerals and strong structural and textural changes in the rock fabric, as fractures in both intercrystalline boundaries and intercrystalline contacts (Borrelli et al., 2014; Criteli et al., 1991; Le Pera et al., 2001; Regmi et al., 2014, Scarciglia et al., 2007)

2.9. On More

Moreover, papers related to dams using RMR and/or DMR have been reviewed: Kangir Dam site (Shaflei & Dusseault, 2008), Shah-wa-Arus Dam site (Zaryab et al., 2015), Anamur Dam site (Ozsan & Karpuz, 1996), Urus Dam (Ozsan & Akin, 2002), Axum Dam site (Leulalem et al., 2016), Sulakyurt Dam site (Basarir, 2006) and Obudu Dam site (Esn et al., 1996). Fraser (2001) gives a guideline to "excavate the dam foundation to slightly weathered granitic rock".

Rinaldi et al. (?) uses "Giraffe" technique for dam foundation mapping in the Great Ethiopian Renaissance Dam Project, GERD Project.

Further, topo sheet No. 2785 02D, google earth maps have been reviewed.

CHAPTER III
METHODOLOGY

The research was carried out in four stages, viz., Desk Work, Field Work, Data Processing, and Report Writing and Submission (Figure 4).

3.1. Desk Work

Conducted in three phases, the Phase I of desk work was Literature Review and Office Studies, during which review of un/published literatures, textbooks, papers, abstracts, journals, reports, maps etc. was done. This Phase also included the selection of necessary materials and equipments. Data Processing, and Report Writing and Submission were the other two sequential Phases of Desk Work, which succeeded the Field Work.

3.2. Field Work

Field work, that succeeded the phase I of desk work, advanced from preliminary field investigation to detail field investigation. It passed through delineation of the study area, the main dam foundation footprint (132 m × 90 m), to geological investigation for lithological and structural measurement, to engineering geological investigation for the computation of the RMR and the DMR where the measurements of the insitu rock strength, weathering grade, discontinuity attitudes and condition, and groundwater condition were noted in the field notebook. The topographic sheet no. 2785 02D, Sundarijal in 1:25000 scale, produced by the Survey Department, Government of Nepal, 2003 reprint, was used for the research. Following were the other tools and instruments used in field work:

- Brunton compass for the measurement of attitude of rock surface, discontinuities and bearing of the traverse lines
- A 50 m long metric tape
- A 5 m long power tape
- Geological hammer with an end blade

- Bi-powered (10x and 20x) hand lens to observe mineral grains and their arrangement
- Sampling bags to collect rock and soil samples
- Mobile phone GPS for accurate positioning of the location of observation points
- Field notebook to record the description and sketch of features and materials observed in the field
- Mobile phone camera to snap pictures
- A 30 cm scale, a circular protractor, pencil, sharpener, eraser and A1 size graph papers
- Field work was classified into two: Mapping and Engineering Geological Investigation.

3.2.1. Mapping

First, demarcation of the study area was carried out. The axis line of the main dam was retrieved from the surveyor which oriented N45ºW – S45ºE. The coordinates and the altitude of the left end of the dam axis was also retrieved from the surveyor and so was done for the right end and the midpoint of the axis. Hence, the first traverse line i.e. the Dam axis line of 132 m was sketched. Next, from the left end point of the axis line, another line going perpendicular to the axis line, i.e. with the bearing of N45ºE – S45ºW going from the point to 45 m upstream and to 45 m downstream was sketched which gave the 90 m width of the dam at the left bank. Then, from the upstream left end another traverse line going N45ºW – S45ºE, parallel to dam axis line, across stream channel, which also extended 132 m in length, was sketched. Similar process was repeated from the left end downstream of dam axis to find the third traverse line. Hence, three traverse lines were determined: the axis line, the upstream boundary line and the downstream boundary line. The coordinates and the altitudes of the ends and the mid-point of the upstream and downstream boundary lines were also retrieved from the surveyor. Therefore, the study area (132 m × 90 m) was delineated.

Second, the mapping was done in a A1 size graph paper. The traverse was taken on 3 traverse lines. During the traverse, a 50 m metric tape was stretched along a traverse line to measure the distance until the topography changed, the slope angle was measured with the help of Brunton compass and the slant height with metric tape, and the profile line was derived. Similar process was repeated for the other two traverse lines. During the traverse, also measured were the weathering grade (table 2), in situ strength, discontinuity condition and spacing, and ground water condition. Twenty location points were marked for the observation. And hence prepared was the engineering geological map in 1:50 scale.

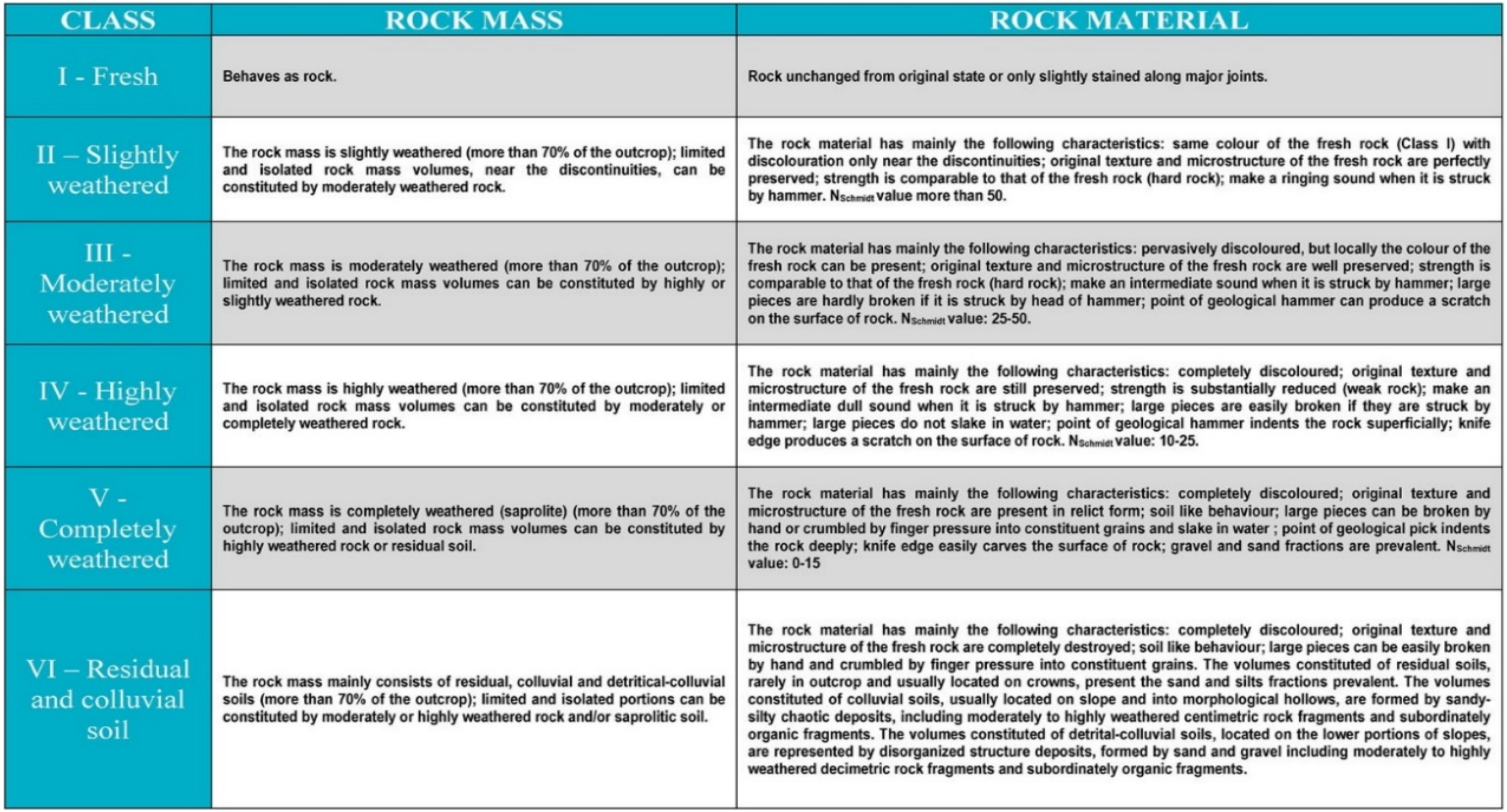
3.2.1. Engineering Geological Investigation

The prime focus of the research was the rock mass classification of the study area, Dam Mass Rating in particular. To meet the objective, hence were applied Rock Mass Rating (RMR-Bieniawski, 1989) and Dam Mass Rating (DMR-Romana, 2003b). Quantitative description of discontinuities including orientation, spacing, persistence, roughness, aperture and filling were determined in-situ by exposure logging in accordance to ISRM standards (1978).

3.2.1.1. Rock Mass Rating (RMR)

RMR was done in accordance with Bieniawski (1989) (Table 3). The first five parameters were measured and rated to sum them into RMR value of the observed points.

Table 2. Reference descriptions for the weathering classes (modified from Borrelli et al., in press).



CLASS	ROCK MASS	ROCK MATERIAL
I - Fresh	Behaves as rock.	Rock unchanged from original state or only slightly stained along major joints.
II – Slightly weathered	The rock mass is slightly weathered (more than 70% of the outcrop); limited and isolated rock mass volumes, near the discontinuities, can be constituted by moderately weathered rock.	The rock material has mainly the following characteristics: same colour of the fresh rock (Class I) with discolouration only near the discontinuities; original texture and microstructure of the fresh rock are perfectly preserved; strength is comparable to that of the fresh rock (hard rock); make a ringing sound when it is struck by hammer. $N_{Schmidt}$ value more than 50.
III - Moderately weathered	The rock mass is moderately weathered (more than 70% of the outcrop); limited and isolated rock mass volumes can be constituted by highly or slightly weathered rock.	The rock material has mainly the following characteristics: pervasively discoloured, but locally the colour of the fresh rock can be present; original texture and microstructure of the fresh rock are well preserved; strength is comparable to that of the fresh rock (hard rock); make an intermediate sound when it is struck by hammer; large pieces are hardly broken if it is struck by head of hammer; point of geological hammer can produce a scratch on the surface of rock. $N_{Schmidt}$ value: 25-50.
IV - Highly weathered	The rock mass is highly weathered (more than 70% of the outcrop); limited and isolated rock mass volumes can be constituted by moderately or completely weathered rock.	The rock material has mainly the following characteristics: completely discoloured; original texture and microstructure of the fresh rock are still preserved; strength is substantially reduced (weak rock); make an intermediate dull sound when it is struck by hammer; large pieces are easily broken if they are struck by hammer; large pieces do not slake in water; point of geological hammer indents the rock superficially; knife edge produces a scratch on the surface of rock. $N_{Schmidt}$ value: 10-25.
V - Completely weathered	The rock mass is completely weathered (saprolite) (more than 70% of the outcrop); limited and isolated rock mass volumes can be constituted by highly weathered rock or residual soil.	The rock material has mainly the following characteristics: completely discoloured; original texture and microstructure of the fresh rock are present in relict form; soil like behaviour; large pieces can be broken by hand or crumbled by finger pressure into constituent grains and slake in water ; point of geological pick indents the rock deeply; knife edge easily carves the surface of rock; gravel and sand fractions are prevalent. $N_{Schmidt}$ value: 0-15
VI – Residual and colluvial soil	The rock mass mainly consists of residual, colluvial and detritical-colluvial soils (more than 70% of the outcrop); limited and isolated portions can be constituted by moderately or highly weathered rock and/or saprolitic soil.	The rock material has mainly the following characteristics: completely discoloured; original texture and microstructure of the fresh rock are completely destroyed; soil like behaviour; large pieces can be easily broken by hand and crumbled by finger pressure into constituent grains. The volumes constituted of residual soils, rarely in outcrop and usually located on crowns, present the sand and silts fractions prevalent. The volumes constituted of colluvial soils, usually located on slope and into morphological hollows, are formed by sandy-silty chaotic deposits, including moderately to highly weathered centimetric rock fragments and subordinately organic fragments. The volumes constituted of detrital-colluvial soils, located on the lower portions of slopes, are represented by disorganized structure deposits, formed by sand and gravel including moderately to highly weathered decimetric rock fragments and subordinately organic fragments.

Table 3. Rock Mass Rating System (after Bieniawski, 1989)

A. CLASSIFICATION PARAMETERS AND THEIR RATINGS

	Parameter		Range of values						
1	Strength of intact rock material	Point-load strength index	>10 MPa	4 - 10 MPa	2 - 4 MPa	1 - 2 MPa	For this low range - uniaxial compressive test is preferred		
		Uniaxial comp. strength	>250 MPa	100 - 250 MPa	50 - 100 MPa	25 - 50 MPa	5 - 25 MPa	1 - 5 MPa	< 1 MPa
	Rating		15	12	7	4	2	1	0
2	RQD		90% - 100%	75% - 90%	50% - 75%	25% - 50%	< 25%		
	Rating		20	17	13	8	3		
3	Spacing of		> 2 m	0.6 - 2 . m	200 - 600 mm	60 - 200 mm	< 60 mm		
	Rating		20	15	10	8	5		
4	**Condition of discontinuities (See E)**		**Very rough surfaces Not continuous No separation Unweathered wall rock**	**Slightly rough surfaces Separation < 1 mm Slightly weathered walls**	**Slightly rough surfaces Separation < 1 mm Highly weathered walls**	**Slickensided surfaces or Gouge < 5 mm thick or Separation 1-5 mm Continuous**	**Soft gouge >5 mm thick or Separation > 5 mm Continuous**		
	Rating		30	25	20	10	0		
5	Ground water	Inflow per 10 m tunnel length (l/m)	None	< 10	10 - 25	25 - 125	> 125		
		(Joint water press)/ (Major principal □)	0	< 0.1	0.1, - 0.2	0.2 - 0.5	> 0.5		
		General conditions	Completely dry	Damp	Wet	Dripping	Flowing		
	Rating		15	10	7	4	0		

B. RATING ADJUSTMENT FOR DISCONTINUITY ORIENTATIONS (See F)

Strike and dip orientations		Very favourable	Favourable	Fair	Unfavourable	Very
Ratings	Tunnels &	0	-2	-5	-10	-12
	Foundations	0	-2	-7	-15	-25
	Slopes	0	-5	-25	-50	

C. ROCK MASS CLASSES DETERMINED FROM TOTAL RATINGS

Rating	100 - 81	80-61	60 - 41	40 -21	< 21
Class number	**I**	**II**	**III**	**IV**	**V**
Description	Very good rock	Good rock	Fair rock	Poor rock	Very poor rock

D. MEANING OF ROCK CLASSES

Class number	**I**	**II**	**III**	**IV**	**V**
Average stand-up time	20 yrs for 15 m	1 year for 10 m	1 week for 5 m	10 hrs for 2.5 m	30 min for 1 m
Cohesion of rock mass (kPa)	> 400	300 - 400	200 - 300	100 - 200	< 100
Friction angle of rock mass (deg)	> 45	35 - 45	25 - 35	15 - 25	< 15

E. GUIDELINES FOR CLASSIFICATION OF DISCONTINUITY conditions

Discontinuity length (persistence) Rating	< 1 m 6	1 - 3 m 4	3 - 10 m 2	10 - 20 m 1	> 20 m 0
Separation (aperture) Rating	None 6	< 0.1 mm 5	0.1 - 1.0 mm 4	1 - 5 mm 1	> 5 mm 0
Roughness Rating	Very rough 6	Rough 5	Slightly rough 3	Smooth 1	Slickensided 0
Infilling (gouge) Rating	None 6	Hard filling < 5 mm 4	Hard filling > 5 mm 2	Soft filling < 5 mm 2	Soft filling > 5 mm 0
Weathering Ratings	Unweathered 6	Slightly weathered 5	Moderately weathered 3	Highly weathered 1	Decomposed 0

F. EFFECT OF DISCONTINUITY STRIKE AND DIP ORIENTATION IN TUNNELLING**

Strike perpendicular to tunnel axis		Strike parallel to tunnel axis	
Drive with dip - Dip 45 – 90°	Drive with dip - Dip 20 - 45°	Dip 45 - 90 °	Dip 20 - 45 °
Very favourable	Favourable	Very unfavourable	Fair
Drive against dip - Dip 45-90 °	Drive against dip - Dip 20-45 °	Dip 0-20 - Irrespective of strike□	
Fair	Unfavourable	Fair	

* Some conditions are mutually exclusive. For example, if infilling is present, the roughness of the surface will be overshadowed by the influence of the gouge. In such cases use A.4 directly.
** Modified after Wickham et al (1972).

(a) Unconfined Compressive Strength (UCS), R_1

The UCS value of rock mass was recorded in accord of the estimates from empirical field tests using standard geological hammer of about 1 kg and Table 4.

Table 4. Field estimates of uniaxial compressive strength of intact rock.

Grade*	Term	Uniaxial Comp. Strength (MPa)	Point Load Index (MPa)	Field estimate of strength	Examples
R6	Extremely Strong	> 250	>10	Specimen can only be chipped with a geological hammer	Fresh basalt, chert, diabase, gneiss, granite, quartzite
R5	Very strong	100 - 250	4 - 10	Specimen requires many blows of a geological hammer to fracture it	Amphibolite, sandstone, basalt, gabbro, gneiss, granodiorite, peridotite , rhyolite, tuff
R4	Strong	50 - 100	2 - 4	Specimen requires more than one blow of a geological hammer to fracture it	Limestone, marble, sandstone, schist
R3	Medium strong	25 - 50	1 - 2	Cannot be scraped or peeled with a pocket knife, specimen can be fractured with a single blow from a geological hammer	Concete, phyllite, schist, siltstone
R2	Weak	5 - 25	**	Can be peeled with a pocket knife with difficulty, shallow indentation made by firm blow with point of a geological hammer	Chalk, claystone, potash, marl, siltstone, shale, rocksalt,
R1	Very weak	1 - 5	**	Crumbles under firm blows with point of a geological hammer, can be peeled by a pocket knife	Highly weathered or altered rock, shale
R0	Extremely weak	0.25 - 1	**	Indented by thumbnail	Stiff fault gouge

* Grade according to Brown (1981).
** Point load tests on rocks with a uniaxial compressive strength below 25 MPa are likely to yield highly ambiguous results.

(b) Rock Quality Designation (RQD), R_2

The RQD, as originally defined by Deere et al. (1967), is the percentage of intact drill core pieces longer than 100 mm (4 inches) in the total length of core.

i.e. RQD = {(sum of core pieces > 100 mm)/total length of core} × 100%

However, when no core is available but the discontinuity traces are visible in surface exposure as in the case of this research, or exploration adits, Palmstrom (1982) suggested a relationship to calculate RQD:

$$RQD = 115 - 3.3\,Jv,\ (4.5 < Jv < 35)$$

Further in another attempt, a new relationship between RQD and Jv was suggested by Palmstrom (2005):

$$RQD = 110 - 2.5\,Jv,\ (4 < Jv < 44)$$

where, Jv is the volumetric joint count, which is the number of joints intersecting a volume of 1 m^3. Palmstrom (2005) has suggested the following relationship to calculate Jv:

$$Jv = \frac{1}{s_1} + \frac{1}{s_2} + \frac{1}{s_3} + \ldots\ldots + \frac{1}{s_n} + Nr/5(\sqrt{A})$$

where, s = spacing of joint set
Nr = no. of random joint sets
A = area covered in m^2

The relationship RQD = 110 - 2.5Jv has been followed throughout the research.

(c) Spacing of Discontinuity, R_3

It is the perpendicular distance between the adjacent discontinuities of the same set (ISRM, 1978). Regarding the spacing of different joint sets, the mean value was taken. A power tape was used for the measurement.

(d) Condition of discontinuity, R_4

The condition of discontinuity was rated as per Table 3.

(e) Groundwater Condition, R_5

Groundwater condition was based upon the field scenario (dry, damp, wet, dripping or flowing), with a higher rating for a drier rock mass (Bieniawski, 1989).

Finally, RMR was calculated as,

$$\mathbf{RMR = R_1 + R_2 + R_3 + R_4 + R_5}$$

Once the rating of RMR for the rock mass was done, the rock mass was classified as per the classification of Bieniawski (1989).

Table 5.RMR value vs Class and Description of rock mass

Rating	100-81	80-61	60-41	40-21	<21
Class number	I	II	III	IV	V
Description	**Very Good rock**	**Good rock**	**Fair rock**	**Poor rock**	**Very Poor rock**

3.2.1.2. Dam Mass Rating (DMR)

The DMR of the rock mass was computed as per Romana (2003b), where a relationship has been suggested:

$$\mathbf{DMR_{STA} = RMR_{BD} + CF \times R_{STA},}$$

where, DMR_{STA} = Dam Mass Rating for the dam stability

RMR_{BD} = Basic Dry RMR

CF = Geometric Correction Factor

R_{STA} = Rating of the adjusting factor for dam stability.

RMR_{BD}, as discussed in Romana (2003b), is the sum of the five parameters of "basic" RMR_B of Bieniawski (1989), but with some modification in the first and the fifth parameters.

i. Compressive strength, tested in water conditions when the rock is going to be saturated, and with the same pH of water, and therefore, scoring half of the UCS value of RMR_B, as the compressive strength of the rock will diminish heavily when saturated and its rating probably will halve (Romana, 2003b).

ii. RQD
iii. Joint spacing, of the significative (s) joint
iv. Condition of the significative (s) joint
v. Water rating, always 15 (as if dry)

CF is a geometric correction factor, (as when the dip direction of the significative joint is not almost parallel to the downstream-upstream axis of the dam the danger of sliding diminishes due to the geometrical difficulties to slide) (Romana, 2003b).

CF is calculated as:

$$\mathbf{CF = (1 - \sin |\alpha_d - \alpha_j|)^2},$$

where, α_d = direction upstream downstream of the dam axis

α_j = dip direction of the significative joint.

R_{STA} is the rating of the adjusting factor for dam stability (Table 6).

Table 6. Rating of the adjusting factors for the dam stability, R_{STA} according to joints orientation (Romana, 2003a)

Type of Dam	**VF (Very favourable)**	**F (Favourable**	**FA (Fair)**	**U (Unfavourable)**	**VU (Very unfavourable**
Fill	Others	10-30 DS	0-10 A	-	-
Gravity	10-60 DS	30-60 US 60-90 A	10-30 US	0-10 A	
Arch	30-60 DS	10-30 DS	30-60 US 60-90 A	10-30 US	0-10 A
R_{STA}	0	-2	-7	-15	-25

DS = Dip Downstream; US = Dip Upstream; A = Any dip

Gravity dam includes CVC and RCC concrete dams.

Once, the DMR_{STA} is computed, a correlation between the value of DMR_{STA} and the degree of safety of the dam against sliding is suggested as a rule of thumb (Table 7), because of the short of data allowing to establish such correlation (Romana, 2003).

Table 7. Correlation between DMR_{STA} and Degree of Safety (Romana, 2003)

DMR_{STA}	<30	30 – 60	>60
Degree of Safety	Serious Concern	Concern	No Primary Concern

Finally some simple guidelines have been tentatively proposed (Table 8) for excavation and for consolidation grouting a few meters deep (Romana, 2003a).

Table 8. Tentative guidelines for dam foundation excavation and consolidation grouting (Romana, 2003b)

Type of Dam	**Excavate to RMR^{+}_{BD}**	**Consolidation Grouting according to DMR_{STA}**		
		Systematic	**Spot**	**None**
Earth	-	-	-	-
Rockfill	>20 (>30)	20 – 30	30 – 50	>50
Gravity	>40 (>60)	40 – 50	50 – 60	>60
Arch	>50 (>70)	50 – 60	60 – 70	>70

(+) minimum (desirable)

- gravity dams included CVC and RCC concrete
- Rockfill dams included are the ones sensible to settlement (like CFRD and AFRD)

3.3. Data Processing

The field work was followed by the working with the collected data. It was the included engrossment of the classification, computation and comprehension of the data to make the interpretation that would justify the result.

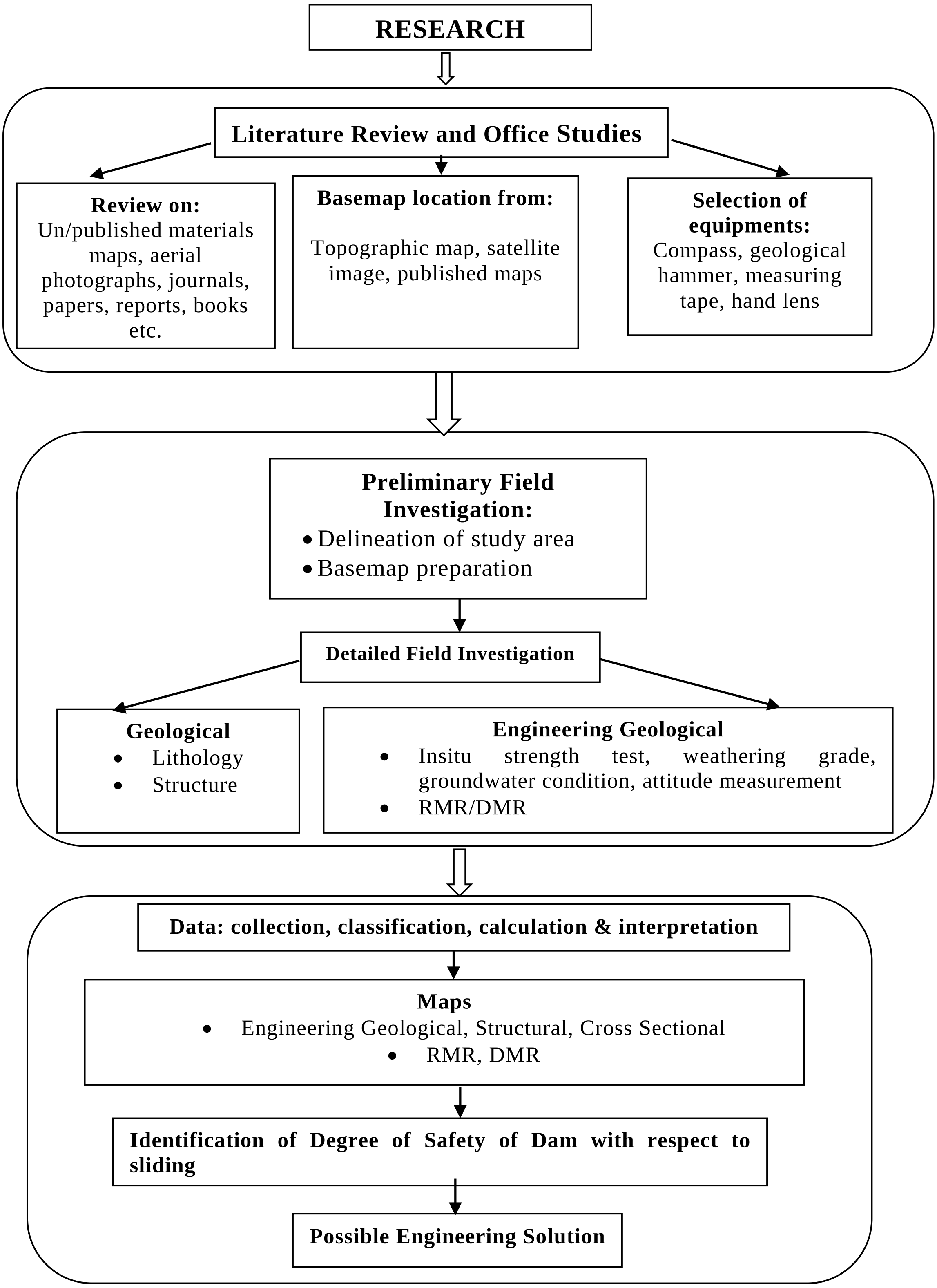


Figure 4. Methodology used during research

CHAPTER IV
RESULTS

The study area, which was in excavating stage, covered the area of 132 m × 90 m, the dam axis running right along the middle of the area and across the stream channel that left 45 m upstream and 45 m downstream widths. Altogether, the data were retrieved from 20 observation points, which were named L1 to L20, for the measurement of the lithology, structuralogy, insitu strength, discontinuity attitudes, spacing and condition, groundwater condition, weathering grade condition, the coordinates and the altitudes above sea level (asl). Of the 20 observation points, seven were located at the upstream, seven along the dam axis and six at the downstream; laterally, there were eleven location points to the left and nine to the right from the stream channel. The stream flows from almost the centre of the upstream traverse line through almost the centre of the axis traverse line towards the mid-left of the downstream traverse line.

The maps were then produced, the RMR and the DMR for the rock mass computed, the chances for the dam failure by sliding checked and the engineering remedy proposed.

4.1. Topography, Lithology and Structure

The topography of the study area was a v-shaped river valley going as low as 2060 m asl at the thalweg of the downstream boundary traverse line and rising as high as 2099.899 m asl at the hilltop of L12, the left end point of the dam axis. At the upstream boundary traverse line the hill descended from 2090.388 m asl at the left to meet the thalweg at 2062 m asl, 55 to 75 m away and ascended to the hilltop of 2088.052 m asl at the right end. Similarly, at the dam axis traverse line, the hill descended from 2099.899 m asl to meet the thalweg at 2061.569 m asl, 50 m away and ascended to the hilltop of 2090.576 m asl at the right end. Likewise, at the downstream boundary traverse line, the hill descended short from 2071.761 m asl to meet the thalweg at 2060 m asl, 20 to 35 m away and rose to 2098.549 m asl at the right end. The stream channel flowed from upstream, 2062 m asl through the axis, 2061 m asl and to the downstream, 2060 m asl.

The coordinates and the altitudes were taken at L5, L11, L12, L15, L16, L17, L18, L19 and L20 (Table 9).

Table 9.Location of observation points

SN	Location name	Situation	Latitude (N)	Longitude (E)	Altitude (m asl)
1	L1	u/s, left	-	-	-
2	L2	u/s, left	-	-	-
3	L3	u/s, left	-	-	-
4	L4	u/s, left			
5	L5	u/s, right	3077212.07	643683.846	2062.735
6	L6	axis, left			
7	L7	axis, left	-	-	-
8	L8	d/s, right	-	-	-
9	L9	axis, right	-	-	-
10	L10	axis, right			
11	L11	axis, right	3077212.919	643604.394	2090.576
12	L12	axis, left	3077134.343	643703.269	2099.899
13	L13	d/s, left	-	-	-
14	L14	d/s, left	-	-	-
15	L15	u/s, left	3077167.861	643733.295	2090.388
16	L16	u/s, right	3077256.395	643634.384	2088.052
17	L17	d/s, right	3077189.358	643574.4	2098.549
18	L18	d/s, right	3077145.006	643623.768	2073.155
19	L19	d/s, left	3077100.784	643673.178	2071.761
20	L20	axis, right	3077178.602	643653.864	2061.869

The lithology of the area, wherever the excavation reached the bedrock was identified as banded gneiss of Sheopuri Formation. The gneiss was in varied weathered condition ranging from Fresh to Residual Soil regarding weathering (Figure 5).

Structurally, the rocks were folded in micro to meso scale. A syncform running almost along the middle of the stream channel was identified, which dipped towards the stream. Three joint sets were observed, dip ranging from the horizontal to the vertical, minor faults and shear zones were also observed (Figure 6).

4.2. Weathering Grade

The weathering grade ranged from Fresh bedrock to Highly Weathered condition to Residual Soil. Fresh gneiss was observed at the valley and towards some lateral extensions, until the Moderately Weathered gneiss, the Highly Weathered gneiss and the Residual Soil. Fresh gneiss of the upstream traverse line was found to have spread as wide as 83 m. This narrowed down towards the axis line to the width of 53 m, which further narrowed towards the downstream traverse line to the width of 43 m. At the upstream, from the centre towards the left, the Moderately weathered gneiss spread across 7 m, then the Highly weathered gneiss for 1 m and the residual soil for more than 26 m, whereas towards the right the only other grade was the Moderately weathered gneiss for more than 15 m. At the dam axis, from the centre, towards the left, the Moderately weathered gneiss was spread for 7 m, the Highly weathered gneiss for 10 m and the Residual soil for more than 15 m, whereas towards the right, the Moderately weathered gneiss was spread across for 24 m, Highly weathered gneiss for 12 m and the residual soil for more than 10 m. At the downstream, at the far left the Moderately Weathered gneiss was spread across more than 7 m, whereas right from the thalweg, the Moderately Weathered gneiss was spread across 8 m, then the Highly Weathered gneiss for more than 63 m. The thickness of the left and the right bank respectively, of the Residual soil, Highly Weathered, and Moderately Weathered gneisses were 14 to 15 m and 7 to 18 m, 1 to 6 m and 5 to 9 m, and 2 to 6 m and 2 to 6 m respectively. The thickness of the Fresh gneiss was more than 7 to more than 22 m (Figures 7, 8 and 9).

4.3. The RMR

The RMR values were deduced from ten location points, five at the upstream, two at the axis and three at the downstream traverse lines, having measured the first five parameters of the RMR (Table 10). They are described with respect to the observation points (Figure 10).

L1

The rock was exposed at the left bank, upstream and was fresh gneiss with (50 – 100) MPa UCS value, 62.525% RQD, discontinuity spacing (0.09 – 0.5)m, medium to low persistency, tight joints, rough to smooth rough surface, hard filling < 5 mm to none and some slightly weathered wall rock, dry. The RMR was determined to be 65, class II and Good rock. The foliation plane had the attitude of 300°/15° (dip direction/ dip amount).

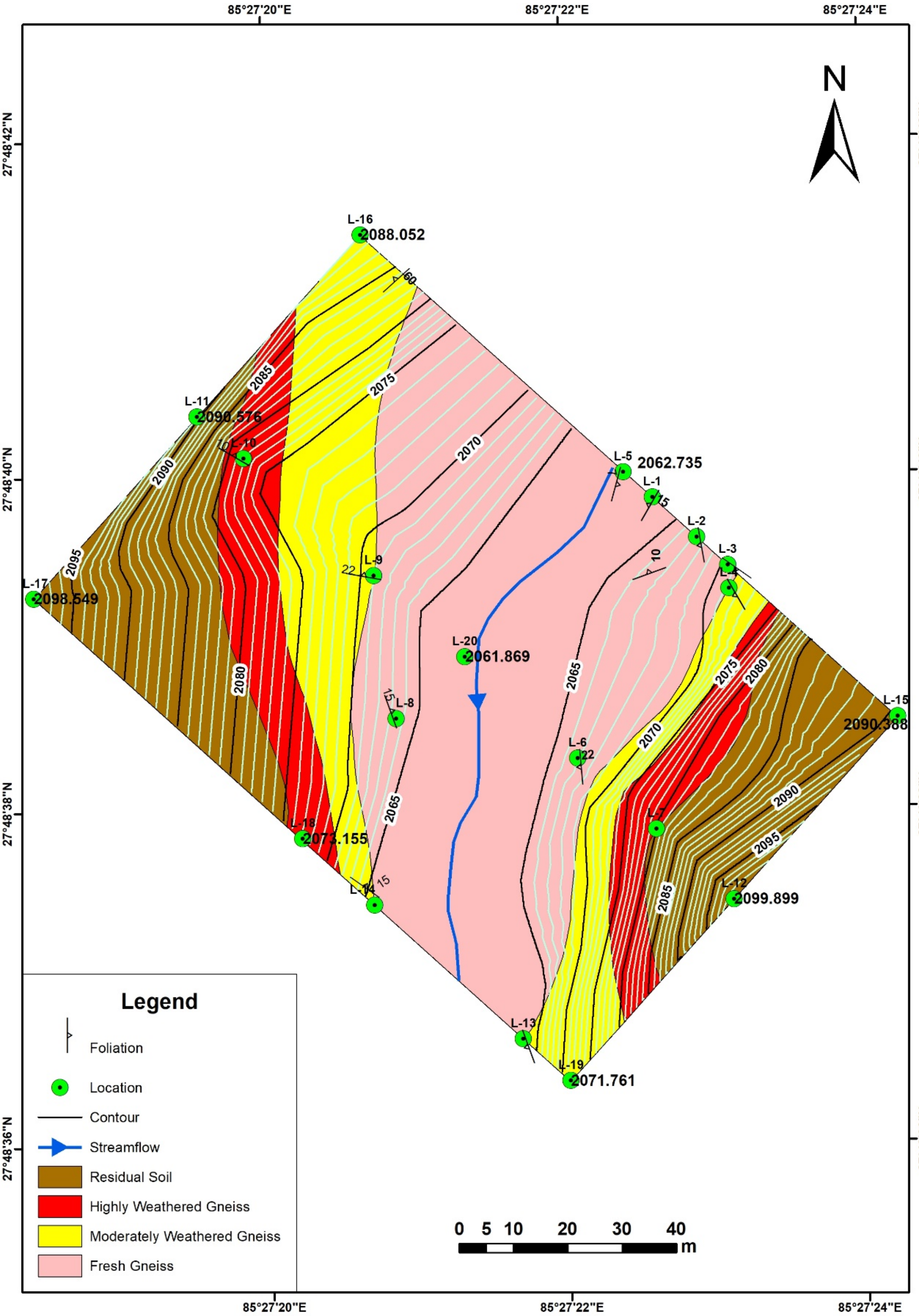


Figure 5. Engineering geological map of the study area

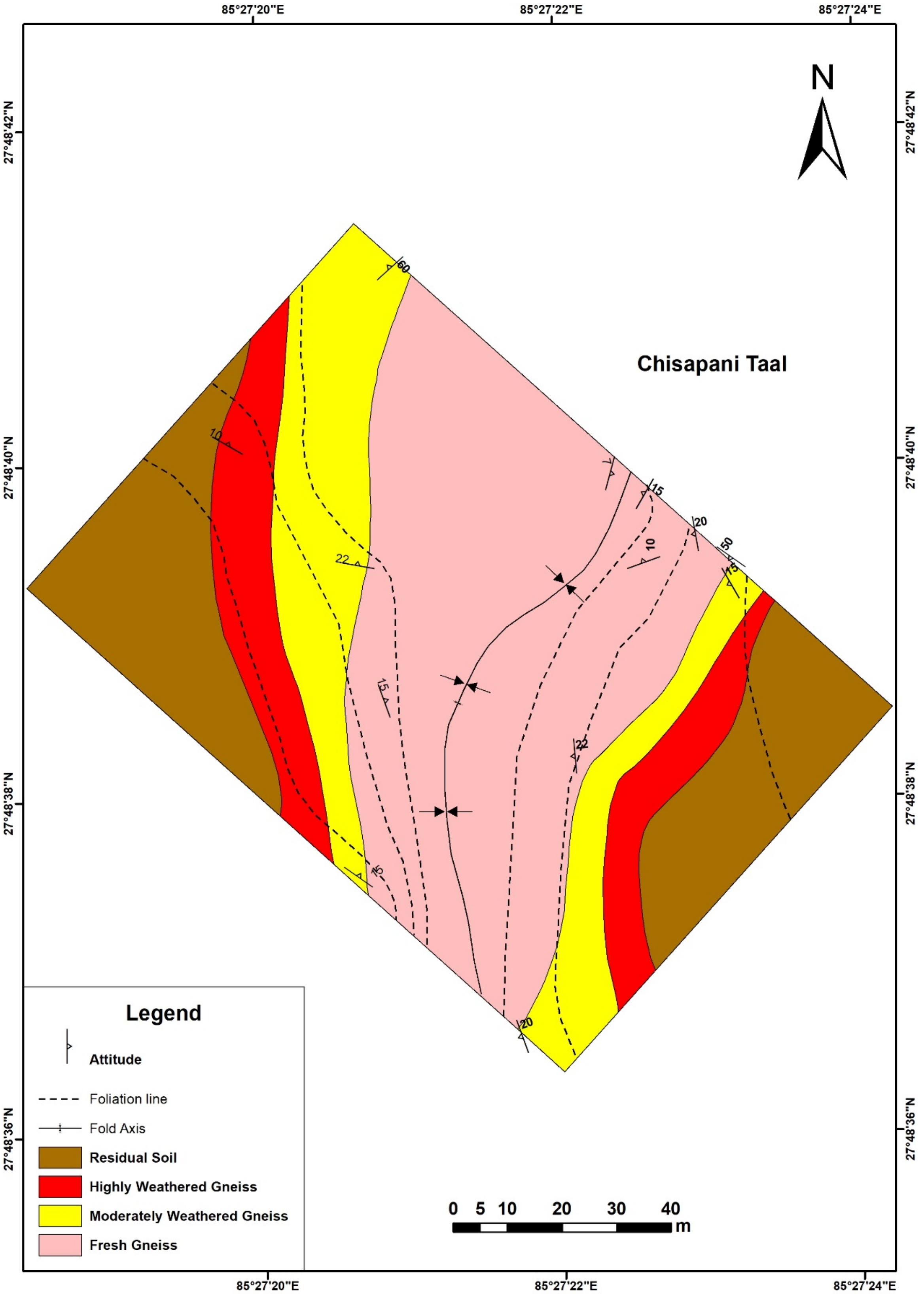


Figure 6. Structural map of the study area

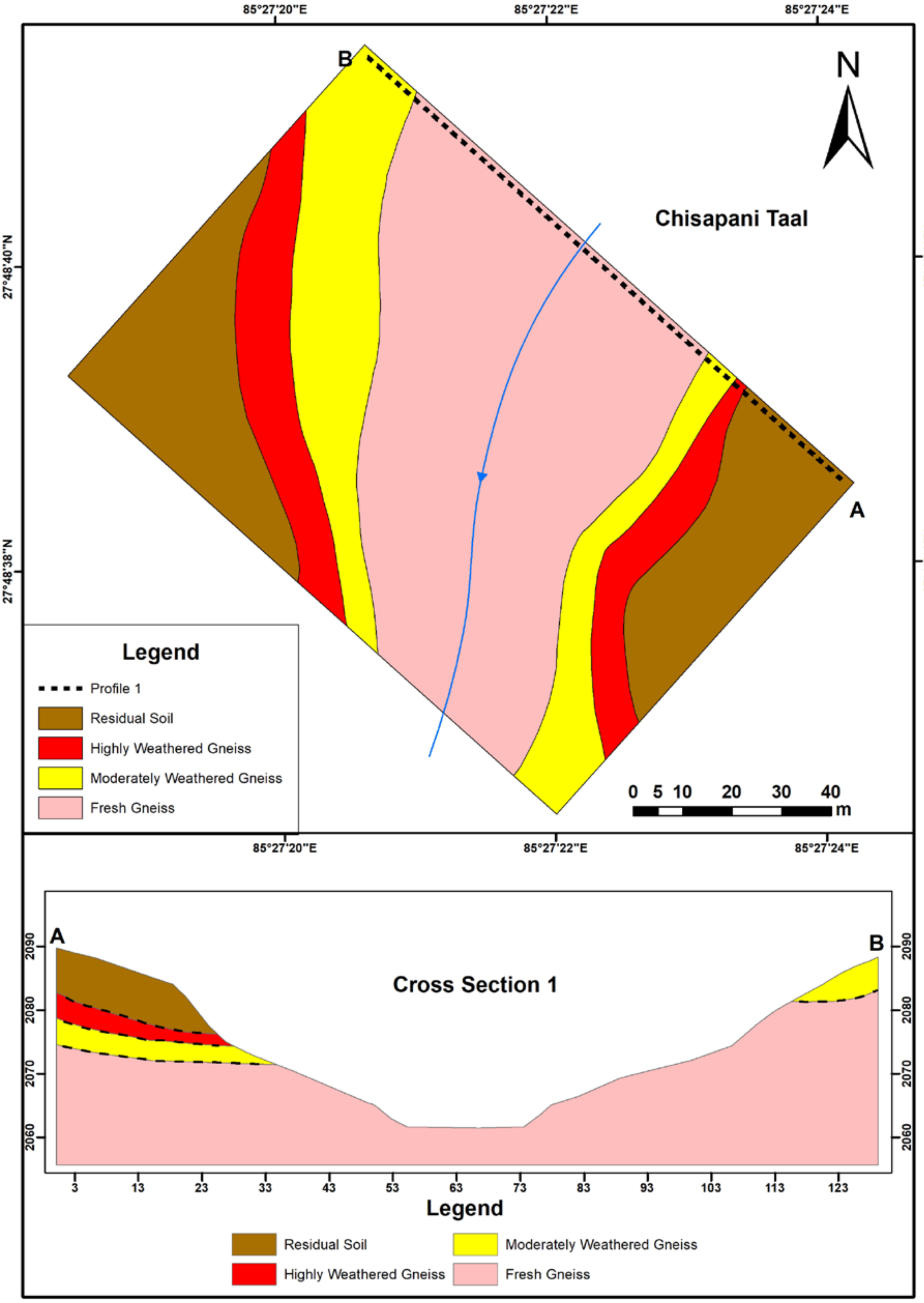


Figure 7. Cross section along the upstream traverse line

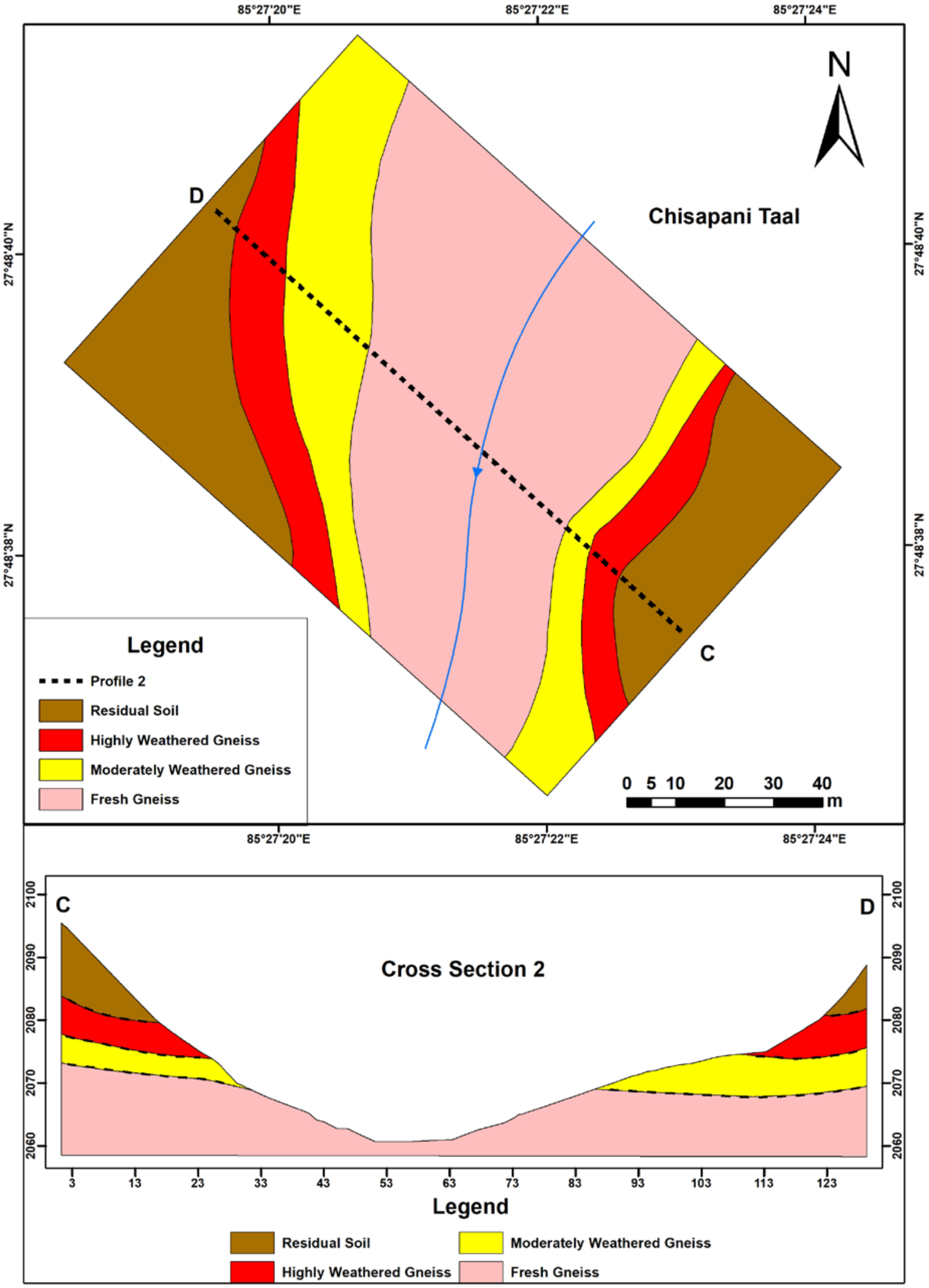


Figure 8. Cross section along the dam axis traverse line

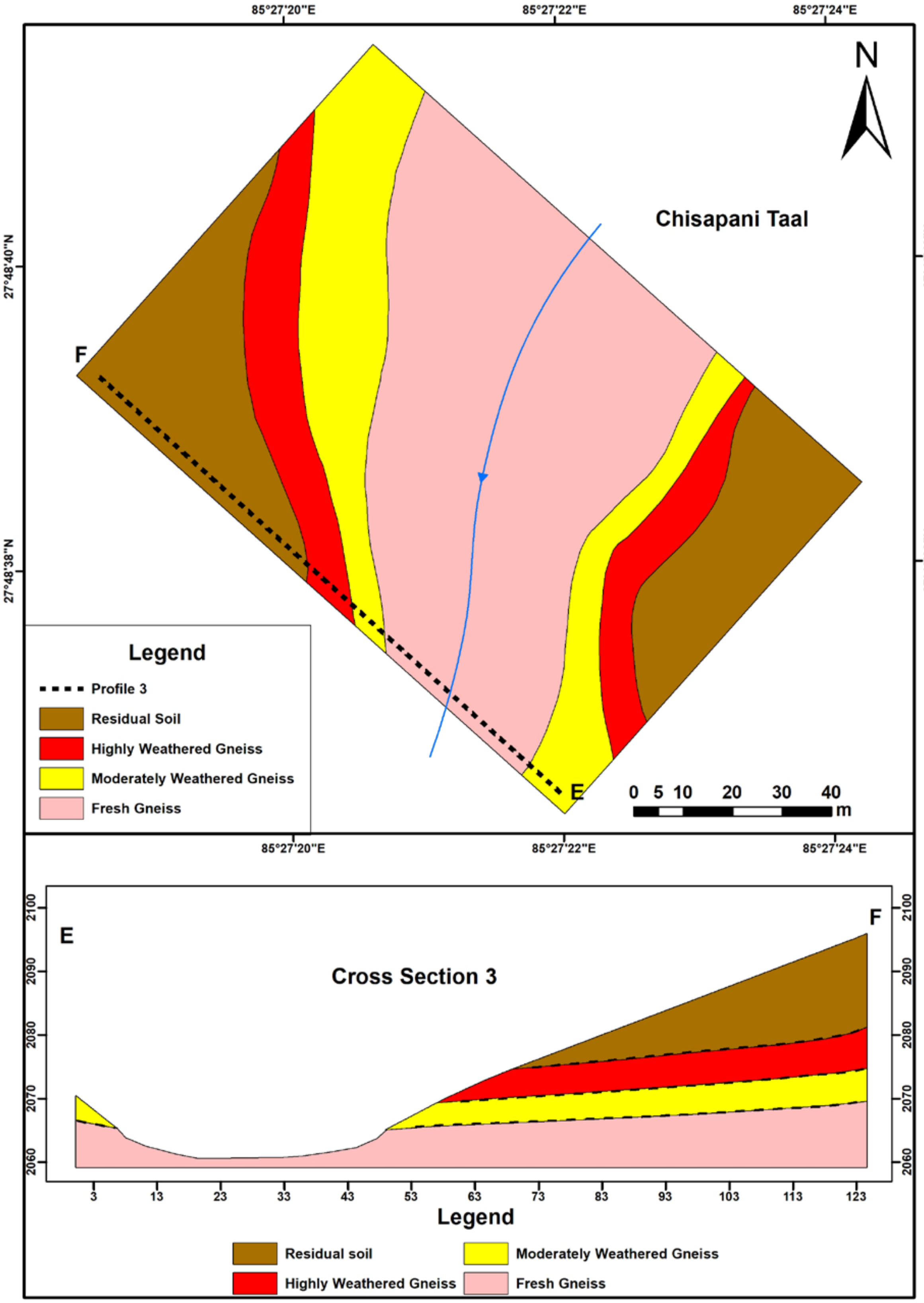


Figure 9. Cross section along the downstream traverse line

L2

The rock was exposed at the left bank, upstream and was fresh gneiss with (50 – 100) MPa UCS value, 82.125% RQD, discontinuity spacing (0.18 – 0.57)m, medium to low persistency, open to tight joints, rough surface, none to soft filling < 5 mm and slightly weathered wall, damp. The RMR was calculated 63, class II, Good rock. The attitude of the foliation plane was 260º/20º.

L3

The rock was exposed at the left bank, upstream and was fresh gneiss with (25 – 50) MPa UCS value, 90.275% RQD, (0.33 – 0.45)m discontinuity spacing, very low to low persistency, moderately open to open joints, soft filling, moderately to slightly weathered wall rock, damp. The RMR was found to be 60, class III and Fair rock. The attitude of the foliation plane was 215º/05º.

L4

The rock was exposed at the left bank, upstream and was moderately weathered gneiss with (5 – 25) MPa UCS value, 54.675% RQD, discontinuity spacing (0.10 – 0.17) m, very low to low persistency, open to tight joints, rough to very rough surfaces, hard filling > 5 mm, moderately weathered wall rock, damp. The RMR was calculated 52, class III, Fair rock. The attitude of the foliation plane was 213º/15º.

L5

The rock was exposed at the right bank, upstream and was fresh gneiss with (25 – 50) MPa UCS value, 13.875% RQD, discontinuity spacing (0.06-0.27) m, very low to low persistency, moderately open to tight joints, smooth rough to rough surfaces hard <5mm to soft > 5mm filling, slightly to highly weathered rock wall, damp. The RMR was computed 42, class III, Fair rock. The attitude of the foliation plane was 105º/7º.

L6

The rock was exposed at the left bank, the dam axis and was fresh gneiss with (25-50) MPa UCS value, 25.375% RQD, discontinuity spacing (0.03-0.78)m., low to high persistency, moderately open to tight joints, smooth rough surface, none to hard filling <5 mm, slightly to moderately weathered wall rock, damp. The RMR was 51, Class III, Fair rock. The attitude of the foliation plane was 265º/22º.

L7

The exposure was at the left bank, the dam axis and was highly weathered gneiss. The attitude of the foliation plane was 150º/05º.

L8

The rock was exposed at the right bank, downstream the dam axis and was fresh gneiss with (25-50) MPa UCS value, 91.475% RQD, discontinuity spacing (0.32 – 0.70)m, low to medium persistency, moderately open to very tight joints, smooth rough to rough surface, none to hard filling < 5mm, slightly to unweathered rock wall, dry. The RMR was computed 72, class II, Good rock. The attitude of the foliation plane was 070º/15º.

L9

The rock was exposed at the right bank, at the dam axis and was moderately weathered gneiss. The attitude of the foliation plane was 010º/32º.

L10

The rock was exposed at the right bank, at the dam axis and was identified as highly weathered gneiss with (5-25) MPa UCS value, -46.6% RQD, discontinuity spacing (0.05-0.06) m, low to medium persistency, moderately open to open joints, rough surface, hard filling, slightly to moderately weathered wall rock, damp. The RMR was calculated 37, class IV, Poor rock. The attitude of the foliation plane was 030º/10º.

L11

The observation point was located at the right end of the dam axis. It was covered with brownish grey residual soil with vegetation.

L12

The observation point was located at the left end of the dam axis and was covered with brownish grey residual soil with vegetation.

L13

The rock was exposed at the left bank, downstream and was fresh gneiss with (50-100) MPa UCS value, 86.5% RQD, discontinuity spacing (0.28-0.40)m, very high to low persistency, moderately open to tight joints, rough surface, none to soft filling 75 mm, moderately to unweathered wall rock, dry. The RMR was calculated 68, class II, Good rock. The attitude of the foliation plane was 245º/20º.

L14

The rock was exposed at the left bank, downstream and was moderately weathered gneiss with (25-50) MPa UCS value, 69.95% RQD, discontinuity spacing (0.15-0.20)m, low persistency, moderately open joints, rough surface, hard filling <5mm, moderately to unweathered wall rock, damp. The RMR was computed 56, class III, Fair rock. The attitude of the foliation plane was 035º/15º.

Therefore, the rock mass fell under Poor rock to Good rock, Poor at one observation point, Fair at five points and Good at four observation points.

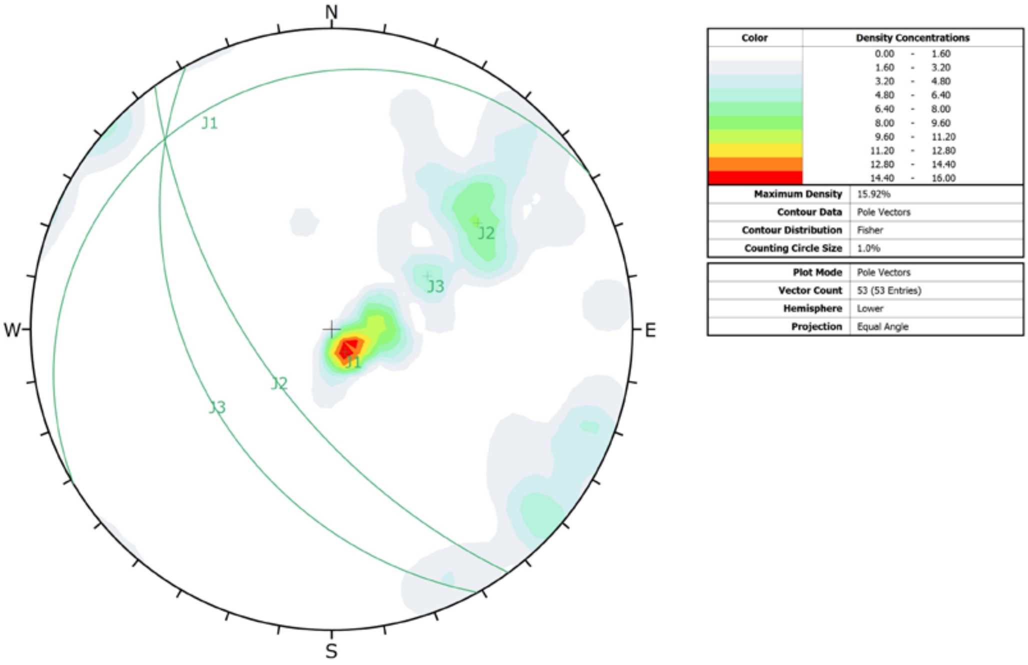
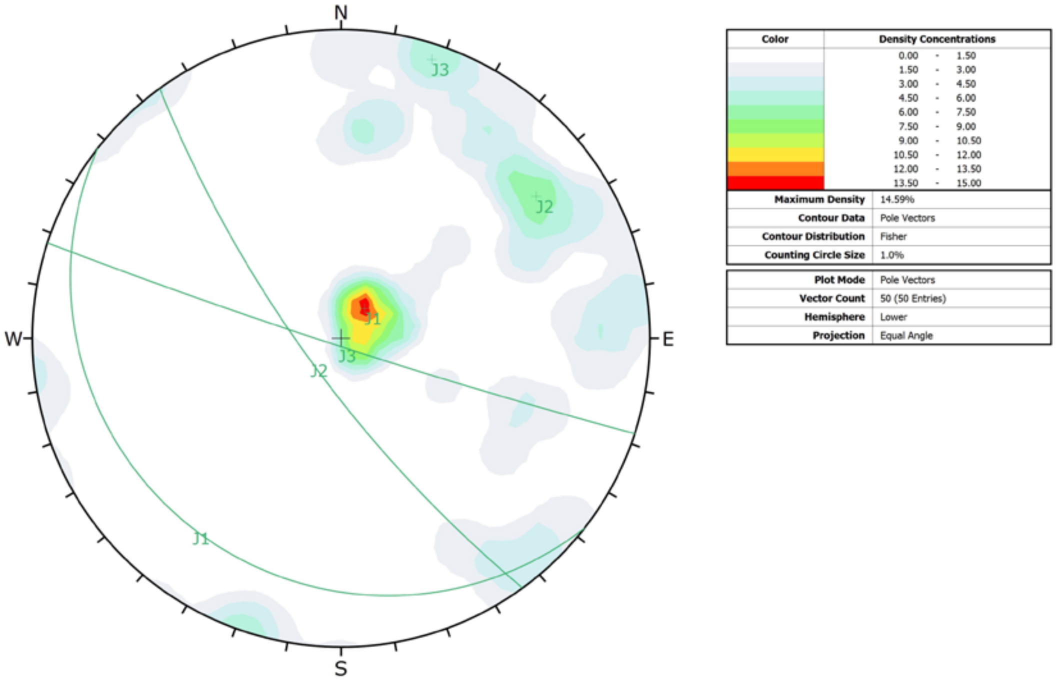


Figure 10. Contour plot of joint sets at L1

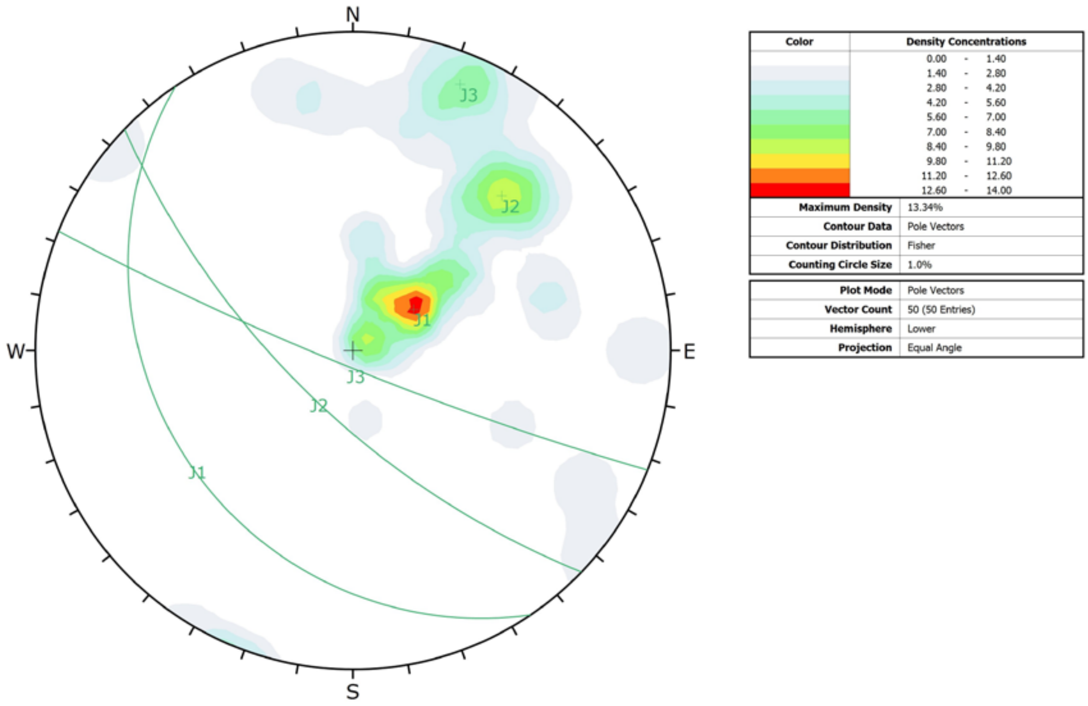


Color	Density Concentrations
⬜	0.00 - 1.50
⬜	1.50 - 3.00
🟦	3.00 - 4.50
🟦	4.50 - 6.00
🟩	6.00 - 7.50
🟩	7.50 - 9.00
🟩	9.00 - 10.50
🟨	10.50 - 12.00
🟧	12.00 - 13.50
🟥	13.50 - 15.00

Maximum Density	14.59%
Contour Data	Pole Vectors
Contour Distribution	Fisher
Counting Circle Size	1.0%

Plot Mode	Pole Vectors
Vector Count	50 (50 Entries)
Hemisphere	Lower
Projection	Equal Angle

Figure 11. Contour plot of joint sets at L2



Color	Density Concentrations
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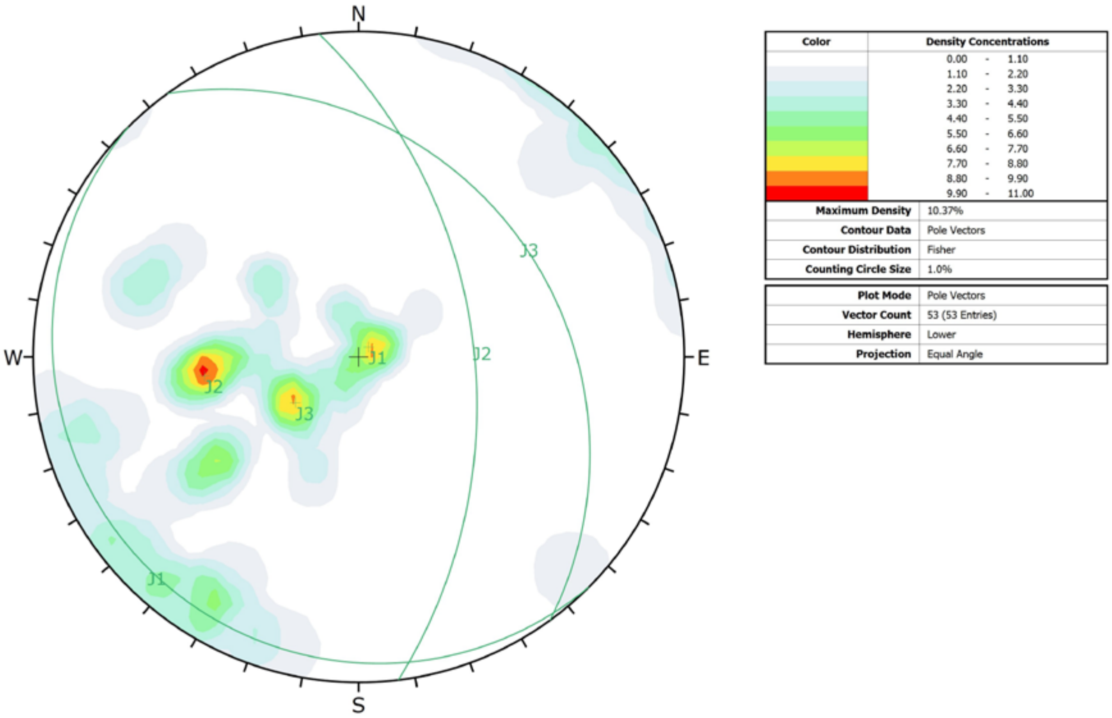
⬜	1.40 - 2.80
🟦	2.80 - 4.20
🟦	4.20 - 5.60
🟩	5.60 - 7.00
🟩	7.00 - 8.40
🟩	8.40 - 9.80
🟨	9.80 - 11.20
🟧	11.20 - 12.60
🟥	12.60 - 14.00

Maximum Density	13.34%
Contour Data	Pole Vectors
Contour Distribution	Fisher
Counting Circle Size	1.0%

Plot Mode	Pole Vectors
Vector Count	50 (50 Entries)
Hemisphere	Lower
Projection	Equal Angle

Figure 12. Contour plot of joint sets at L3



Color	Density Concentrations
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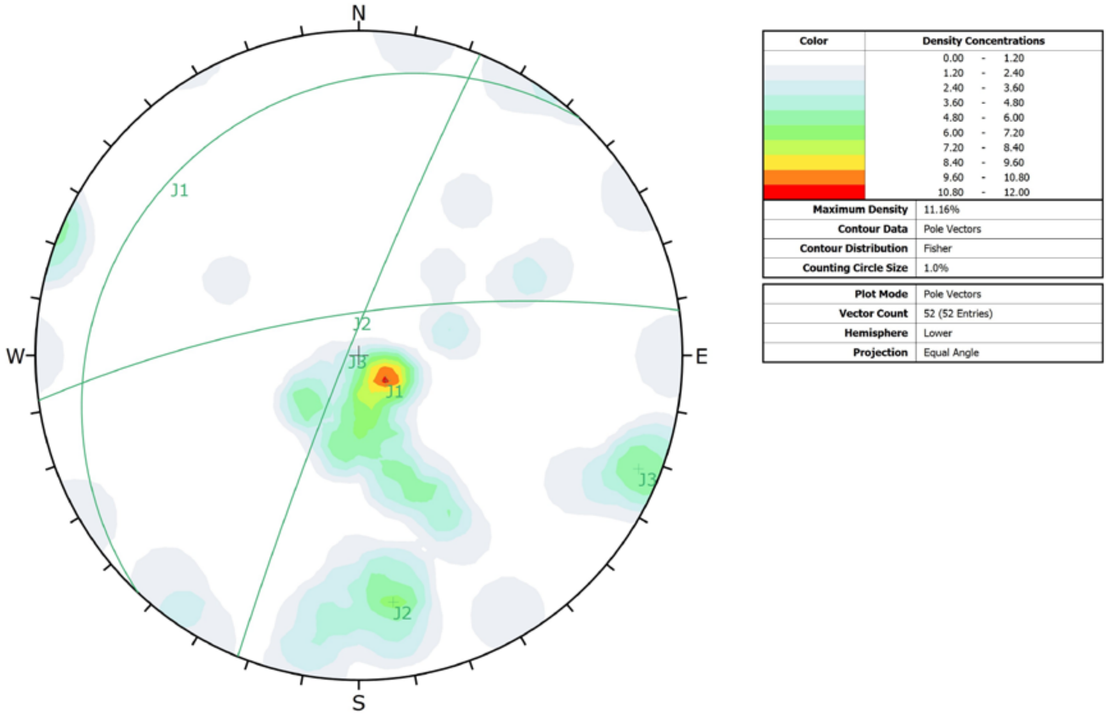
⬜	1.10 - 2.20
⬜	2.20 - 3.30
🟩	3.30 - 4.40
🟩	4.40 - 5.50
🟩	5.50 - 6.60
🟩	6.60 - 7.70
🟨	7.70 - 8.80
🟧	8.80 - 9.90
🟥	9.90 - 11.00
Maximum Density	10.37%
Contour Data	Pole Vectors
Contour Distribution	Fisher
Counting Circle Size	1.0%

Plot Mode	Pole Vectors
Vector Count	53 (53 Entries)
Hemisphere	Lower
Projection	Equal Angle

Figure 13. Contour plot of joint sets at L4



Color	Density Concentrations
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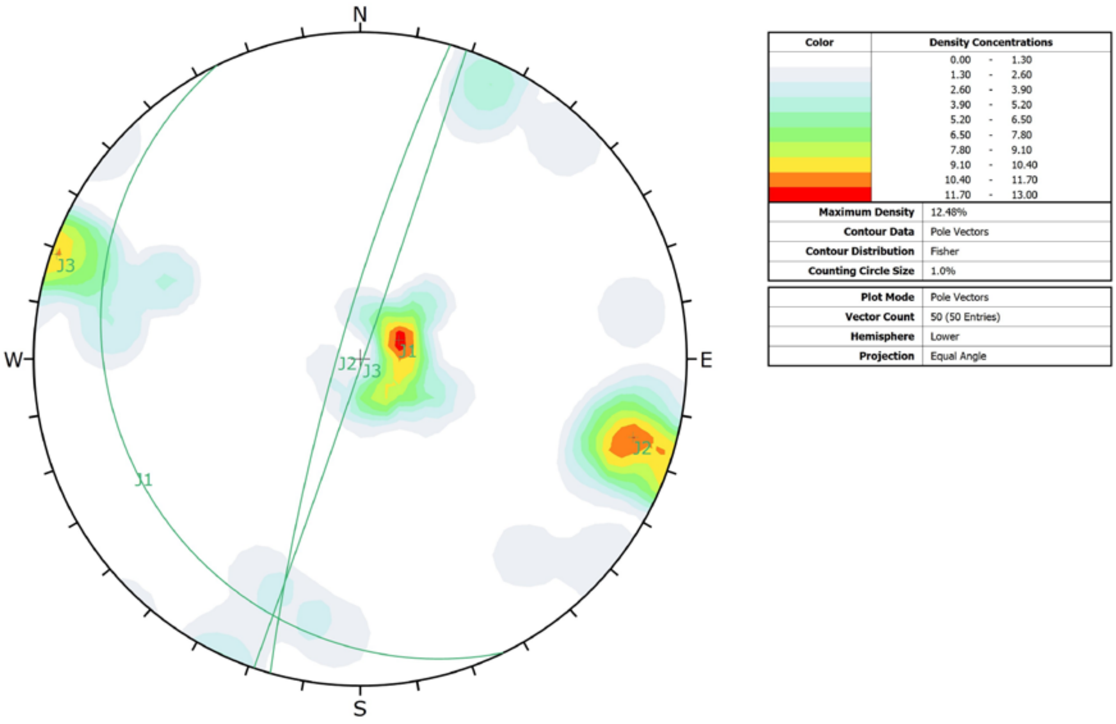
⬜	1.20 - 2.40
⬜	2.40 - 3.60
🟩	3.60 - 4.80
🟩	4.80 - 6.00
🟩	6.00 - 7.20
🟩	7.20 - 8.40
🟨	8.40 - 9.60
🟧	9.60 - 10.80
🟥	10.80 - 12.00
Maximum Density	11.16%
Contour Data	Pole Vectors
Contour Distribution	Fisher
Counting Circle Size	1.0%

Plot Mode	Pole Vectors
Vector Count	52 (52 Entries)
Hemisphere	Lower
Projection	Equal Angle

Figure 14. Contour plot of joint sets at L5

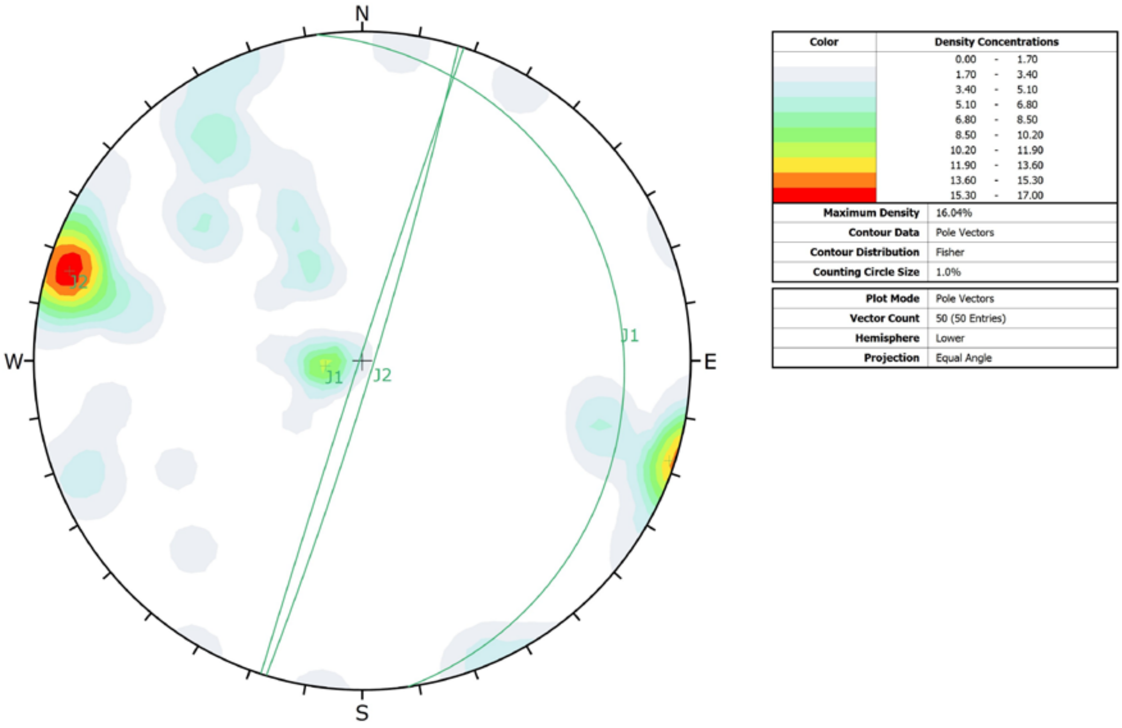


Color	Density Concentrations
⬜	0.00 - 1.30
⬜	1.30 - 2.60
🟦	2.60 - 3.90
🟦	3.90 - 5.20
🟩	5.20 - 6.50
🟩	6.50 - 7.80
🟩	7.80 - 9.10
🟨	9.10 - 10.40
🟧	10.40 - 11.70
🟥	11.70 - 13.00

Maximum Density	12.48%
Contour Data	Pole Vectors
Contour Distribution	Fisher
Counting Circle Size	1.0%

Plot Mode	Pole Vectors
Vector Count	50 (50 Entries)
Hemisphere	Lower
Projection	Equal Angle

Figure 15. Contour plot of joint sets at L6



Color	Density Concentrations
⬜	0.00 - 1.70
⬜	1.70 - 3.40
🟦	3.40 - 5.10
🟦	5.10 - 6.80
🟩	6.80 - 8.50
🟩	8.50 - 10.20
🟩	10.20 - 11.90
🟨	11.90 - 13.60
🟧	13.60 - 15.30
🟥	15.30 - 17.00

Maximum Density	16.04%
Contour Data	Pole Vectors
Contour Distribution	Fisher
Counting Circle Size	1.0%

Plot Mode	Pole Vectors
Vector Count	50 (50 Entries)
Hemisphere	Lower
Projection	Equal Angle

Figure 16. Contour plot of joint sets at L8

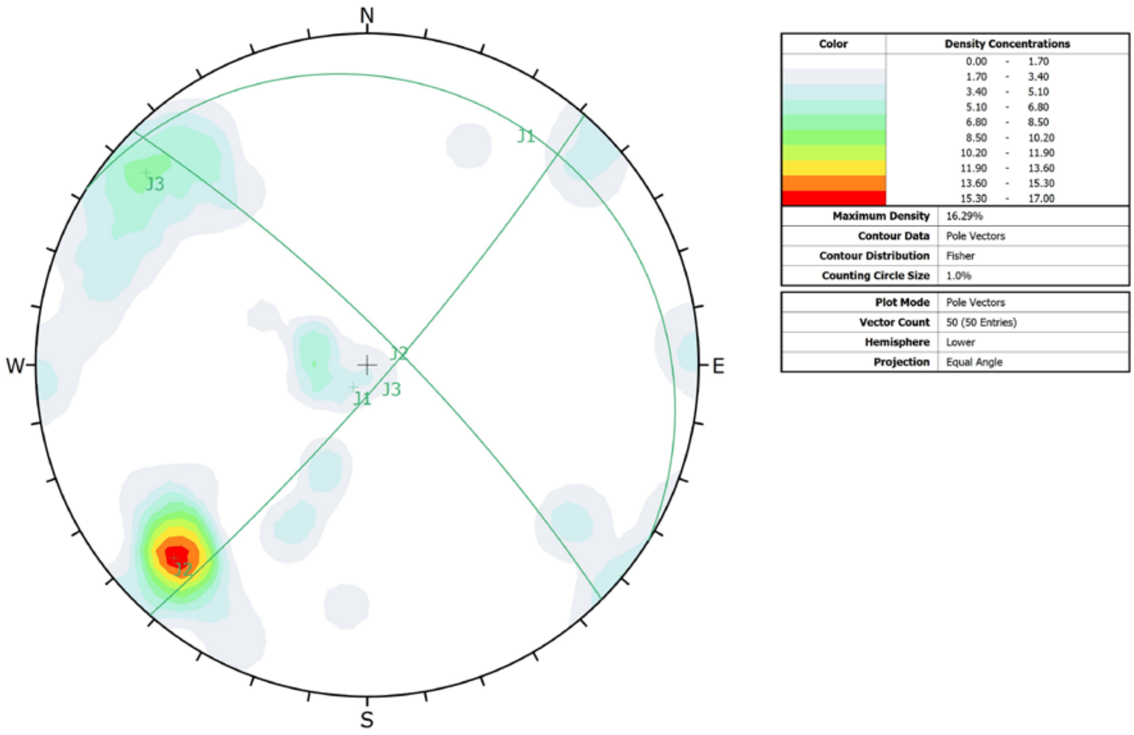


Figure 17. Contour plot of joint sets at L10

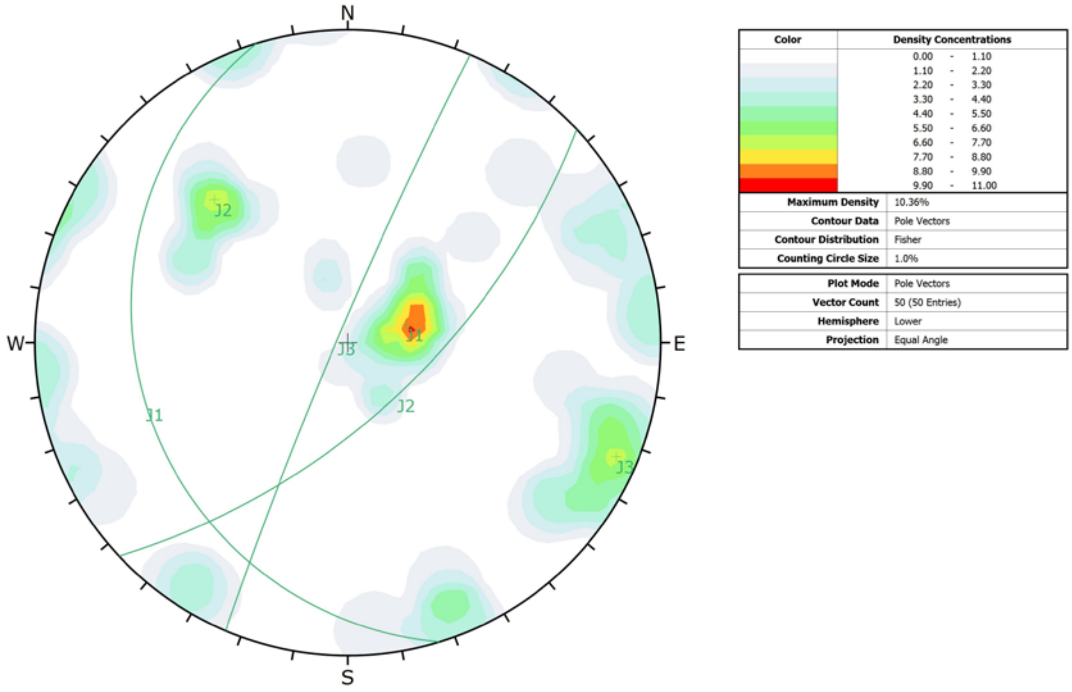


Figure 18. Contour plot of joint sets at L13

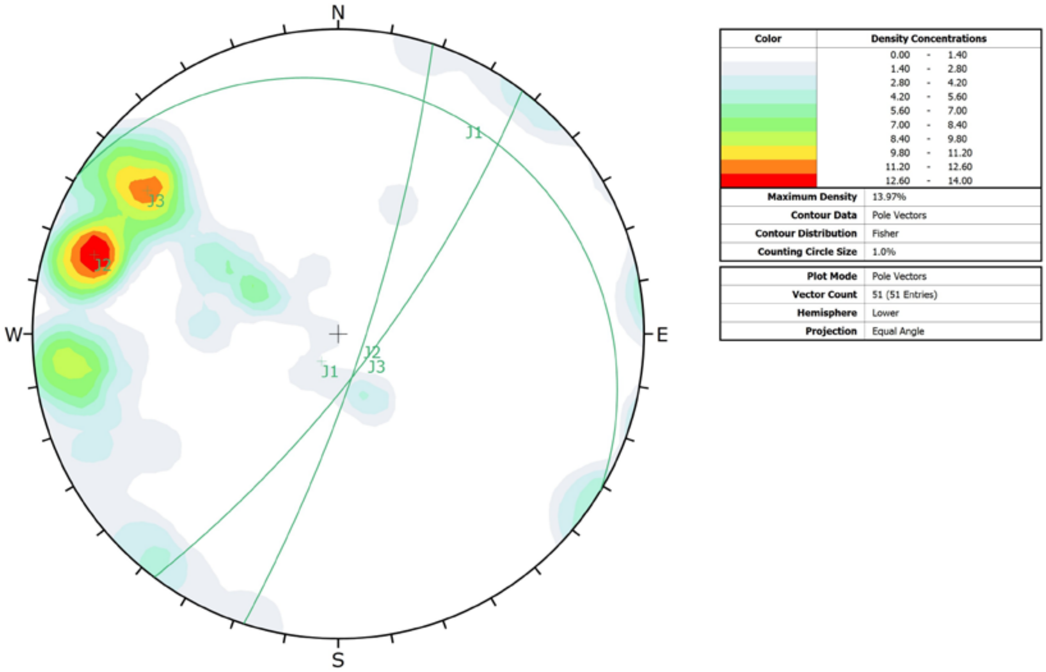


Figure 19. Contour plot of joint sets at L14

4.4. The DMR

For all the observation points for which RMR was computed, the DMR was computed too. RMR_{BD} was obtained from RMR_{B} (Table 11). C.F. was calculated for each of the three joint sets, with varying α_j but constant α_d (Table 13). The streamflow direction upstream-downstream the dam axis was determined as N45°E. However, because in all the observation points joint sets J2 and J3 dipped >30, the R_{STA} was scored 0 (Table 12), which equaled C.F. × R_{STA} to 0, which in turn equaled DMR_{STA} for joint sets J2 and J3 to RMR_{BD} alone. Therefore, only the joint set J1 was taken as the significative (s) joint to compute DMR_{STA} for that joint set. However, the final DMR_{STA} for each observation point was computed as the mean of the three DMR_{STA}'s at each observation point (Table 14). The DMR ranged from 39.719 to 70 (Table 14).

Table 10.Calculation for RMR, summarized

SN	Location name	UCS (Mpa)	R1	Jv	RQD	R2	S1	Spacing S2	S3	R3	Discontinuity condition R4	GW	R5	RMR_B	Class	Description
1	L1	50 - 100	7	18.99	62.525	13	0.09	0.5	0.17	9	21	c. dry	15	65	II	Good
2	L2	50 - 100	7	11.15	82.125	17	0.26	0.57	0.18	9	20	damp	10	63	II	Good
3	L3	25 - 50	4	7.89	90.275	20	0.36	0.33	0.48	10	16	damp	10	60	III	Fair
4	L4	5--25	2	22.13	54.675	13	0.17	0.16	0.1	8	19	damp	10	52	III	Fair
5	L5	25 - 50	4	38.45	13.875	3	0.06	0.17	0.27	9	16	damp	10	42	III	Fair
6	L6	25 - 50	4	33.85	25.375	8	0.04	0.22	0.78	10	19	damp	10	51	III	Fair
7	L7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	L8	25 - 50	4	7.41	21.475	20	0.32	0.7	0.35	12	21	c. dry	15	72	II	Good
9	L9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	L10	5--25	2	59.66	39.166	3x	0.05	0.03	0.05	5	17	damp	10	37	IV	Poor
11	L11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	L12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13	L13	50 - 100	7	9.4	86.5	17	0.28	0.4	0.3	10	19	c. dry	15	68	II	Good
14	L14	25 - 50	4	17.22	69.95	13	0.18	0.15	0.2	8	21	damp	10	56	III	Fair

L1

The DMR_{STA} was computed as 60.057. This by the definition of degree of safety of the dam against sliding fell under No Concern category. Hence, no engineering remedy is required.

L2

The DMR_{STA} was 61.34 which meant No Concern regarding the degree of safety. Therefore, no engineering remedy is required.

L3

The DMR_{STA} was calculated 61.045 which meant No Concern to require any engineering remedy for the safety of the dam against sliding.

L4

The DMR_{STA} was computed 55.582 which fell under the category of Concern as per the degree of safety. Therefore, spot consolidation grouting is proposed as engineering remedy.

L5

The DMR_{STA} was confirmed to 44.960. This showed the concern category in the Degree of safety. Therefore, spot consolidation grouting as an engineering remedy is proposed.

L6

The DMR_{STA} was calculated to 52.534. This required the concern for the degree of safety. Hence, spot consolidation grouting is proposed as an engineering remedy.

L8

The DMR_{STA} was computed to 70 that signaled 'No Concern' for the degree of safety. Therefore, no engineering remedy ought to be called.

L10

The DMR_{STA} was calculated to 39.719. This alarmed the degree of safety to 'Concern' category and therefore calls for spot consolidation grouting as an engineering remedy.

L13

The DMR_{STA} was calculated to 65, a good rating to call it a 'No Concern' category in the degree of safety. Hence, no engineering remedy is required.

L14

The DMR_{STA} was confirmed to 59 which alarmed the degree of safety of the dam against sliding to place it under 'Concern' category and thus, spot consolidation grouting is sought for as an engineering remedy.

Hence, the calculated DMR_{STA} signaled that five observation points demanded an engineering treatment of the rock mass whereas the other five did not (Figure 10).

Table 11.Calculation for RMR_{BD}

SN	Location name	UCS_{BD}	$R1_{BD}$	RQD	R2	S1	Spacing S2	S3	R3	Discontinuity condition R4	$GW,R5_{BD}$	RMR_{BD}
1	L1	25 - 50	4	62.525	13	0.09	0.5	0.17	9	21	15	62
2	L2	25 - 50	4	82.125	17	0.26	0.57	0.18	9	20	15	63
3	L3	5--25	2	90.275	20	0.36	0.33	0.48	10	16	15	63
4	L4	1 -- 5	1	54.675	13	0.17	0.16	0.1	8	19	15	56
5	L5	5--25	2	13.875	3	0.06	0.17	0.27	9	16	15	45
6	L6	5--25	2	25.375	8	0.04	0.22	0.78	10	19	15	54
7	L7	-	-	-	-	-	-	-	-	-	-	-
8	L8	5--25	2	21.475	20	0.32	0.7	0.35	12	21	15	70
9	L9	-	-	-	-	-	-	-	-	-	-	-
10	L10	1--5	1	39.166	3x	0.05	0.03	0.05	5	17	15	41
11	L11	-	-	-	-	-	-	-	-	-	-	-
12	L12	-	-	-	-	-	-	-	-	-	-	-
13	L13	25 - 50	4	86.5	17	0.28	0.4	0.3	10	19	15	65
14	L14	5--25	2	69.95	13	0.18	0.15	0.2	8	21	15	59

Table 12.Calculation for R_{STA}

SN	Location name	Dip/R_{STA}		
		J1(dip)/R_{STA}	J2(dip)/R_{STA}	J3(dip)/R_{STA}
1	L1	15 DS/-2	65 DS/0	82 DS/0
2	L2	20 DS/-2	75 DS/0	75 DS/0
3	L3	05 DS/-7	75 DS/0	85 DS/0
4	L4	15 DS/-2	65 US/0	85 DS/0
5	L5	07 US/-7	70 US/0	55 DS/0
6	L6	22 DS/-2	80 DS/0	85 DS/0
7	L7	-	-	-
8	L8	15 US/-2	80 DS/0	77 DS/0
9	L9	-	-	-
10	L10	10 US/-7	84 US/0	90 DS/0
11	L11	-	-	-
12	L12	-	-	-
13	L13	20 DS/0	66 DS/0	84 US/O
14	L14	15 US/0	88 US/0	48 DS/0

Table 13. Calculation for CF

			J1			J2			J3	
SN	Location name	α_{j1}	$\lvert\alpha_d-\alpha_{j1}\rvert$	CF1	α_{j2}	$\lvert\alpha_d-\alpha_{j2}\rvert$	CF2	α_{j3}	$\lvert\alpha_d-\alpha_{j3}\rvert$	CF3
1	L1	300	255	2.914	135	90	0	220	175	0.833
2	L2	260	215	2.476	135	90	0	210	165	0.549
3	L3	215	170	0.682	290	245	3.634	215	170	0.682
4	L4	213	168	0.627	110	65	0.008	225	180	1
5	L5	105	60	0.017	110	65	0.008	200	155	0.333
6	L6	265	220	2.698	280	235	3.309	220	175	0.833
7	L7									
8	L8	70	25	0.333	145	100	0.0002	285	240	3.482
9	L9									
10	L10	30	15	0.549	45	0	1	135	90	0
11	L11									
12	L12									
13	L13	245	200	1.801	144	99	0.0001	30	15	0.549
14	L14	35	10	0.682	105	60	0.017	225	180	1

Table 14. Calculation for DMR

SN	Location name	RMR_{BD}	CF1	R_{STA1}	DMR_{STA1}	CF2	R_{STA2}	DMR_{STA2}	CF3	R_{STA3}	DMR_{STA3}	DMR_{STA}	DoS	Remedy
1	L1	62	2.914	-2	56.172	0	0	62	0.833	0	62	60.057	NC	none
2	L2	63	2.476	-2	58.048	0	0	63	0.549	0	63	61.34	NC	none
3	L3	63	0.682	-7	58.276	3.634	0	63	0.682	0	63	61.048	NC	none
4	L4	56	0.627	-2	54.746	0.008	0	56	1	0	56	55.582	C	spot consolidation grouting
5	L5	45	0.017	-7	44.881	0.008	0	45	0.333	0	45	44.96	C	spot consolidation grouting
6	L6	54	2.698	-2	49.604	3.309	0	54	0.833	0	54	52.534	C	spot consolidation grouting
7	L7	-						-			-		-	-
8	L8	70	0.333	0	70	0.0002	0	70	3.482	0	70	70	NC	none
9	L9	-						-			-		-	-
10	L10	41	0.549	-7	37.157	1	0	41	0	0	41	39.719	C	spot consolidation grouting
11	L11	-						-			-		-	-
12	L12	-						-			-		-	-
13	L13	65	1.801	0	65	0.0001	0	65	0.549	0	65	65	NC	none
14	L14	59	0.682	0	59	0.017	0	59	1	0	59	59	C	spot consolidation grouting

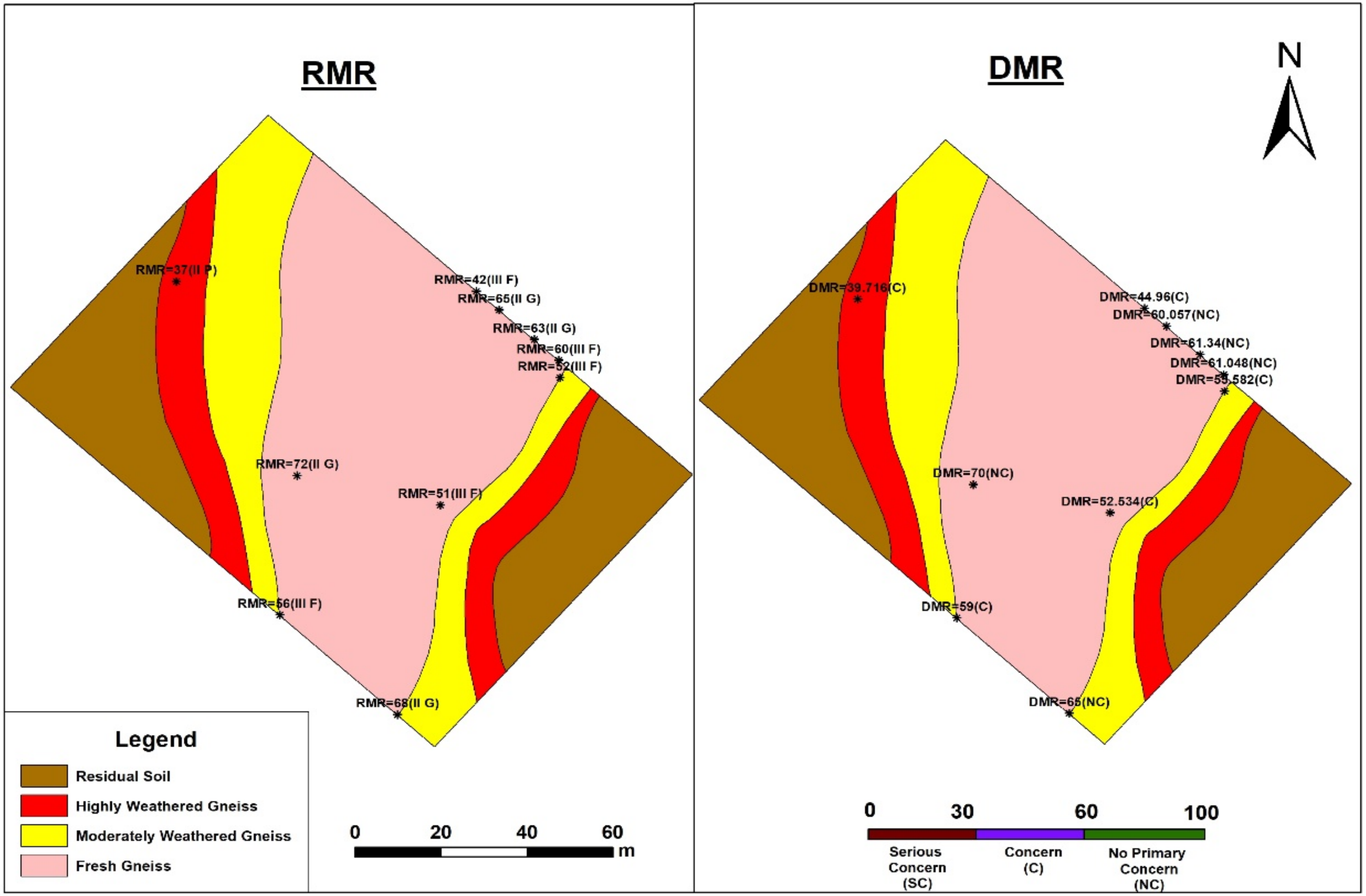


Figure 20. RMR vs DMR of the study area

CHAPTER V
DISCUSSION

The footprint of the dam foundation preserved the records of foliation trend going along NNW to SSE. Several fractures and faults were also observed. This is attributed to the metamorphism in gneiss which also resulted in intense folding. The synform, almost along the axis of which flowed the stream channel, was the outcome of such folding that ran throughout the study area upstream – downstream. It is assumed that same is the case in the upstream, thereby contributing to the accumulation of water towards the reservoir.

The cross sections depict the odd layering at the opposite banks. It is because the distinction made therein was not of the bedding plane but of the weathering grade layers, the progression of which was hard to detect. Moreover, it was assumed that the layering went near parallel to the hill slope before excavation, as such has been assumed that water penetrates to near equal depth from the surface, provided the geology is same, to weather the underlying strata. In Cross section 1 the Fresh rock was met at the shallower depth at right end compared to that at the left. It was because the topography at the right before the excavation had been higher, which difficulted the water penetration. However, those at the left and the right in Cross section 2 were at similar elevation to place Fresh gneiss to similar depth, whereas in Cross section 3 the absences of the grades of weathering at the left bank is accounted to the streambed lying therein, which is an agent to wash away the weaker materials which in turn affects the maturity of the slope.

The RMR and the DMR of the rock masses of the study area varied spatially even when weathering grade of the gneiss was same. At L1 the RMR was 65 which was attributed to the optimum Groundwater rating and to all other ratings being of medium value; the DMR was 60.057 as the significative joint was of Favourable R_{STA} rating. The rock mass of L2 had RMR 63 which came out of Good Quality RQD rating and of the other ratings being above medium; the DMR was 61.34 accounting to Favourable R_{STA} rating. The rock mass at L3 had RMR 60 despite the decreased UCS value, as the RQD rating was at its optimum value and the other ratings above the medium; the DMR, however, was 61.048, greater than RMR, which was accounted to the increased RMR_{BD} – 63, despite the R_{STA} rating going as low as just to be Fair. At L4, climbing further up towards the left, the rock mass had RMR 52 which was because the observation point was located at Fresh – Moderately weathered condition of gneiss where the UCS was weak and RQD Fair, also the spacing of the discontinuity was close; the DMR here too exceeded the RMR, 55.582 as because the RMR_{BD} exceeded the RMR_{B} and the R_{STA} rating was in Favourable value. L5, in spite of being located in the centre of the upstream traverse line, had even lower RMR – 42, as because the RQD value was Very Poor therein, and also the UCS value just being medium strong; the DMR, because of the RMR_{BD} exceeding the RMR_{B}, was again higher than the RMR – 44.96. The rock mass at L6 had RMR 51 and DMR 52.534; the RMR value was attributed to Poor RQD and Medium strong UCS value whereas the DMR was accounted to the RMR_{BD} value which was greater than RMR_{B} value, and to the Favourable R_{STA} value. L7 rested on Residual soil and hence no RMR and DMR were computed. The rock mass at L8 had the highest RMR value – 72, which was attributed to the optimum values of the RQD and of the Groundwater condition, plus the above medium rating of the other parameters; the DMR too was the highest – 70, accounted to the Very Favourable R_{STA} value. The rock mass at L10 was a Poor rock with the lowest RMR – 37, which was attributed to very low spacing of all three joint sets, that heightened the volumetric joint count, Jv, to as high as 59.66, which even exceeded the range ($4.5 < Jv < 35$) to negatively score the RQD, and also brought low UCS value, (5-25) MPa; the DMR too was the lowest – 39.719 because of the R_{STA} value going as low as just to be Fair despite the RMR_{BD} exceeding RMR_{B}. The observation points of L11 and L12 rested on Residual soil. The rock mass at L13 had RMR 68 attributed to optimum Groundwater value and Good RQD, and DMR 65, attributed to Very Favourable R_{STA} rating. The rock mass at L14 had RMR 56, all ratings being above medium, and DMR 59 because the RMR_{BD} exceeded RMR_{B} and the R_{STA} rating was Very Favourable.

CHAPTER VI

CONCLUSION

The selection of the area for the construction of the dam, where this research has been carried out, seems to be very befitting in engineering geological perspective. The geology of the site is banded gneiss of Higher Himalayan Crystalline. Most of the central section of the upstream-downstream portion of the proposed dam rests on Fresh gneiss that is spread for more than half of the total foundation area. The weathering grade of the rock mass ranged from Fresh rock to Residual soil; the RMR is as high as 72 and as low as 37; the DMR is the highest at 70 and the lowest at 39.7. A fold, synform has been observed. The axis of the fold runs from almost the centre of the upstream boundary in NE – SW direction until the dam axis and then bends to the N – S direction to leave off the downstream boundary of the study area. The stream runs almost along this fold axis.

The prime focus of the research was the rock mass condition of the dam site with respect to DMR system. The following statements have been deduced as conclusion:

i. Most rock masses are damp, ranging from class IV to class I, Poor Rock to Good Rock.
ii. The rock masses at L4, L5, L6, L10 and L14 are the 'Concern' category in degree of safety of dam against sliding. Therefore, spot consolidation grouting is recommended. Special attention be given to L10.
iii. Both of the ends of the dam axis rest on the residual soil, which weakens the dam by the seepage of water through abutments. Engineering remedy is felt of need, one such remedy can be the further excavation to meet the bed rock.

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ANNEX

APPENDIX I TABLES

Table 15.Calculation for Jv

SN	Location name	S1	Spacing(m) S2	S3	Jv
1	L1	0.09	0.5	0.17	18.99
2	L2	0.26	0.57	0.18	11.15
3	L3	0.36	0.33	0.48	7.89
4	L4	0.17	0.16	0.1	22.13
5	L5	0.06	0.17	0.27	38.45
6	L6	0.04	0.22	0.78	33.85
7	L7	-	-	-	-
8	L8	0.32	0.7	0.35	7.41
9	L9	-	-	-	-
10	L10	0.05	0.03	0.05	59.66
11	L11	-	-	-	-
12	L12	-	-	-	-
13	L13	0.28	0.4	0.3	9.4
14	L14	0.18	0.15	0.2	17.22

Table 16.Calculation for apparent dip

SN	Location name	Strike of foliation	α	θ	δ
1	L1	30	105	5	4.8304
2	L2	170	35	20	11.791
3	L3	125	10	5	0.8703
4	L4	123	12	15	3.1886
5	L5	15	120	7	6.0697
6	L6	175	40	22	14.558
7	L7	60	75	5	4.8304
8	L8	160	25	15	6.4606
9	L9	100	35	22	13.047
10	L10	120	15	10	2.6129
11	L11	R.Soil			
12	L12	R.Soil			
13	L13	155	20	20	7.095
14	L14	125	10	15	2.665

α=|profile-foliation strike|; θ = true dip;
δ = apparent dip = $\tan^{-1}(\sin\alpha . \tan\theta)$

Table 17.Location of observation points

SN	Location name	Situation	Latitude (N)	Longitude (E)	Altitude (m asl)
1	L1	u/s, left	-	-	-
2	L2	u/s, left	-	-	-
3	L3	u/s, left	-	-	-
4	L4	u/s, left			
5	L5	u/s, right	3077212.07	643683.846	2062.735
6	L6	axis, left			
7	L7	axis, left	-	-	-
8	L8	d/s, right	-	-	-
9	L9	axis, right	-	-	-
10	L10	axis, right			
11	L11	axis, right	3077212.919	643604.394	2090.576
12	L12	axis, left	3077134.343	643703.269	2099.899
13	L13	d/s, left	-	-	-
14	L14	d/s, left	-	-	-
15	L15	u/s, left	3077167.861	643733.295	2090.388
16	L16	u/s, right	3077256.395	643634.384	2088.052
17	L17	d/s, right	3077189.358	643574.4	2098.549
18	L18	d/s, right	3077145.006	643623.768	2073.155
19	L19	d/s, left	3077100.784	643673.178	2071.761
20	L20	axis, right	3077178.602	643653.864	2061.869

Table 18.Attitude of foliations

SN	Location name	Foliation		
		Strike	Dip amount	Dip direction
1	L1	30	15	300
2	L2	170	20	260
3	L3	125	5	215
4	L4	123	15	213
5	L5	15	7	105
6	L6	175	22	265
7	L7	60	5	150
8	L8	160	15	70
9	L9	100	22	-
10	L10	120	10	30
11	L11	R.Soil	-	-
12	L12	R.Soil	-	-
13	L13	155	20	245
14	L14	125	15	35

Table 19. Measurement of random joint sets

SN	L1		L2		L3		L4		L5		L6		L8		L10		L13		L14	
	DD	DA	DD	DA	DD	DA	DD	DA	DD	DA	DD	DA	DD	DA	DD	DA	DD	DA	DD	DA
1	285	85	325	7	275	15	20	20	10	80	225	21	65	17	75	17	30	85	115	52
2	225	75	240	80	175	75	55	50	295	85	195	15	80	5	42	80	35	86	105	80
3	270	20	215	20	190	75	95	45	350	80	290	85	100	15	125	75	255	35	70	82
4	250	10	230	75	200	70	85	45	290	10	175	18	147	85	75	22	230	32	105	83
5	320	12	225	20	220	65	105	70	335	10	260	16	160	62	112	18	220	38	38	19
6	245	60	225	20	230	30	225	80	335	2	100	75	285	75	22	11	160	20	105	83
7	325	10	255	25	245	45	82	53	330	55	260	20	125	88	25	85	120	60	120	34
8	240	40	260	20	230	70	87	50	350	70	320	20	160	90	224	85	250	28	120	30
9	230	65	170	10	235	35	50	28	345	45	240	16	95	31	20	36	265	88	110	34
10	325	10	190	70	230	65	55	70	1	65	205	85	132	70	128	80	250	80	125	90
11	240	40	260	90	235	25	95	35	290	88	290	75	80	76	145	81	250	22	32	88
12	230	65	275	80	310	90	47	85	330	25	340	15	65	15	145	65	116	58	107	82
13	325	10	295	40	200	10	80	55	295	20	280	80	115	90	45	75	230	35	60	85
14	245	40	200	90	205	15	255	10	345	30	260	80	140	5	135	88	240	25	110	76
15	355	15	305	65	200	25	255	5	295	15	310	30	150	72	5	72	285	9	120	85
16	270	15	290	60	190	37	85	57	250	30	315	10	70	86	45	78	60	85	120	40
17	265	40	280	15	250	65	85	47	330	15	110	85	65	84	205	72	135	61	85	88
18	285	25	180	65	225	5	160	18	350	70	110	82	106	80	60	75	240	8	98	50
19	240	60	260	20	200	85	195	4	260	35	5	80	104	84	140	76	338	88	130	46
20	280	20	320	85	165	80	235	27	305	15	230	30	95	555	265	88	265	90	85	83
21	230	85	245	85	215	25	55	30	290	88	260	15	151	35	25	60	250	90	160	25
22	310	85	240	5	205	80	115	30	5	75	290	34	103	72	115	38	340	88	88	80
23	340	85	310	87	295	58	15	85	335	55	280	85	290	76	115	88	270	20	125	88
24	355	10	225	15	230	45	80	87	300	10	290	85	143	36	45	85	290	80	130	80
25	330	85	325	87	220	75	65	20	15	35	290	20	108	88	125	85	145	55	105	80
26	225	60	230	75	235	25	65	31	2	20	265	12	125	38	20	46	355	85	58	70
27	310	10	265	75	215	70	165	15	225	40	290	25	158	31	55	15	270	16	115	75
28	200	75	325	5	260	65	45	32	5	30	95	75	155	90	90	88	271	29	125	60
29	245	80	180	85	185	40	60	10	270	88	205	80	102	71	115	75	338	78	120	50
30	295	85	235	75	220	60	70	85	355	80	112	65	280	71	45	77	135	65	90	5
31	230	55	215	85	215	55	35	85	5	35	220	15	155	44	140	80	380	9	120	20
32	320	10	285	10	195	25	30	75	215	60	305	15	130	65	130	88	225	75	80	85
33	245	65	220	75	245	25	110	70	120	50	385	15	157	50	40	80	286	25	82	82
34	220	35	320	10	225	70	250	10	245	55	110	85	110	88	45	75	290	85	40	88
35	210	45	265	85	260	0	75	75	330	65	223	85	70	10	115	20	285	85	45	87
36	310	75	210	75	250	20	35	85	340	35	15	76	150	54	100	80	255	28	330	25
37	5	25	290	70	230	75	120	65	345	45	330	14	210	88	110	21	310	78	355	20
38	215	60	195	90	225	35	55	60	245	65	295	76	145	80	110	80	280	70	17	90
39	245	55	200	85	230	25	220	10	355	20	80	12	48	30	125	4	305	80	335	30
40	220	85	240	10	350	25	50	87	330	45	25	88	145	75	35	79	185	60	125	70
41	285	25	330	75	230	50	60	88	210	90	310	88	130	60	297	7	230	55	75	75
42	305	10	235	35	200	85	25	85	10	15	230	30	105	87	50	75	240	80	90	45
43	315	87	245	65	250	30	50	60	50	25	235	16	187	88	25	35	165	30	205	50
44	265	85	245	70	230	40	20	45	50	27	285	76	105	87	310	75	140	70	130	70
45	230	70	215	10	275	10	5	5	30	28	355	20	60	66	55	64	330	25	130	80
46	295	85	200	12	210	20	130	40	240	90	320	76	110	85	50	75	135	60	120	75
47	300	70	230	50	250	5	80	30	330	85	286	80	90	20	135	67	230	18	110	80
48	245	20	195	15	270	84	55	55	75	10	112	65	98	88	25	55	300	88	135	80
49	165	40	195	20	210	87	130	40	10	90	25	72	42	75	230	82	298	90	130	75
50	210	65	190	70	300	80	25	35	60	20	110	90	110	88	305	76	325	20	125	75
51	245	20					15	10	40	85									85	70
52	250	20					55	25	300	75										
53	310	90					315	85												

Table 20. RMR, L1

Rock Mass Rating (RMR) System (Bieniawski, 1989)	
LOCATION	**DESCRIPTION**
L1	
Elevation:-	upstrem, left bank

R1. STRENGTH OF INTACT ROCK MATERIAL						**R2. ROCK QUALITY DESIGNATION**				**R5. GROUNDWATER**		
Designation	**UCS (MPa)**		**PLI)MPa)**		**Rating**	**Designation**	**%**	**Rating**		**General Condition**	**Rating**	
Extremely strong	> 250		>10		15	Excellent quality	90 - 100	20		Completely dry	15	
Very strong	100 - 250		4 to 10		12	Good quality	75 - 90	17		Damp	10	
Strong	50 - 100		2 to 4		7	Fair quality	50 - 75	13		Wet	7	
Medium strong	25 - 50		1 to 2		4	Poor quality	25 - 50	8		Dripping	4	
Weak	5 to 25		<1		2	V. Poor quality	< 25	3		Flowing under	0	
V. Weak	1 to 5				1							

R3. SPACING OF DISCONTUNITIES											**STRIKE AND DIP ORIENTATION**	
		J1	**J2**	**J3**	**J4**	**J5**	**J6**	**J7**	**Rating**		**Discontinuity**	**Strike/Dip**
Very wide	>2m								20		J1	
Wide	0.6-2m								15		J2	
Moderate	20-60cm		■						10		J3	
Close	6-20cm	■		■					8	9	J4	
Very close	< 6cm								5		J5	
											J6	

R4. CONDITION OF DISCONTINUITY									
PERSISTENCE		**J1**	**J2**	**J3**	**J4**	**J5**	**J6**	**Rating**	21
Very low	< 1 m							6	
Low	1 - 3 m	■		■				4	
Medium	3 - 10 m		■					2	
High	10 - 20 m							1	
Very high	> 20 m							0	3.3
SEPERATION (APERTURE)									
Very tight joints	none							6	
Tight joints	< 0.1mm	■	■	■				5	
Moderately open joints	0.1 - 1mm							4	
Open joints	1 - 5 mm							1	
Very wide aperture	> 5 mm							0	5
ROUGHNESS									
Very Rough Surface								6	
Rough			■	■				5	
Slightly rough								3	
Smooth rough		■						1	3.6
Slikenside rough								0	
FILLING (GAUGE)									
None		■						6	
Hard filling < 5mm			■	■				4	
Hard filling > 5mm								2	
Soft filling < 5mm								2	
Soft filling > 5mm								0	4.6
WALL ROCK OF DISCONTINUITIES									
Unweathered								6	
Slightly Weathered		■	■					5	
Moderately				■				3	
Highly								1	
Decomposed								0	4.3
TOTAL RATING (RMR = R1 + R2 + R3 + R4 + R5) : 65									

ROCK MASS CLASSES DETERMINED FROM TOTAL RATING							
Rating		**Class**	**Description**	**Rating**		**Class**	**Description**
81 - 100		I	Very good rock	21 - 40	21 -40	IV	poor rock
61 - 80		II	good rock	<21	<21	V	very poor rock
40 - 60		III	fair rock	**Rock Mass Class from total rating**			

Table 21. RMR, L2

Rock Mass Rating (RMR) System (Bieniawski, 1989)														
LOCATION							**DESCRIPTION**							
L2														
Elevation:-							upstream, left							
R1. STRENGTH OF INTACT ROCK MATERIAL						**R2. ROCK QUALITY DESIGNATION**						**R5. GROUNDWATER**		
Designation	**UCS (MPa)**		**PLI)MPa)**		**Rating**	**Designation**			**%**	**Rating**		**General Condition**	**Rating**	
Extremely strong	> 250		>10		15	Excellent quality			90 - 100	20		Completely dry	15	
Very strong	100 - 250		4 to 10		12	Good quality			75 - 90	17		Damp	10	
Strong	50 - 100		2 to 4		7	Fair quality			50 - 75	13		Wet	7	
Medium strong	25 - 50		1 to 2		4	Poor quality			25 - 50	8		Dripping	4	
Weak	5 to 25		<1		2	V. Poor quality			< 25	3		Flowing under	0	
V. Weak	1 to 5				1									
R3. SPACING OF DISCONTUNITIES												**STRIKE AND DIP ORIENTATION**		
		J1	**J2**	**J3**	**J4**	**J5**	**J6**	**J7**		**Rating**		**Discontinuity**	**Strike/Dip**	
Very wide	>2m									20		J1		
Wide	0.6-2m									15		J2		
Moderate	20-60cm	■	■							10		J3		
Close	6-20cm			■						8		J4		
Very close	< 6cm									5		J5		
											9	J6		
R4. CONDITION OF DISCONTINUITY														
PERSISTENCY						**J1**	**J2**	**J3**	**J4**	**J5**	**J6**	**Rating**		**20**
Very low			< 1 m									6		
Low			1 - 3 m			■		■				4		
Medium			3 - 10 m				■					2		
High			10 - 20 m									1		
Very high			> 20 m									0	3.3	
SEPERATION (APERTURE)														
Very tight joints			none									6		
Tight joints			< 0.1mm			■						5		
Moderately open joints			0.1 - 1mm					■				4		
Open joints			1 - 5 mm				■					1		
Very wide aperture			> 5 mm									0	3.3	
ROUGHNESS														
Very Rough Surface												6		
Rough						■	■	■				5		
Slightly rough												3		
Smooth rough												1		
Slikenside rough												0	5	
FILLING (GAUGE)														
None						■						6		
Hard filling < 5mm												4		
Hard filling > 5mm												2		
Soft filling < 5mm							■	■				2		
Soft filling > 5mm												0	3.3	
WALL ROCK OF DISCONTINUITIES														
Unweathered												6		
Slightly Weathered						■	■	■				5		
Moderately												3		
Highly												1		
Decomposed												0	5	
TOTAL RATING (RMR = R1 + R2 + R3 + R4 + R5) :63														
ROCK MASS CLASSES DETERMINED FROM TOTAL RATING														
Rating						**Class**	**Description**	**Rating**		**Class**	**Description**			
81 - 100						I	Very good rock	21-40		IV	poor rock			
61 - 80						II	good rock	<21		V	very poor rock			
40 - 60						III	fair rock	**Rock Mass Class from total rating**						

Table 22. RMR, L3

Rock Mass Rating (RMR) System (Bieniawski, 1989)														
LOCATION							**DESCRIPTION**							
L3														
Elevation:-							upstream, left							
R1. STRENGTH OF INTACT ROCK MATERIAL						**R2. ROCK QUALITY DESIGNATION**						**R5. GROUNDWATER**		
Designation	**UCS (MPa)**		**PLI)MPa)**		**Rating**	**Designation**			**%**	**Rating**		**General Condition**	**Rating**	
Extremely strong	> 250		>10		15	Excellent quality			90 - 100	20		Completely dry	15	
Very strong	100 - 250		4 to 10		12	Good quality			75 - 90	17		Damp	10	
Strong	50 - 100		2 to 4		7	Fair quality			50 - 75	13		Wet	7	
Medium strong	25 - 50		1 to 2		4	Poor quality			25 - 50	8		Dripping	4	
Weak	5 to 25		<1		2	V. Poor quality			< 25	3		Flowing under	0	
V. Weak	1 to 5				1									
R3. SPACING OF DISCONTUNITIES												**STRIKE AND DIP ORIENTATION**		
		J1	**J2**	**J3**	**J4**	**J5**	**J6**	**J7**		**Rating**		**Discontinuity**	**Strike/Dip**	
Very wide	>2m									20		J1		
Wide	0.6-2m									15		J2		
Moderate	20-60cm	🟦	🟦	🟦						10		J3		
Close	6-20cm									8		J4		
Very close	< 6cm									5		J5		
												J6		
R4. CONDITION OF DISCONTINUITY														
PERSISTENCY						**J1**	**J2**	**J3**	**J4**	**J5**	**J6**	**Rating**		
Very low			< 1 m			🟦						6		
Low			1 - 3 m				🟦	🟦				4		
Medium			3 - 10 m									2		
High			10 - 20 m									1		
Very high			> 20 m									0	4.6	
SEPERATION (APERTURE)														
Very tight joints			none									6		
Tight joints			< 0.1mm									5		
Moderately open joints			0.1 - 1mm			🟦						4		
Open joints			1 - 5 mm				🟦	🟦				1		
Very wide aperture			> 5 mm									0	2	
ROUGHNESS														
Very Rough Surface												6		
Rough							🟦	🟦				5		
Slightly rough						🟦						3		
Smooth rough												1		
Slikenside rough												0	4.3	
FILLING (GAUGE)														
None												6		
Hard filling < 5mm												4		
Hard filling > 5mm												2		
Soft filling < 5mm						🟦		🟦				2		
Soft filling > 5mm							🟦					0	1.3	
WALL ROCK OF DISCONTINUITIES														
Unweathered												6		
Slightly Weathered						🟦						5		
Moderately							🟦	🟦				3		
Highly												1		
Decomposed												0	3.6	
TOTAL RATING (RMR = R1 + R2 + R3 + R4 + R5) :53														
ROCK MASS CLASSES DETERMINED FROM TOTAL RATING														
Rating						**Class**	**Description**	**Rating**		**Class**	**Description**			
81 - 100						I	Very good rock	21-40		IV	poor rock			
61 - 80						II	good rock	<21		V	very poor rock			
40 - 60						III	fair rock	**Rock Mass Class from total rating**						

Table 23. RMR, L4

Rock Mass Rating (RMR) System (Bieniawski, 1989)

LOCATION	**DESCRIPTION**
L4	
Elevation:-	upstream, left

R1. STRENGTH OF INTACT ROCK MATERIAL						**R2. ROCK QUALITY DESIGNATION**				**R5. GROUNDWATER**		
Designation	**UCS (MPa)**		**PLI)MPa)**		**Rating**	**Designation**	**%**	**Rating**		**General Condition**	**Rating**	
Extremely strong	> 250		>10		15	Excellent quality	90 - 100	20		Completely dry	15	
Very strong	100 - 250		4 to 10		12	Good quality	75 - 90	17		Damp	10	
Strong	50 - 100		2 to 4		7	Fair quality	50 - 75	13		Wet	7	
Medium strong	25 - 50		1 to 2		4	Poor quality	25 - 50	8		Dripping	4	
Weak	5 to 25		<1		2	V. Poor quality	< 25	3		Flowing under	0	
V. Weak	1 to 5				1							

R3. SPACING OF DISCONTUNITIES											**STRIKE AND DIP ORIENTATION**	
		J1	**J2**	**J3**	**J4**	**J5**	**J6**	**J7**	**Rating**		**Discontinuity**	**Strike/Dip**
Very wide	>2m								20		J1	
Wide	0.6-2m								15		J2	
Moderate	20-60cm								10		J3	
Close	6-20cm	🟦	🟦	🟦					8		J4	
Very close	< 6cm								5		J5	
											J6	

R4. CONDITION OF DISCONTINUITY										
PERSISTENCY		**J1**	**J2**	**J3**	**J4**	**J5**	**J6**	**Rating**		19
Very low	< 1 m	🟦						6		
Low	1 - 3 m		🟦	🟦				4		
Medium	3 - 10 m							2		
High	10 - 20 m							1		
Very high	> 20 m							0	4.6	
SEPERATION (APERTURE)										
Very tight joints	none							6		
Tight joints	< 0.1mm		🟦	🟦				5		
Moderately open joints	0.1 - 1mm							4		
Open joints	1 - 5 mm	🟦						1		
Very wide aperture	> 5 mm							0	3.6	
ROUGHNESS										
Very Rough Surface			🟦	🟦				6		
Rough		🟦						5		
Slightly rough								3		
Smooth rough								1		
Slikenside rough								0	5.6	
FILLING (GAUGE)										
None								6		
Hard filling < 5mm								4		
Hard filling > 5mm		🟦	🟦	🟦				2		
Soft filling < 5mm								2		
Soft filling > 5mm								0	2	
WALL ROCK OF DISCONTINUITIES										
Unweathered								6		
Slightly Weathered								5		
Moderately		🟦	🟦	🟦				3		
Highly								1		
Decomposed								0	3	
TOTAL RATING (RMR = R1 + R2 + R3 + R4 + R5) :52										
ROCK MASS CLASSES DETERMINED FROM TOTAL RATING										

Rating		**Class**	**Description**	**Rating**		**Class**	**Description**
81 - 100		I	Very good rock	21-40		IV	poor rock
61 - 80		II	good rock	<21		V	very poor rock
40 - 60		III	fair rock	**Rock Mass Class from total rating**			

Table 24. RMR, L5

Rock Mass Rating (RMR) System (Bieniawski, 1989)

LOCATION	**DESCRIPTION**
L5	
Elevation:-	upstream, right

R1. STRENGTH OF INTACT ROCK MATERIAL						**R2. ROCK QUALITY DESIGNATION**				**R5. GROUNDWATER**		
Designation	**UCS (MPa)**		**PLI)MPa)**		**Rating**	**Designation**	**%**	**Rating**		**General Condition**	**Rating**	
Extremely strong	> 250		>10		15	Excellent quality	90 - 100	20		Completely dry	15	
Very strong	100 - 250		4 to 10		12	Good quality	75 - 90	17		Damp	10	
Strong	50 - 100		2 to 4		7	Fair quality	50 - 75	13		Wet	7	
Medium strong	25 - 50		1 to 2		4	Poor quality	25 - 50	8		Dripping	4	
Weak	5 to 25		<1		2	V. Poor quality	< 25	3		Flowing under	0	
V. Weak	1 to 5				1							

R3. SPACING OF DISCONTUNITIES											**STRIKE AND DIP ORIENTATION**	
		J1	**J2**	**J3**	**J4**	**J5**	**J6**	**J7**	**Rating**		**Discontinuity**	**Strike/Dip**
Very wide	>2m								20		J1	
Wide	0.6-2m								15		J2	
Moderate	20-60cm			■					10		J3	
Close	6-20cm	■	■						8		J4	
Very close	< 6cm								5		J5	
										9	J6	

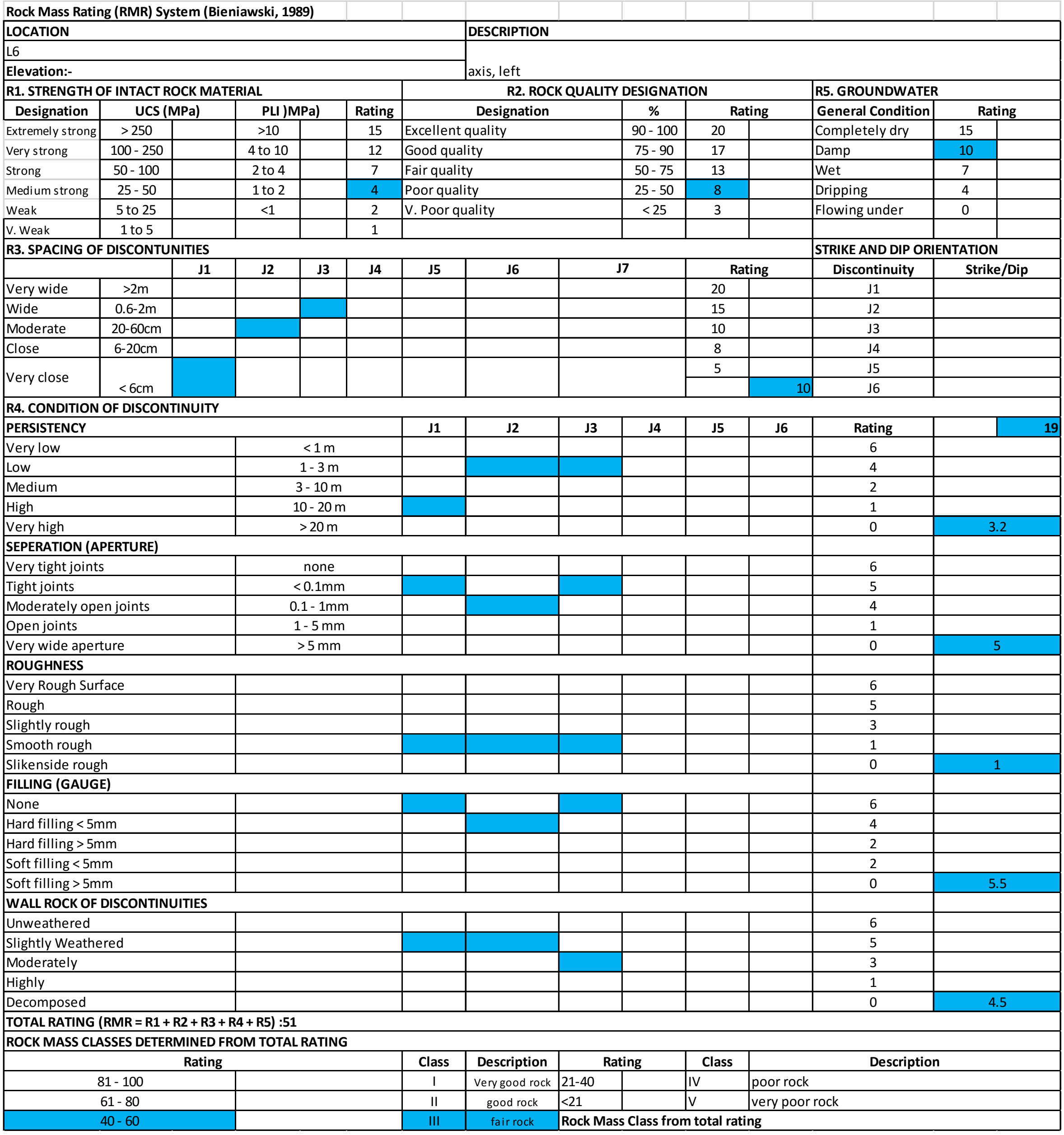
R4. CONDITION OF DISCONTINUITY										
PERSISTENCY		**J1**	**J2**	**J3**	**J4**	**J5**	**J6**	**Rating**		**16**
Very low	< 1 m	■						6		
Low	1 - 3 m		■	■				4		
Medium	3 - 10 m							2		
High	10 - 20 m							1		
Very high	> 20 m							0	4.6	
SEPERATION (APERTURE)										
Very tight joints	none							6		
Tight joints	< 0.1mm	■						5		
Moderately open joints	0.1 - 1mm		■	■				4		
Open joints	1 - 5 mm							1		
Very wide aperture	> 5 mm							0	4.3	
ROUGHNESS										
Very Rough Surface								6		
Rough		■						5		
Slightly rough								3		
Smooth rough			■	■				1		
Slikenside rough								0	2.3	
FILLING (GAUGE)										
None								6		
Hard filling < 5mm		■						4		
Hard filling > 5mm								2		
Soft filling < 5mm								2		
Soft filling > 5mm			■	■				0	1.3	
WALL ROCK OF DISCONTINUITIES										
Unweathered								6		
Slightly Weathered		■						5		
Moderately			■					3		
Highly				■				1		
Decomposed								0	3	

TOTAL RATING (RMR = R1 + R2 + R3 + R4 + R5) :42

ROCK MASS CLASSES DETERMINED FROM TOTAL RATING

Rating		**Class**	**Description**	**Rating**		**Class**	**Description**
81 - 100		I	Very good rock	21-40		IV	poor rock
61 - 80		II	good rock	<21		V	very poor rock
40 - 60		III	fair rock	**Rock Mass Class from total rating**			

Table 25. RMR, L6



Rock Mass Rating (RMR) System (Bieniawski, 1989)	
LOCATION	**DESCRIPTION**
L6	
Elevation:-	axis, left

R1. STRENGTH OF INTACT ROCK MATERIAL						**R2. ROCK QUALITY DESIGNATION**				**R5. GROUNDWATER**		
Designation	**UCS (MPa)**		**PLI)MPa)**		**Rating**	**Designation**	**%**	**Rating**		**General Condition**	**Rating**	
Extremely strong	> 250		>10		15	Excellent quality	90 - 100	20		Completely dry	15	
Very strong	100 - 250		4 to 10		12	Good quality	75 - 90	17		Damp	10	
Strong	50 - 100		2 to 4		7	Fair quality	50 - 75	13		Wet	7	
Medium strong	25 - 50		1 to 2		4	Poor quality	25 - 50	8		Dripping	4	
Weak	5 to 25		<1		2	V. Poor quality	< 25	3		Flowing under	0	
V. Weak	1 to 5				1							

R3. SPACING OF DISCONTUNITIES											**STRIKE AND DIP ORIENTATION**	
		J1	**J2**	**J3**	**J4**	**J5**	**J6**	**J7**	**Rating**		**Discontinuity**	**Strike/Dip**
Very wide	>2m								20		J1	
Wide	0.6-2m			■					15		J2	
Moderate	20-60cm		■						10		J3	
Close	6-20cm								8		J4	
Very close	< 6cm	■							5		J5	
										10	J6	

R4. CONDITION OF DISCONTINUITY									
PERSISTENCY		**J1**	**J2**	**J3**	**J4**	**J5**	**J6**	**Rating**	19
Very low	< 1 m							6	
Low	1 - 3 m		■	■				4	
Medium	3 - 10 m							2	
High	10 - 20 m	■						1	
Very high	> 20 m							0	3.2
SEPERATION (APERTURE)									
Very tight joints	none							6	
Tight joints	< 0.1mm	■		■				5	
Moderately open joints	0.1 - 1mm		■					4	
Open joints	1 - 5 mm							1	
Very wide aperture	> 5 mm							0	5
ROUGHNESS									
Very Rough Surface								6	
Rough								5	
Slightly rough								3	
Smooth rough		■	■	■				1	
Slikenside rough								0	1
FILLING (GAUGE)									
None		■		■				6	
Hard filling < 5mm			■					4	
Hard filling > 5mm								2	
Soft filling < 5mm								2	
Soft filling > 5mm								0	5.5
WALL ROCK OF DISCONTINUITIES									
Unweathered								6	
Slightly Weathered		■	■					5	
Moderately				■				3	
Highly								1	
Decomposed								0	4.5
TOTAL RATING (RMR = R1 + R2 + R3 + R4 + R5) :51									

ROCK MASS CLASSES DETERMINED FROM TOTAL RATING							
Rating		**Class**	**Description**	**Rating**		**Class**	**Description**
81 - 100		I	Very good rock	21-40		IV	poor rock
61 - 80		II	good rock	<21		V	very poor rock
40 - 60		III	fair rock	**Rock Mass Class from total rating**			

Table 26. RMR, L8

Rock Mass Rating (RMR) System (Bieniawski, 1989)														
LOCATION							**DESCRIPTION**							
L8														
Elevation:-							downstream, right							
R1. STRENGTH OF INTACT ROCK MATERIAL						**R2. ROCK QUALITY DESIGNATION**						**R5. GROUNDWATER**		
Designation	**UCS (MPa)**		**PLI)MPa)**		**Rating**	**Designation**			**%**	**Rating**		**General Condition**	**Rating**	
Extremely strong	> 250		>10		15	Excellent quality			90 - 100	20		Completely dry	15	
Very strong	100 - 250		4 to 10		12	Good quality			75 - 90	17		Damp	10	
Strong	50 - 100		2 to 4		7	Fair quality			50 - 75	13		Wet	7	
Medium strong	25 - 50		1 to 2		4	Poor quality			25 - 50	8		Dripping	4	
Weak	5 to 25		<1		2	V. Poor quality			< 25	3		Flowing under	0	
V. Weak	1 to 5				1									
R3. SPACING OF DISCONTUNITIES												**STRIKE AND DIP ORIENTATION**		
		J1	**J2**	**J3**	**J4**	**J5**	**J6**	**J7**		**Rating**		**Discontinuity**	**Strike/Dip**	
Very wide	>2m									20		J1		
Wide	0.6-2m		🟦							15		J2		
Moderate	20-60cm	🟦		🟦						10		J3		
Close	6-20cm									8		J4		
Very close	< 6cm									5		J5		
											12	J6		
R4. CONDITION OF DISCONTINUITY														
PERSISTENCY						**J1**	**J2**	**J3**	**J4**	**J5**	**J6**	**Rating**		**21**
Very low			< 1 m									6		
Low			1 - 3 m			🟦	🟦					4		
Medium			3 - 10 m					🟦				2		
High			10 - 20 m									1		
Very high			> 20 m									0	3.3	
SEPERATION (APERTURE)														
Very tight joints			none			🟦						6		
Tight joints			< 0.1mm				🟦					5		
Moderately open joints			0.1 - 1mm					🟦				4		
Open joints			1 - 5 mm									1		
Very wide aperture			> 5 mm									0	5	
ROUGHNESS														
Very Rough Surface												6		
Rough							🟦	🟦				5		
Slightly rough												3		
Smooth rough						🟦						1		
Slikenside rough												0	3.6	
FILLING (GAUGE)														
None						🟦	🟦					6		
Hard filling < 5mm								🟦				4		
Hard filling > 5mm												2		
Soft filling < 5mm												2		
Soft filling > 5mm												0	5.3	
WALL ROCK OF DISCONTINUITIES														
Unweathered							🟦					6		
Slightly Weathered						🟦		🟦				5		
Moderately												3		
Highly												1		
Decomposed												0	3.6	
TOTAL RATING (RMR = R1 + R2 + R3 + R4 + R5) :72														
ROCK MASS CLASSES DETERMINED FROM TOTAL RATING														
Rating						**Class**	**Description**	**Rating**		**Class**	**Description**			
81 - 100						I	Very good rock	21-40		IV	poor rock			
61 - 80						II	good rock	<21		V	very poor rock			
40 - 60						III	fair rock	**Rock Mass Class from total rating**						

Table 27. RMR, L10

Rock Mass Rating (RMR) System (Bieniawski, 1989)														
LOCATION							**DESCRIPTION**							
L10														
Elevation:-							axis, right							
R1. STRENGTH OF INTACT ROCK MATERIAL						**R2. ROCK QUALITY DESIGNATION**						**R5. GROUNDWATER**		
Designation	**UCS (MPa)**		**PLI)MPa)**		**Rating**	**Designation**			**%**	**Rating**		**General Condition**	**Rating**	
Extremely strong	> 250		>10		15	Excellent quality			90 - 100	20		Completely dry	15	
Very strong	100 - 250		4 to 10		12	Good quality			75 - 90	17		Damp	10	
Strong	50 - 100		2 to 4		7	Fair quality			50 - 75	13		Wet	7	
Medium strong	25 - 50		1 to 2		4	Poor quality			25 - 50	8		Dripping	4	
Weak	5 to 25		<1		2	V. Poor quality			< 25	3		Flowing under	0	
V. Weak	1 to 5				1									
R3. SPACING OF DISCONTUNITIES												**STRIKE AND DIP ORIENTATION**		
		J1	**J2**	**J3**	**J4**	**J5**	**J6**	**J7**		**Rating**		**Discontinuity**	**Strike/Dip**	
Very wide	>2m									20		J1		
Wide	0.6-2m									15		J2		
Moderate	20-60cm	🟦		🟦						10		J3		
Close	6-20cm		🟦							8		J4		
Very close										5		J5		
	< 6cm										5	J6		
R4. CONDITION OF DISCONTINUITY														
PERSISTENCY						**J1**	**J2**	**J3**	**J4**	**J5**	**J6**	**Rating**		**17**
Very low			< 1 m									6		
Low			1 - 3 m			🟦		🟦				4		
Medium			3 - 10 m				🟦					2		
High			10 - 20 m									1		
Very high			> 20 m									0	3.3	
SEPERATION (APERTURE)														
Very tight joints			none									6		
Tight joints			< 0.1mm									5		
Moderately open joints			0.1 - 1mm			🟦						4		
Open joints			1 - 5 mm				🟦	🟦				1		
Very wide aperture			> 5 mm									0	2	
ROUGHNESS														
Very Rough Surface												6		
Rough						🟦	🟦	🟦				5		
Slightly rough												3		
Smooth rough												1		
Slikenside rough												0	5	
FILLING (GAUGE)														
None												6		
Hard filling < 5mm						🟦						4		
Hard filling > 5mm							🟦	🟦				2		
Soft filling < 5mm												2		
Soft filling > 5mm												0	2.6	
WALL ROCK OF DISCONTINUITIES														
Unweathered												6		
Slightly Weathered						🟦						5		
Moderately							🟦	🟦				3		
Highly												1		
Decomposed												0	3.6	
TOTAL RATING (RMR = R1 + R2 + R3 + R4 + R5) :37														
ROCK MASS CLASSES DETERMINED FROM TOTAL RATING														
Rating						**Class**	**Description**	**Rating**		**Class**	**Description**			
81 - 100						I	Very good rock	21-40		IV	poor rock			
61 - 80						II	good rock	<21		V	very poor rock			
40 - 60						III	fair rock	**Rock Mass Class from total rating**						

Table 28. RMR, L13

Rock Mass Rating (RMR) System (Bieniawski, 1989)														
LOCATION							**DESCRIPTION**							
L13														
Elevation:-							downstream, left							
R1. STRENGTH OF INTACT ROCK MATERIAL						**R2. ROCK QUALITY DESIGNATION**						**R5. GROUNDWATER**		
Designation	**UCS (MPa)**		**PLI)MPa)**		**Rating**	**Designation**			**%**	**Rating**		**eneral Conditio**	**Rating**	
Extremely strong	> 250		>10		15	Excellent quality			90 - 100	20		Completely dry	15	
Very strong	100 - 250		4 to 10		12	Good quality			75 - 90	17		Damp	10	
Strong	50 - 100		2 to 4		7	Fair quality			50 - 75	13		Wet	7	
Medium strong	25 - 50		1 to 2		4	Poor quality			25 - 50	8		Dripping	4	
Weak	5 to 25		<1		2	V. Poor quality			< 25	3		Flowing under	0	
V. Weak	1 to 5				1									
R3. SPACING OF DISCONTUNITIES												**STRIKE AND DIP ORIENTATION**		
		J1	**J2**	**J3**	**J4**	**J5**	**J6**	**J7**		**Rating**		**Discontinuity**	**Strike/Dip**	
Very wide	>2m									20		J1		
Wide	0.6-2m									15		J2		
Moderate	20-60cm	■	■	■						10		J3		
Close	6-20cm									8		J4		
Very close										5		J5		
	< 6cm										10	J6		
R4. CONDITION OF DISCONTINUITY														
PERSISTENCY						**J1**	**J2**	**J3**	**J4**	**J5**	**J6**	**Rating**		19
Very low			< 1 m									6		
Low			1 - 3 m				■					4		
Medium			3 - 10 m					■				2		
High			10 - 20 m									1		
Very high			> 20 m			■						0	2	
SEPERATION (APERTURE)														
Very tight joints			none									6		
Tight joints			< 0.1mm					■				5		
Moderately open joints			0.1 - 1mm			■	■					4		
Open joints			1 - 5 mm									1		
Very wide aperture			> 5 mm									0	4.3	
ROUGHNESS														
Very Rough Surface												6		
Rough						■	■	■				5		
Slightly rough												3		
Smooth rough												1		
Slikenside rough												0	5	
FILLING (GAUGE)														
None								■				6		
Hard filling < 5mm												4		
Hard filling > 5mm							■					2		
Soft filling < 5mm												2		
Soft filling > 5mm						■						0	2.6	
WALL ROCK OF DISCONTINUITIES														
Unweathered							■	■				6		
Slightly Weathered												5		
Moderately						■						3		
Highly												1		
Decomposed												0	5	
TOTAL RATING (RMR = R1 + R2 + R3 + R4 + R5) :68														
ROCK MASS CLASSES DETERMINED FROM TOTAL RATING														
Rating						**Class**	**Description**	**Rating**		**Class**	**Description**			
81 - 100						I	Very good rock	21-40		IV	poor rock			
61 - 80						II	good rock	<21		V	very poor rock			
40 - 60						III	fair rock	**Rock Mass Class from total rating**						

Table 29. RMR, L14

Rock Mass Rating (RMR) System (Bieniawski, 1989)														
LOCATION							**DESCRIPTION**							
L14														
Elevation:-							downstream, left							
R1. STRENGTH OF INTACT ROCK MATERIAL						**R2. ROCK QUALITY DESIGNATION**						**R5. GROUNDWATER**		
Designation	**UCS (MPa)**		**PLI)MPa)**		**Rating**	**Designation**			**%**	**Rating**		**General Condition**	**Rating**	
Extremely strong	> 250		>10		15	Excellent quality			90 - 100	20		Completely dry	15	
Very strong	100 - 250		4 to 10		12	Good quality			75 - 90	17		Damp	10	
Strong	50 - 100		2 to 4		7	Fair quality			50 - 75	13		Wet	7	
Medium strong	25 - 50		1 to 2		4	Poor quality			25 - 50	8		Dripping	4	
Weak	5 to 25		<1		2	V. Poor quality			< 25	3		Flowing under	0	
V. Weak	1 to 5				1									
R3. SPACING OF DISCONTUNITIES												**STRIKE AND DIP ORIENTATION**		
		J1	**J2**	**J3**	**J4**	**J5**	**J6**	**J7**		**Rating**		**Discontinuity**	**Strike/Dip**	
Very wide	>2m									20		J1		
Wide	0.6-2m									15		J2		
Moderate	20-60cm									10		J3		
Close	6-20cm	■	■	■						8		J4		
Very close	< 6cm									5		J5		
											8	J6		
R4. CONDITION OF DISCONTINUITY														
PERSISTENCY						**J1**	**J2**	**J3**	**J4**	**J5**	**J6**	**Rating**		21
Very low			< 1 m									6		
Low			1 - 3 m			■	■	■				4		
Medium			3 - 10 m									2		
High			10 - 20 m									1		
Very high			> 20 m									0	4	
SEPERATION (APERTURE)														
Very tight joints			none									6		
Tight joints			< 0.1mm									5		
Moderately open joints			0.1 - 1mm			■	■	■				4		
Open joints			1 - 5 mm									1		
Very wide aperture			> 5 mm									0	4	
ROUGHNESS														
Very Rough Surface												6		
Rough						■	■	■				5		
Slightly rough												3		
Smooth rough												1		
Slikenside rough												0	5	
FILLING (GAUGE)														
None												6		
Hard filling < 5mm						■	■	■				4		
Hard filling > 5mm												2		
Soft filling < 5mm												2		
Soft filling > 5mm												0	4	
WALL ROCK OF DISCONTINUITIES														
Unweathered								■				6		
Slightly Weathered												5		
Moderately						■	■					3		
Highly												1		
Decomposed												0	4	
TOTAL RATING (RMR = R1 + R2 + R3 + R4 + R5) :56														
ROCK MASS CLASSES DETERMINED FROM TOTAL RATING														
Rating						**Class**	**Description**	**Rating**		**Class**	**Description**			
81 - 100						I	Very good rock	21-40		IV	poor rock			
61 - 80						II	good rock	<21		V	very poor rock			
40 - 60						III	fair rock	**Rock Mass Class from total rating**						

APPENDIX II PLATES

Plate 1: Microfold of gneiss band in a boulder

Plate 2: Downstream section of the study area, from the right bank

Plate 3: Upstream section of the study area, from the right bank

Plate 4: Top of the left abutment of the dam axis

Plate 5: Fresh gneiss, at the left bank, dam axis

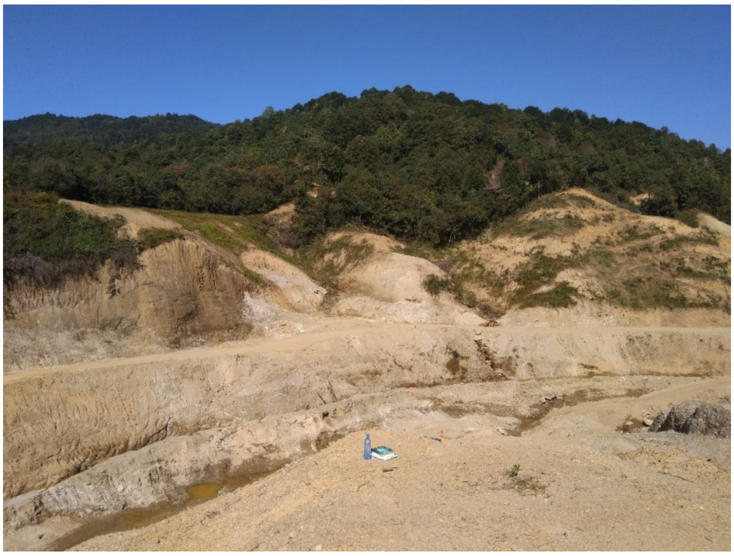


Plate 6: Top of the right abutment, across (top left hilltop)

Plate 7: Left section of the study area, from the right abutment

Plate 8: Rock boulders for the embankment construction