Detailed Project Report
Mitigation of Mangan Landslide at North District Headquarters
Mangan, North Sikkim - India

Submitted by

Sikkim State Disaster Management Authority (SSDMA)

Land Revenue & Disaster Management Department (LR&DMD)

Government of Sikkim – July, 2018

COMPLIANCE REPORT

for Submission of Comments / Inputs on Revised DPR to NDMA

Sl. No	Recommendation / Suggestion of member from GSI of TEC Experts in the Last Meeting & Clarification Sought	Clarification by the State	Reference Page no. of DPR
1.	Micro-piles with suitable depth and driven beyond the interface of debris-bed rock need to be ascertained. The depths of micro-piles may vary from place to place according to local geological conditions. The connection of micro-piles with pile cap at ground surface level is to be designed and provided. Micro-piles in rows at different suitable benches from crest to the lower level of slope are to be provided with proper inter-connection of piles in the form of a framework.	Accepted and modified.	Incorporated in the design drawings no. Mangan/Sikkim/SSDMA-114.
2.	Self-drilling fully cement-grouted anchors with end-anchorage bulbs in zigzag (staggered) pattern with varying lengths and with increased anchor angle to penetrate beyond the interface of debris-bed rock to be applied on the slope face in between rows of the micro-piles with increased angle to be mentioned in the DPR, so that the self-driven anchors can be placed down to a greater depth.	Accepted and modified.	Incorporated in the design drawings no. Mangan/Sikkim/SSDMA-114.
3.	Suitable designed surface and sub-surface drainage corrections shall be planned and implemented to drain out water from the affected area of the landslide and its upper reaches with appropriate weep holes.	Accepted.	Shown in the design drawings no. Mangan/Sikkim/SSDMA-113 & 114.
4.	Submit additional technical document 4-5 pages as annexure in DPR on the basis of above TEC recommendations along with comments, if any in DPR to be incorporated in DPR.	Accepted and modified.	Correction done in DPR
5.	Vetting the structural stability of proposed mitigation measures and other structural components is the responsibility of state government and executing agency.	Yes, Accepted	The DPR has been vetted by the Principal Chief Engineer -cum-Secretary, Water Resource and River Development Department

State Name: Sikkim

Designation: Special Secretary

Special Secretary
Land Revenue & Disaster Mangt. Deptt.
Government of Sikkim, Gangtok

Organization: Sikkim State Disaster Management Authority, Land Revenue and Disaster Management Department, Govt. of Sikkim, Gangtok, East Sikkim.

GOVERNMENT OF SIKKIM
LAND REVENUE & DISASTER MANAGEMENT DEPARTMENT
MANAN BHAWAN
GANGTOK 737101

TO WHOM IT MAY CONCERN

The structural stability of the proposed mitigation measures and other structural components for the project "Mitigation of Mangan Landslide at North District headquarters" has been examined by Water Resource and River Development Department of Government of Sikkim. The Detail Project Report of the project is hereby technically vetted.

Place: Gangtok
Date: 18th July, 2018

PCE-cum-Secretary,
WR& RD Department

PCE cum Secretary
Water Resources &
River Development Deptt.
Govt. of Sikkim

SUMMARY OF DETAILED PROJECT REPORT (DPR) FOR MITIGATIONS OF MANGAN LANDSLIDE AT NORTH DISTRICT HEADQUARTERS - MANGAN, NORTH SIKKIM, INDIA.

EXECUTIVE SUMMARY

Mangan town is the district headquarter of North Sikkim, located at 27.52°N 88.53°E, on the left bank of the Teesta river valley. Lower and upper area of Mangan has experienced a number of landslides in the past. The situation becomes bad to worse after jolt of 18th September 2011 earthquake, specially the area along Jhoras and old slide zones. The affected area was further devastated by landslide during cloud burst / heavy rainfall between September 19th to 23rd 2012. Protection works provided along Raffong Khola & Rimit Khola was completely wash away and heavy scouring of slopes took place. As a result, slope lying above Jhora section got badly damaged and the buildings along North Sikkim highway are at high risk. The culvert constructed over Raffong Khola was washed away by slush & debris carried by heavy discharge during the year 2016. The area above Mangan remained cut-off almost for few weeks.

The present study on recommendation of Expert Committee of NDA is limited to the following locations.

- Old Mangan bazaar & below SNT Complex & just adjacent to left bank of Raffong Khola in the lower reaches immediately below the SNT Complex landslide
- Lower reach of multi-storey parking area at Rinzing Namgyal Marg
- Surrounding area of Senior-Secondary School and close to left bank of Raffong Khola
- Upper and lower reach of Raffong Khola Profile (Taken into report, however not consider in 1st stage as advice by NDA, Thus cost is not included).

SALIENT FEATURES

S. No.	Description	
1.	Name of slide / Area	i) Old Mangan bazaar & below SNT Complex & just adjacent to left bank of Raffong Khola ii) Mangan bazaar & Lower reach of multi-storey parking area at Rinzing Namgyal Marg iii) Surrounding area of Senior-Secondary School and close to left bank of Ruffong Khola iv) Upper and lower reach of Raffong Khola Profile
2.	Location	North District Headquarters, Mangan
3.	Affected stretch	i) 100 m wide and 200 m long stretch ii) 70 m wide and 80 m long stretch iii) 130 m wide and 350 m long stretch v) About 500 m stretch of Raffong Khola is affected in the upper and lower reaches
4.	Nearest Approach Road	National Highway No. 10
5.	Nearest Railway Station	New Jalpaigudi Jn., West Bengal
6.	District	North Sikkim District
7.	State	Sikkim
8.	Nature of Scheme / Project	Landslides slope stabilization works
9.	Purposes	Stabilization of slopes in or around Mangan Town
10.	Total Estimated cost of the project	INR 14.4462 crores
11.	Basis of rates	MoRTH, PWD and budgetary quotations
12.	Terms of reference	To safeguard man and machinery and un-interrupted movement in the region.
13.	Name of the Department	Sikkim State Disaster Management Authority (SSDMA), land Revenue & Mines, Mineral Department (LR&DMD)
14.	Implementing Department/Agency	SSDMA and LR&DMD
15.	Monitoring Department	SSDMA and LR&DMD

IDENTIFIED LANDSLIDES CAUSATIVE FACTORS

Sikkim is one of the regions where all such factors prevail and where several landslides have occurred in the recent past. Mangan town in north Sikkim is particularly affected by several major slides. Some of the site specific causative factors responsible for this phenomenon are given below:

- Mangan Town area is bounded by Raffong Khola in North & Ramet Kyong khola in south, which is delineated as high & very high hazard zone. It is a very unstable zone.
- The MCT is passing by close vicinity of the Mangan Town; hence entire area is under high stress.
- Present landslides represent reactivation of the older landslides and their shape/size is gradually increasing after monsoon rains.
- Soil of Mangan Town area has moderate absorbing capacity and bed rock in this area shows low compressive strength and normal moisture absorption capacity.
- Landslide and sinking zones are more prominent on either side of the Raffong Khola and Ramet Kyong khola.
- During the site visit it has been observed that continuous water ingress through joint plane, removal of soft strata and presence of structural discontinuity.
- Geological factors - Weak zones, Sensitive and sheared materials, presence of fissures, joints, contact in permeability or stiffness of the slope forming material.
- Morphological factors - Such as tectonic uplift, glacial rebound & erosion of the hill slope or toe etc.
- Physical factors – Like heavy rainfall, Debris torrential, massive infiltrated rainwater in the upper slope of the slide areas will seep downwards and accumulate to raise the ground water level and it alternatively increase the pore-water pressure on the potential sliding body.
- Earthquakes Activities.
- Anthropogenic factors – Such as mining, deforestation and excavation of the slope or toe
- Agriculture – Cultivation of the residential for a prolonged period over the hill slopes loosens the finer material from the soil and makes the area vulnerable for sliding and sinking.
- Human Activities – construction of high-rise buildings houses, movement of heavy vehicles/loading on the week hill slopes etc.
- Inadequate, lack of proper Drainage system & Choking of existing drains

The worst affected area is towards South East of the SNT complex adjacent to Raffong Khola in which about 200 m length of road has been damaged completely. Due to impact of mass mobilization, the building was totally damaged and several wooden/ Ekra houses and buildings in the area were partially major damages. In the adjacent area, there is no indication of damages in the main school building. The district authority vacated the area and declared it unsafe. Mangan School Complex lying south of Raffong Khola has under gone varying degree of instability. Area closer to Jhora section has suffereing but primary school buildings has developed partial cracks and are also observed on the ground.

CONCLUDING REMARKS - GEOTECHNICAL DESIGN AND SUPPORT PROVISIONS

Taking into consideration all the above factors, the appropriate support provisions for the slide area would be as follows, in order of priority:

- Utilisation of the calculated input parameters to determine the total downward force exerted by the surcharged mass and to reciprocate the same by a reactionary force in the form of support elements covering toe and slope protection, so that the FOS is sufficiently 1.5, considering dynamic earthquake parameters too.
- Network of RCC piles of 0.4mm dia with a spacing of 0.5 m c/c extending to well below the saturated debris cover and well below the slip circle, each column is to be interconnected by others in a staggered manner by steel wire .The piles should sufficiently cover the slide area.
- Fully grouted self-drilling anchor of capacity 190KN, 1.5M c/c to be used as support
- Provision of subsurface drainage in the form of slotted large diameter pipes inserted at lower levels but with provision to filter access of fines from the ground mass, as specified, also interconnected in a staggered manner. For that perforated PVC pipe with filter material inclined downward of 10 deg to avoid saturation outfall structure.
- Garland drains along the southern apex of the slide to collect surface drainage during rains. These should follow the hill contours and drain into the side nallahs and should follow the highway aligned along the contours.
- Another extremely important step is to intercept any subsurface flow from recharging the ground mass of the slide, this would involve channelizing of all nallahs of Mangan town away from the area by construction of large paved drains so that no subsurface infiltration takes place through them to lower levels.

	ABSTRACT OF COST	
Sl. No.	**Item**	**Cost in INR (in Lakhs)**
A	Preliminary Works	65.00
B	Infrastructural works	50.00
	Sub Total (A)	**115.00**
	Main Civil Works	
C	Treatment works at old mangan bazaar & below SNT complex & just adjacent to left bank of raffongkhola.	826.32
D	Treatment works at Mangan bazaar & Lower reach of multi-storey parking area at RinzingNamgyal Marg.	59.61
E	Surrounding area of Senior Secondary School and close to left bank of RuffongKhola	478.181
	Sub Total (B)	**1364.111**
	Total of Works (A+B=C)	**1479.111**
	0.2% of total cost (C) is for Local Awareness**(D)**	**2.958**
	0.8% of total cost for training of locals and officials**(E)**	**11.833**
	Grand Total (C+D+E)	**1493.90**
	Rupees Forteen Crore Ninety Three Lakhs Ninety Thousand only	

Table of Content

1.0 Introduction

Mangan town is the district headquarter of North Sikkim, located at 27.52°N 88.53°E, on the left bank of the Teesta river valley. Lower and upper area of Mangan has experienced a number of landslides in the past The situation becomes bad to worse after jolt of 18th September 2011 earthquake, specially the area along jhoras and old slide zones. The affected area was further devastated by landslide during cloud burst / heavy rainfall between September 19th to 23rd 2012. Protection works provided along Raffong Khola & Rimit Khola was completely washaway and heavy scouring of slopes took place. As a result, slope lying above jhora section got badly damaged and the building along North Sikkim highway is at high risk. The culvert constructed over Raffong Khola was washed away by slush & debris carried by heavy discharge during the year 2016.The area above Mangan remained cut-off almost for few weeks.

2.0 Back ground information

In response to DPR prepared by SSDMA, an expert team comprising of Prof. Raoof IIT, Delhi and Dr.SaibalGhosh of GSI, representing NDMA visited the area. During their visit,experts and officials from SSDMA, DMMG & Irrigation Department also joined the expert team. During discussion it was finalized that mitigation measures of entire Mangan shall be taken up on two stages based on degree of vulnerably. In view of that discussion and advised by experts, SSDMA & DMMG has to take up following areas in stage-I.

The Expert Committee advised SSDMA & DMMG to carry out the following.

1. Approximation of depth of slip surface and bed rock by geophysical investigation and field investigation.
2. Drilling data & geotechnical parameter of rock & soil.
3. Geological reports carried out by GSI & DMMG.

Based on the data available, SSDMA has planned preparation of Detail Project on the mitigation of Mangan and surrounding Landslides. In continuation, SSDMA engaged a consultant for preparation of detail project report and the revised DPR has been submitted to NDMA for approval. The Experts committee has scrutinized the DPR and suggested some more investigation to ensure the ground conditions. As per the committee advised, the detail investigations have been carried out. Based on the updated field data with a revised mitigation design and plan is summarised in updated DPR.

3.0 Location and Approach

The nearest railway station from Mangan town is the New Jalpaiguri junction at district Jalpaiguri and the nearest Airport is at Bagdogra of district of Darjeeling of West Bengal. Both are connected to Sikkim state by the national Highway No. 10 (NH-10) (earlier NH-31A). The North Sikkim highway passes through the Mangan which connects north Sikkim with Gangtok and Siliguri. Mangantown is spread around 5 – 6 Sq km and is connected to the Capital city of Gangtok by three routes through all weathered metalled roads, 60 km via Kabiabout58 km via Pangthang and 80 km via Singtam. It can also be accessed directly from Siliguri& Darjeeling districts of West Bengal via Malli, Rampo and Singtam along the Teesta River. Mangan is located within Survey of India Toposheet no. 78A/10 and 11.For location of study area Ref. drawing no.***Mangan/Sikkim/SSDMA-101***

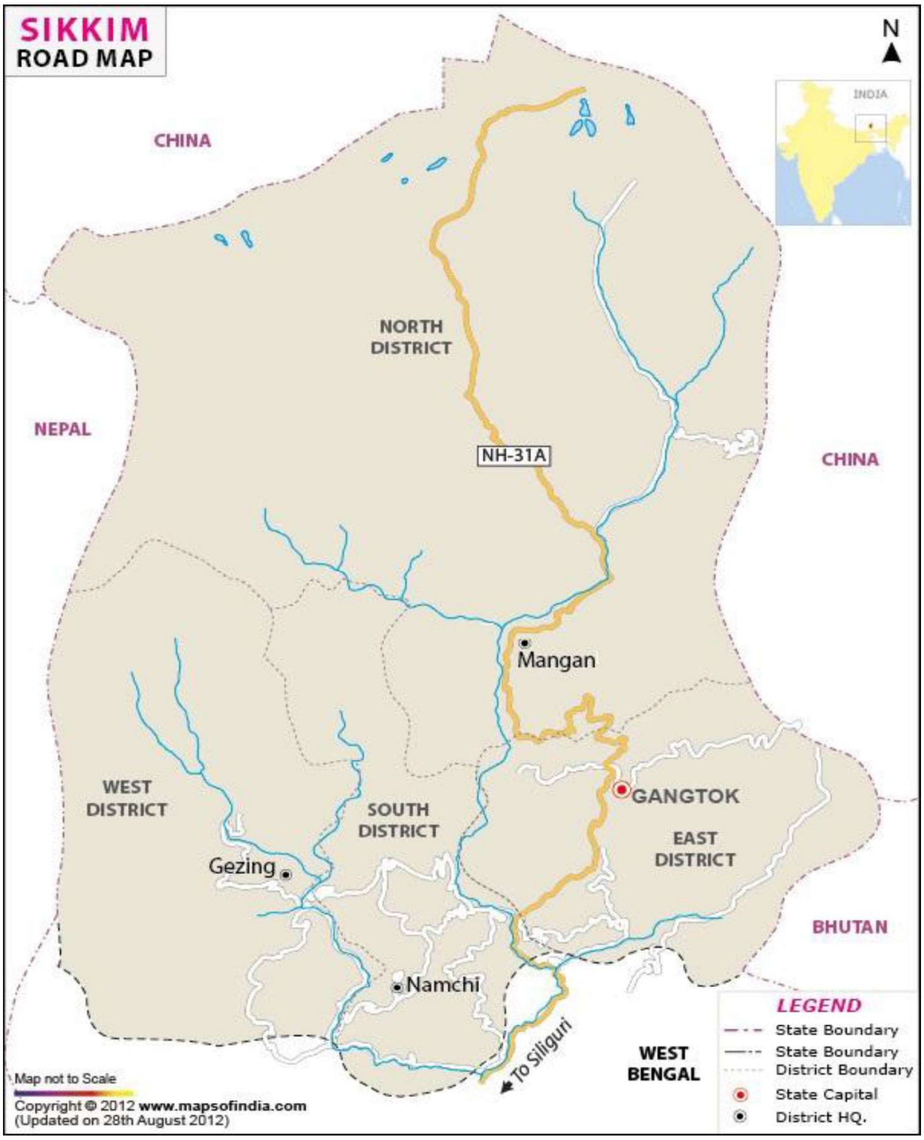


Fig 1: Image showing locations of Mangan Town (Source Google)

4.0 Project Settings

4.1 Topography

The area represents a highly rugged topography characterized by moderate to steep slopes that are intervened by narrow valleys. The topography of the region appears to be controlled by structural and lithological factors. The area thus exhibits high relative relief. Presence of overburden on steep slopes and high precipitation make this area a landslide prone zone.

Mangan is a town and district headquarters of the North Sikkim district of Sikkim state in India. The town is 67 km from Gangtok and well connected to the capital city by a metalled road. North Sikkim is the largest district of Sikkim in terms of area. The town lies in the geographic south of the district and highly rugged topography characterized by moderate to steep slopes.

Topography of the study area is on the west facing slope of mountains whose elevation varies from the top to bottom in terms of height i.e. about 3500 m to 650 m. Westward slope of the mountain is mostly gentle with different slope angles. Slope angles ranging from less than 15 degree to greater than 45 degree towards west with deviations, towards northwest and southwest at different places.

Mangan is located at an average elevation of 956 metres. The upper slopes with elevations of 1600m are occupied by dense forest of Pamthang Reserve Forest on the northward slope and Kaley Reserve Forest on the Southward slope.

Teesta River is the main river which flows in the west of the Mangan Town. Flow direction of the Teesta River is from North to South. Several tributaries such as Devi Khola, Raffongkhola, RametKyongKhola and an mbithangKhola of different orders joined Teesta River.

Mangan town has witnessed a spurt in its economy, mostly due to organic farming. The town opens up the Tibetan Plateau in the north, which also serves the towns of Lachung, Chungthang and Lachen in the far north. Owing to its elevation, the town enjoys a temperate climate. As of 2011 India census, Mangan had a population of 4644. Males constitute 55% of the population and females 45%. Mangan has an average literacy rate of 83.81%, higher than state average of 81.42 %: male literacy is 87.80%, and female literacy is 79.34%.

4.2 Climate

Mangan's climate is varies which can be defined as warm and temperate combination. The maximum Average annual temperature is 23 °C in July month and minimum temperatures remains 1° C in January month. March, April and May are the summer months. Monsoon in the region is during the months of July, August and September. These months experience good rainfall, and temperatures are brought down further during this time. The average rainfall is less in winter than in summer. Winters in the region are quite cold, and they extend through the months of October, November, December, January and February.

4.3 Meteorology

Geographically Sikkim is located on the South facing slopes of the Himalayan mountain range. The Area is exposed to high variation of precipitation during the year. Mangan Town located in the north Sikkim & enjoys a tropical climate as rainfall occurs almost in every month of the year. The rainfall data provided by the Sub-Divisional Magistrate Mangan, for seven years i.e. from 2009 to March, 2017. In this total span of time from last 7 years yearly **m**inimum rainfall is recorded 2783 mm in 2013 and maximum 4213 mm in year 2016.

Last 7 years monthly rainfall data is presented below:

DIS DISTRICT RAINFALL DATE (mm) FROM 2009 TO 2014

DISTRICT: NORTH SIKKIM

Note: (1) The district rainfall in millimeters (R/F)shown below are the arithmatic averages of Rainfall of Stations under the District.
(2) % Dep. Are the Departures of rainfall from the long period averages of rainfall for the district
(3) Blank spaces show non-availability of Data.

YEAR	JANUARY		FEBRUARY		MARCH		APRIL		MAY		JUNE		JULY		AUGUST		SEPTEMBER		OCTOBER		NOVEMBER		DECEMBER	
	R/F	%DEP	R/F	%DEP	R/F	%DEP	R/F	%DEP	R/F	%DEP	R/F	%DEP	R/F	%DEP	R/F	%DEP	R/F	%DEP	R/F	%DEP	R/F	%DEP	R/F	%DEP
2009																								
2010									424.9	21	582.8	8	531.6	10	599.1	30	329.1	6	106.7	-52	111.8	131	11.4	-65
2011	31.8	-48	72.4	-26	79.7	-60	150.3	-37	190.8	-46	393.8	-22	442.8	-10	397.2	-7	261.5	-33	126.8	-52	68.8	58	12.4	-45
2012	94.4	56	39.5	-60	208.3	4	365.3	53	139.7	-61	599.2	19	595.9	22	316.2	-26	785.4	102	302.4	14	0	-100	17.5	-22
2013	9.6	-84	62.8	-36	120.8	-39	200.5	-16	615.5	73	313.6	-38	530.2	8	301.8	-30	310.3	-20	226.7	-14	82.4	89	10.4	-54
2014	0	-100	29.8	-70	163	-18	194.4	-18	417	17	651.6	30	605.1	24	629.8	47	297.5	-24	36.7	-86	25.2	-42	13.6	-39

SOURCE: HYDROME DIVISION, INDIA METEOROLOGICAL DEPARTMENT, NEW DELHI
Data Hosted in ENVIS SIKKIM Website www.sikemvis.nic.in

RAINFALL DATA PROVIDED BY SUB DIVISIONAL MAGISTRATE - MANGAN TOWN FROM 2010 TO 2017

Note: Rainfaill data from January, 2010 to March, 2017 supplied by NHPC Ltd. vide their letter No. NH/TS-IV/Mgr./Works/2017/134 dated 21 on the request of Sub-Divisional Magistrate, Managan, Office of District Collector, North Sikkim, Mangan
The rainfaill data was recorded at Station installed near Sankalang Checkpost.

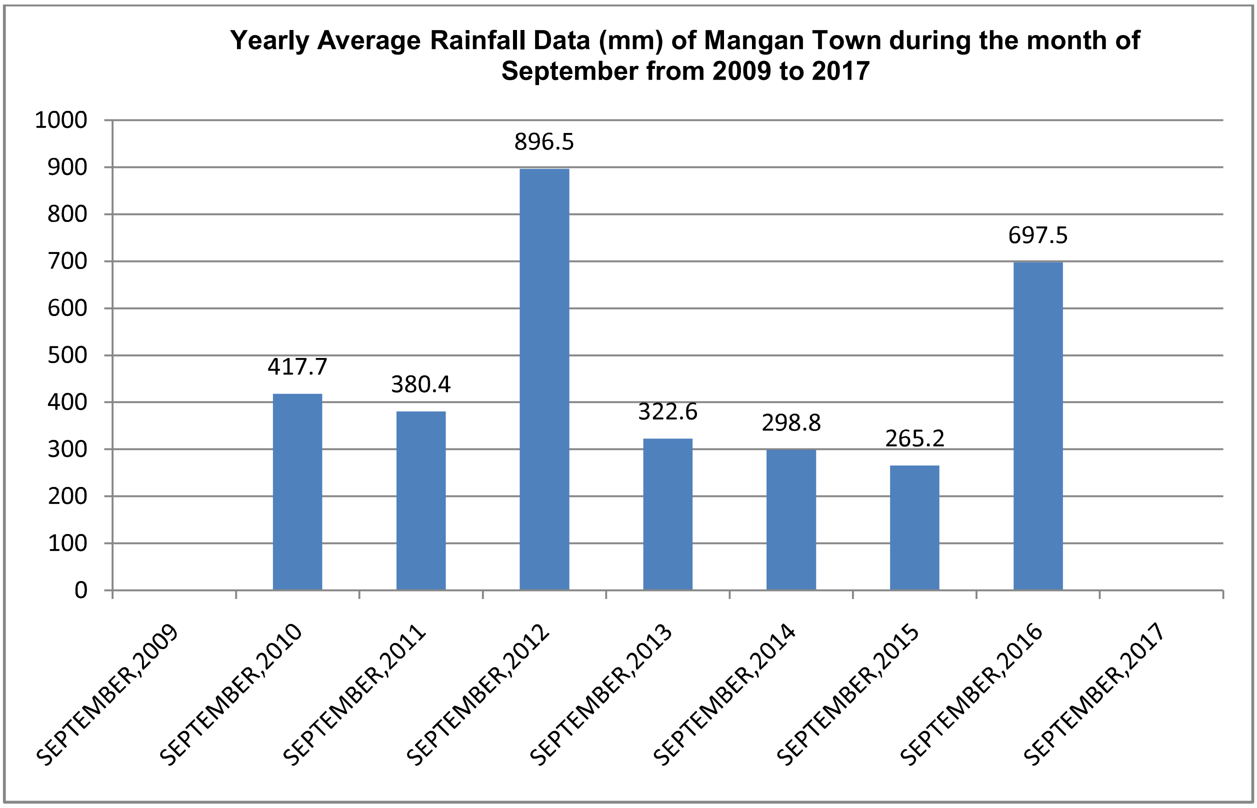
YEAR	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
	R/F	R/F	R/F	R/F	R/F	R/F	R/F	R/F	R/F	R/F	R/F	R/F
2010	0	46.2	258.9	195.6	529.6	748.9	507.4	1045	417.7	123.5	74.8	13.8
2011	36.5	82.2	92.8	180.2	187.7	450.8	603.8	483.3	380.4	142.4	60.4	7.7
2012	130.5	47.4	237.6	292	202.6	709.8	576	385	896.5	248	0	11.8
2013	9.2	74.6	154.2	247	546	368.1	447.8	329	322.6	223.6	52	9.8
2014	4.4	47.7	157	209.1	372.2	977.4	543.8	651.9	298.8	32.4	19.2	8
2015	18.5	36.6	156.5	234	761	1116	528.4	889.2	265.2	110.2	42.4	55.8
2016	110.2	43	325	292.4	443.9	653.2	521.2	378.9	697.5	136.3	0	0
2017	7.4	29.4	204.9									

Daily rainfall data provided by the local authorities, Mangan for the month of September, 2012, where highest ever rainfall data is recorded on September, 19th, 2012. Rainfall data table, yearly and exceptional case of precipitation of 24 hours graphical chart is also presented below:

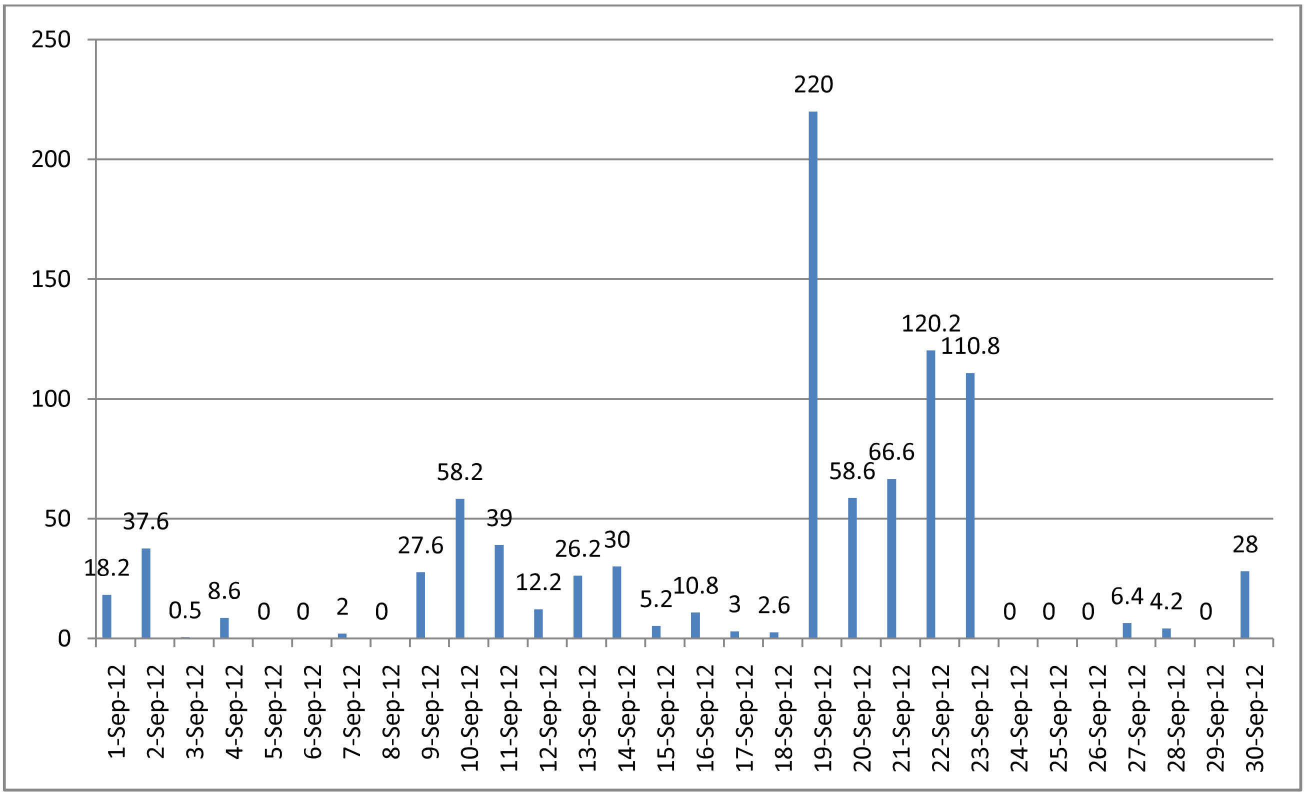
RAINFALL DATA PROVIDED BY SUB DIVISIONAL MAGISTRATE - MANGAN TOWN

Daily rainfall data for the month of September, 2012

Date	1-Sep-12	2-Sep-12	3-Sep-12	4-Sep-12	5-Sep-12	6-Sep-12	7-Sep-12	8-Sep-12	9-Sep-12	10-Sep-12	11-Sep-12	12-Sep-12	13-Sep-12	14-Sep-12	15-Sep-12	16-Sep-12	17-Sep-12	18-Sep-12	19-Sep-12	20-Sep-12	21-Sep-12	22-Sep-12	23-Sep-12	24-Sep-12	25-Sep-12	26-Sep-12	27-Sep-12	28-Sep-12	29-Sep-12	30-Sep-12
Rainfall in mm	18.2	37.6	0.5	8.6	0	0	2	0	27.6	58.2	39	12.2	26.2	30	5.2	10.8	3	2.6	220	58.6	66.6	120.2	110.8	0	0	0	6.4	4.2	0	28



THE EXCEPTIONAL CASE OF DAILY PRECIPITATIONAL INTENSITY OF 24 hrs. (mm) DURING THEMONTH OF SEPTEMBER, 2012 AT MANGAN TOWN



As discussed above, Raffong Khola is the most critical vulnerable site having the catchment area of 3.2 sq.km , which carries the maximum flood during the monsoon season and carries lots of debris with their torrential flow. Peak Design flood estimation for Raffong Khola is discussed under in the next para4.4.

4.4 RaffongKholaDesign Flood Estimation using synthetic unit hydrograph (SUH)

4.4.1 General

As short interval catchment rainfall and runoff data for flood events at project site are not available, the parameters of unit hydrograph may be evaluated by using CWC sub-zonal reports. For the derivation of regional unit hydrograph and its application to compute design flood hydrograph, reference may be made to relevant CWC study report of the sub zone to which the catchment of proposed SHP belongs.

A method based on synthetic unit hydrograph (SUH) principle has been developed for the various subzones of India. For this purpose, the country has been divided into 26 hydro-meteorologically-homogeneous subzones. These reports have been prepared jointly by Central Water Commission (CWC), Bridges and Flood Wing of Research Designs and Standards Organization (RDSO) of Ministry of Railways, Ministry of Transport (MOT)andIndia Meteorological Department (IMD).

As the Flood Estimation Report for the project area falling in sub zone 2c is not prepared by CWC/IMD, the Report for the adjoining Subzone 2b has been adopted. Accordingly, the present flow studies are based on “Flood Estimation Report for South Brahmaputra Basin Subzone 2b” of CWC. The formulae for calculation of various parameters of synthetic U.G. are given below in Table 1.

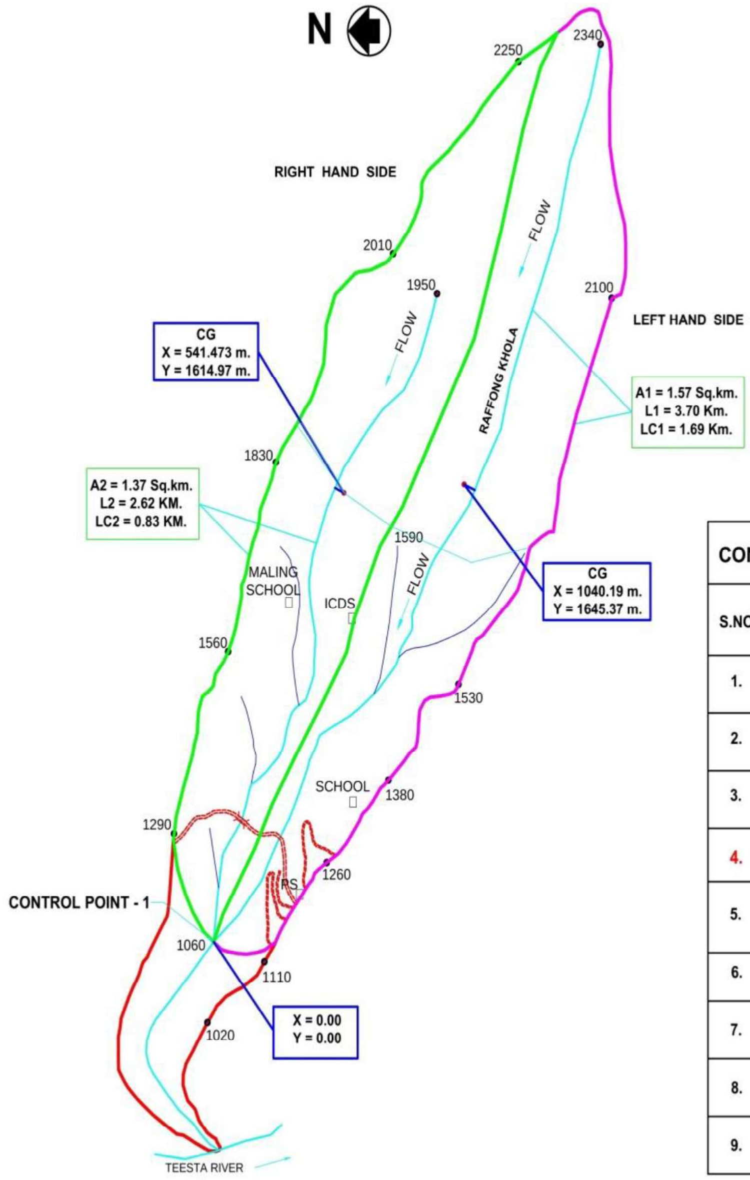
Table 1: Relationships between SUH parameters and catchment characteristics

Symbol	Description	Formula
q_p	Peak discharge unit Hydrograph per sq km	$q_p = Q_p / A$
t_p	Time from centre of effective rainfall duration to Unit Hydrograph Peak.	$t_p = 2.87*(q_p)^{-0.0839}$
W_{50}	Width of Uh measured at 50% peak discharge ordinate	$W_{50} = 2.304/(q_p)^{1.035}$
W_{75}	Width of Uh measured at 75% peak discharge ordinate	$W_{75} = 1.339/(q_p)^{0.978}$
W_{R50}	width of rising limb of UH measured at 50% of peak discharge ordinates	$W_{R50} = 0.814/(q_p)^{1.018}$
W_{R75}	width of rising limb of UH measured at 75% of peak discharge ordinates	$W_{R75} = 0.494/(q_p)^{0.996}$
T_B	base width of UH	$T_B = 2.447(t_p)^{1.157}$
T_m	time from start of rise to the peak of UH	$T_m = t_p + (t_r/2)$
Q_p	Peak discharge of UH	$Q_p = 0.905 /(A)^{0.758}$
T_D	Design Storm Duration	$T_D = 1.1 t_p$

4.4.2 Physiographic parameters of the catchment:

a. Catchment Area (A):

It is derived by delineating the project catchment area by using relevant topo-sheets. In the present case total catchment area up to project site is 3.2 km^2 and the same is presented below:



LEGENDS:

S.NO	DESCRIPTION	SYMBOL
1.	MAJOR NALA / MINOR NALA	
2.	MAIN ROAD	
3.	SPOT LEVEL	
4.	BRIDGE	
5.	VILLAGES	

CONTROL POINT - 1 CATCHMENT AREA DETAILS:

S.NO	DESCRIPTION	AREA IN Sq.Km.
1.	LEFT SIDE FORK CATCHMENT AREA	1.57
2.	RIGHT SIDE FORK CATCHMENT AREA	1.37
3.	BELOW CONTROL POINT - 1 CATCHMENT AREA	0.26
4.	RAFFONG KHOLA TOTAL CATCHMENT AREA	3.20
5.	RAFFONG KHOLA LEFT & RIGHT FORK CONFLUENCE SITE CATCHMENT AREA AT CONTROL POINT SITE	2.94
6.	RIGHT HAND STREAM LENGTH AT CONFLUENCE	2.62 km.
7.	LEFT HAND STREAM LENGTH AT CONFLUENCE	3.70 km.
8.	RIGHT HAND LEVEL DIFFERENCE	1950 - 1060 = 890 m.
9.	LEFT HAND LEVEL DIFFERENCE	2340 - 1060 = 1280 m.

Fig 2: Showing catchment area Plan of RaffongKhola
(Ref. drawing no.***Mangan/Sikkim/SSDMA-102)***

b. River Length parameters of the Main Stream (L &Lc):

This implies the longest length of the main river from the farthest watershed boundary of rainfed catchment to the diversion site (L). The center of gravity of the catchment is derived based on graphical method for a closed polygon. The stream may or may not pass through the center of gravity but the nearest point of the river to the center of gravity is considered to find the length of the main river from the center of gravity to the point of study (Lc).

- The longest length of the main river (L) = 3.7 km
- The length of the main river from the center of gravity to the point of study (Lc) = 1.59 km.

c. Equivalent Stream Slope (S):

This is one of the physiographical parameters used in the derivation of Synthetic Unit Hydrograph.

The L section of the river is derived from the relevant topo-sheets. It is broadly divided into segments representing broad ranges of the slopes of the segments. Following formula is used to compute equivalent slope (S).

$$S = \frac{\sum L_i\left(D_{(i-1)} + D_i\right)}{L^2}$$

Elevations of river/Nalla bed at intersection points of contours reckoned from the bed elevation at diversion site is considered as datum and D(i-1) and Di are the heights of successive bed location at contour intersections.

Equivalent Stream Slope (S) = 250 m/km

d. Derivation of 1-hour Unit Hydrograph:

The empirical relations for deriving Synthetic Unit Hydrograph is referred from CWC Subzone 2 (b) report and the same formulae are listed in table-1. The 1-hour Unit Hydrograph is obtained from the given parameters.

e. Design Storm:

The 1-day (24hr) Maximum Precipitation for present study has been taken from observed rainfall value i.e 220mm.

f. Design Loss Rate:

As recommended in the CWC report, the design loss has been adopted as 0.35 cm/hr.

g. Base flow:

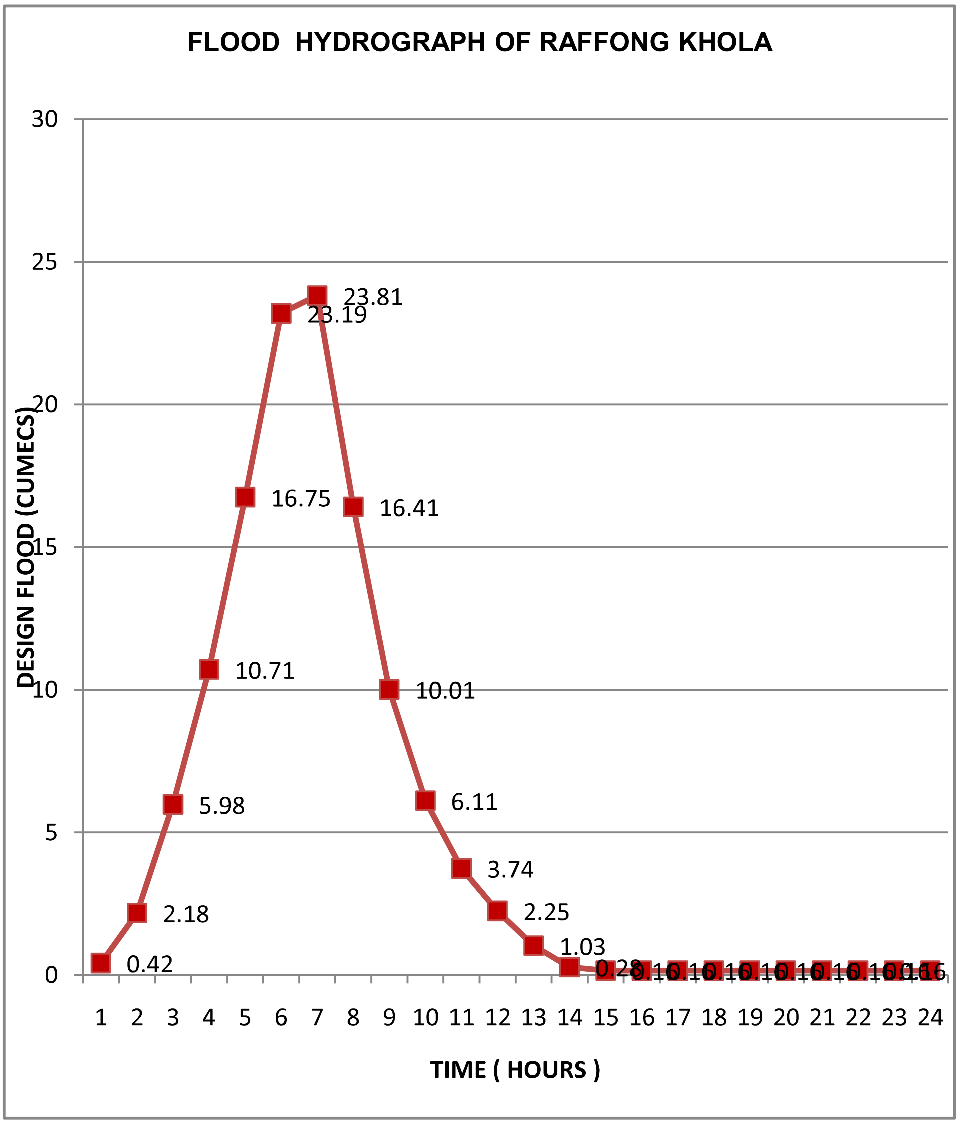
The base flow contribution for the design flood has been computed as per the suggestion of CWC sub zone report – 2(b) i.e. 0.05cumec per sq. km.

h. Estimation of Flood Hydrograph:

The effective rainfall for design storm duration is to be applied to the unit hydrograph of a catchment and design flood have been computed for maximum observed rainfall value is23.81m^3/s. The ordinates of design flood hydrograph as well as plots are shown below inTable 2.

Table 2:Showing yearly, Monthly and daily rainfall data i.e. 2010 to March, 2017

Time (hours)	Design Flood (cumecs)
1	0.42
2	2.18
3	5.98
4	10.71
5	16.75
6	23.19
7	23.81
8	16.41
9	10.01
10	6.11
11	3.74
12	2.25
13	1.03
14	0.28
15	0.16
16	0.16
17	0.16
18	0.16
19	0.16
20	0.16
21	0.16
22	0.16
23	0.16
24	0.16



Based on the above calculations and flood hydrograph for the safety point of view 1.25 factor is also applied, hence design flood is derived 29.76m^3/s and by rounded off 30m^3/s shall be adopted for the required parameters.

4.5 Flora and Fauna

Mangan Town area is generally low laying gentle terrace slopes, cultivated, ridge tops with steep flanks and characterised by dense reserve forests. The main flora of this area is rhododendron, bamboo, chap, rani chap, cardamom, Dhupi, Oak, Walnut and Ginger. Some pine trees are also seen during the site visit along the high slopes & higher reach of the roads.Wild animals around the Mangantown area discussed in earlier different studiesare Wolves, beer, deer, fox, wild cock,poisonous snakes and other reptiles likeleeches etc.

4.6 Socio-Economic study

Mangan is a Nagar Panchayat city in district of North Sikkim. The Mangan city is divided into 5 wards for which elections are held every 5 years. The Mangan Nagar Panchayat has population of 4,644 of which 2,456 are males while 2,188 are females as per report released by Census India 2011 (Source Google). Population of Children with age of 0-6 is 585 which is 12.60 % of total population of Mangan (NP). In Mangan Nagar Panchayat, Female Sex Ratio is of 891 against state average of 890. Moreover Child Sex Ratio in Mangan is around 893 compared to Sikkim state average of 957. Literacy rate of Mangan city is 83.81 % higher than state average of 81.42 %. In Mangan, Male literacy is around 87.80 % while female literacy rate is 79.34 %.

Mangan Nagar Panchayat has total administration over 1,054 houses to which it supplies basic amenities like water and sewerage. It is also authorize to build roads within Nagar Panchayat limits and impose taxes on properties coming under its jurisdiction.

4.7 History of Mangan Slides

From the decades systematic landslide studies were studied by GSI since 1980 for the preparation of landslides hazard zonation maps and formulate its guidelines. Chatterjee (1986) prepared landslide overview map and superimposed them on the land slope, landuse and lithological maps to evaluate the role of different parameters in inducing slope failure. Several works of GSI (Majumdar 1980, Gupta 1988, Gairola and Shukla 1990, Sharan 1992, Chandra 1992, Sharma and Khandpal 1996, Mehrotra et al., 1996 etc) have also prepared landslide hazard maps.

In 1998, Bureau of Indian standards (BIS) proposed guidelines for systematic study of the Landslide hazards zonation (LHZ) on 1:25000 / 1:50000 scales. Based on these guidelines, Geo-Environment appraisal and micro-zonation of Mangan Town has been initiated by Department of State Disaster Management Authority (SSDMA), land Revenue & Mines, Mineral Department (LR&DMD) and furthermore the detailed investigation was carried out.

As data provided by the SSDMA landslide Hazard zonation of Mangan was carried out by GSI in the last decade on the request of State Govt. In the report they have suggested to discourage construction of building in the area. However due to space constrains, it was not possible to adhere to the suggestion.

4.8 Regional Geology

Entire study area is a part of Darjeeling/Sikkim Himalayas, located between the Himalayan Kingdom of Nepal in the West and Bhutan in the East. The geological set up and stratigraphical position of rock units of North Sikkim are complex because of Tectonic complex city, polyphase metamorphism and unfossiliferous nature of most of rock units.

In the Western as well as in the Eastern part of Sikkim - Darjeeling Himalayas, MBT and MCT runs parallel, exposing a strip of lesser Himalayan. However, in the central part of Sikkim – Darjeeling lesser Himalayas, a domal shaped re-entrant of MCT has exposed a wide expense of the lesser Himalayan rocks. The MBT, with the Mio-Pliocene Sion-Orogenic Shivalik group of Footwall and the Permo-Carboniferous Gondwana in the hanging wall, has not been affected by the Culmination structure and has a roughly E-W running Terrace. Daling group of rocks overlies the Gondwana Sheet. The Gondwana rocks as well as the Buxa and Rangit Pebble Slate are exposed in the Rangit window.

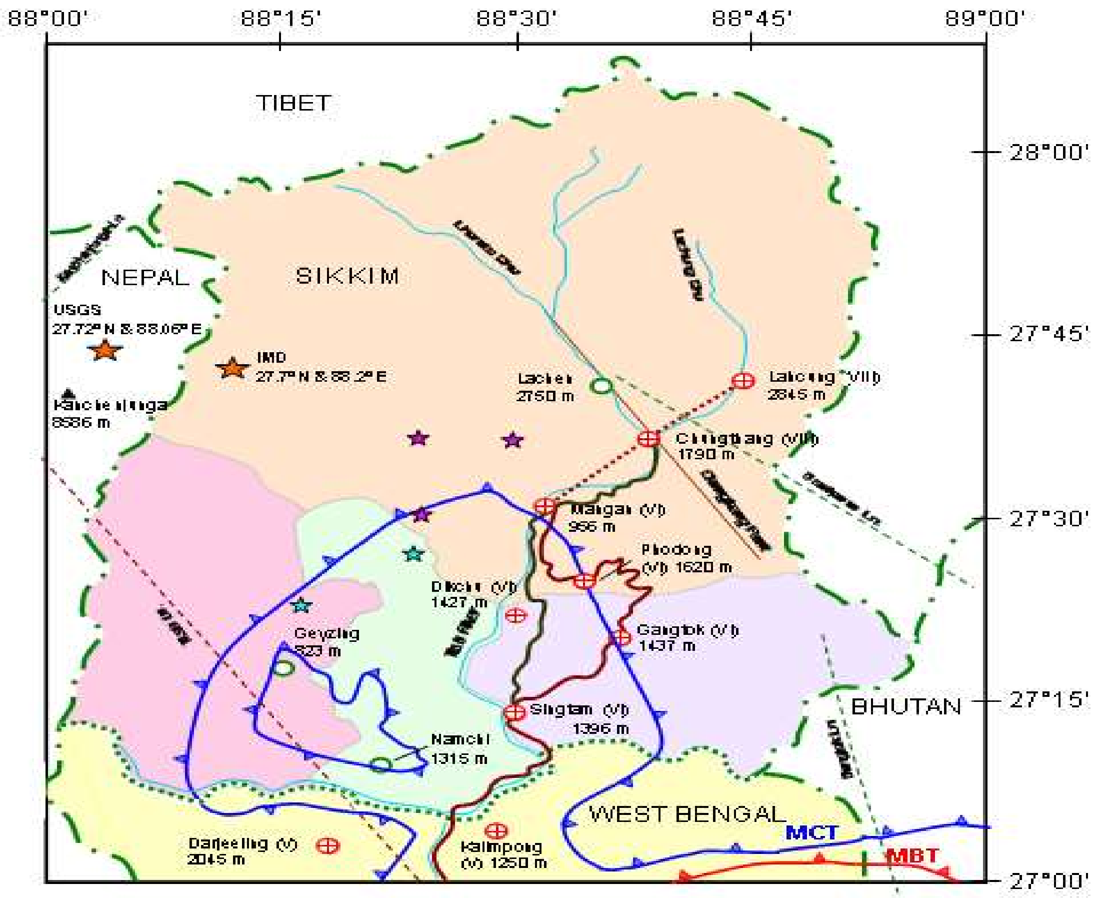


Fig 3: Showing locations MBT & MCT on Darjeeling- Sikkim Map (Source Google)

The main boundary thrust (MBT) separates the Shivaliks of the sub-Himalaya from the over laying rocks of the lesser Himalayan belt. The Daling sequence is over laying by medium to high grade dominantly politic schist, with minor inter-banded quartzite's, calc-silicate rocks commonly known as Chungthang / Paro formation and small bodies of granites (Lingtse Gneiss), which is overlay by a magmatic terrain known as Darjeeling Gneiss/ Kanchenjunga

Gneiss and throughout the equivalent of central crystalline constituting the greater Himalayan crystalline (GHC/HHC).

The main central thrust separate the lesser Himalaya and the higher Himalaya. In the far north, a thick pile of fossiliferous Cambrian to Eocene sediments, belongs to the Tethyan Belt (Tethyan Sedimentary sequence) overlies the GHC (GSI Misc. Pub. No.30, Part-XIX-Sikkim, 2012). This zone is surrounded by daling group of rocks (Gansser, 1964, Acharya, 1989, the mapped area is covered by quartz-biotite schist / phyllite with interbands of quartzite at places. The litho units can be correlated with Gorubathan Formation of Daling group (Chakraborty and Bannerjee, 1982). The rocks in general, show NW-SE to MNW-SSE foliation trends with dip varying from 25° to 60° towards NE to ENE.

4.9 Seismicity

On 18th September, 2011 Sikkim Earthquake of 6.9 – A Seismological Investigation report from the Analysis/ Synthesis and advance processing of the record events by the Sikkim, Strong motion earthquake monitoring network occurred at 6:10:48 PM. Earthquake occurred near the boundary between India and Eurasia Projects in the proximity of the Kanchanjunga Lineament near the Sikkim – Nepal border at 68 km north west of Gangtok, the state capital of Sikkim which is very much near to the Mangan vicinity.

The site specific earthquake parameters for Teesta-III Dam site (near Chungthang) have been studied by the department of Earthquake Engineering, IIT, Roorkee in their report EQ: 2007-15 as provided by the Sikkim Government. The main central thrust (MCT), a regional seismo – tectonic feature has been estimated to have the potential of magnitude 8 and its closest distance to Dam site (15 km). A. Peak Ground Acceleration (PGA) as 0.36g has been estimated, which represents the maximum credible earthquake.

The main boundary thrust (MBT) has been assigned and earthquake magnitude of 7.5 within an estimated PGA at Dam site (distance 15 km) as 0.31g. Another fault F1 has been assigned an earthquake magnitude of 6, which shall produce a PGA of 0.15g at Dam site (distance 14 km). PGA corresponding to MCE has been assigned as 0.36g and PGA corresponding to DBE has been assigned as 0.18g. Provided data tables are placed below:

Table 2- Peak ground horizontal acceleration from various source around teesta-III HE Project site

SL. No.	Source	Magnitude	Closest Distance	Max. Accl. (g)
1	Fault F1	6.0	14	0.15
2	Main Central Thrust	8.0	15	0.36

3	Main Boundary Thrust	7.5	15	0.31
4	Teesta Lineament	6.0	58	0.05
5	Kanchanjunga Lineament	6.0	67	0.04
6	Arun Lineament	6.0	113	0.03
7	Everest Lineament	6.0	134	0.02
8	Purnea Everest Lineament	6.0	153	0.02
9	YardangGuluGraben	6.0	91	0.03
10	KatiharNailphamari Fault	7.0	182	0.02
11	Indus Suture Zone	6.0	186	0.02

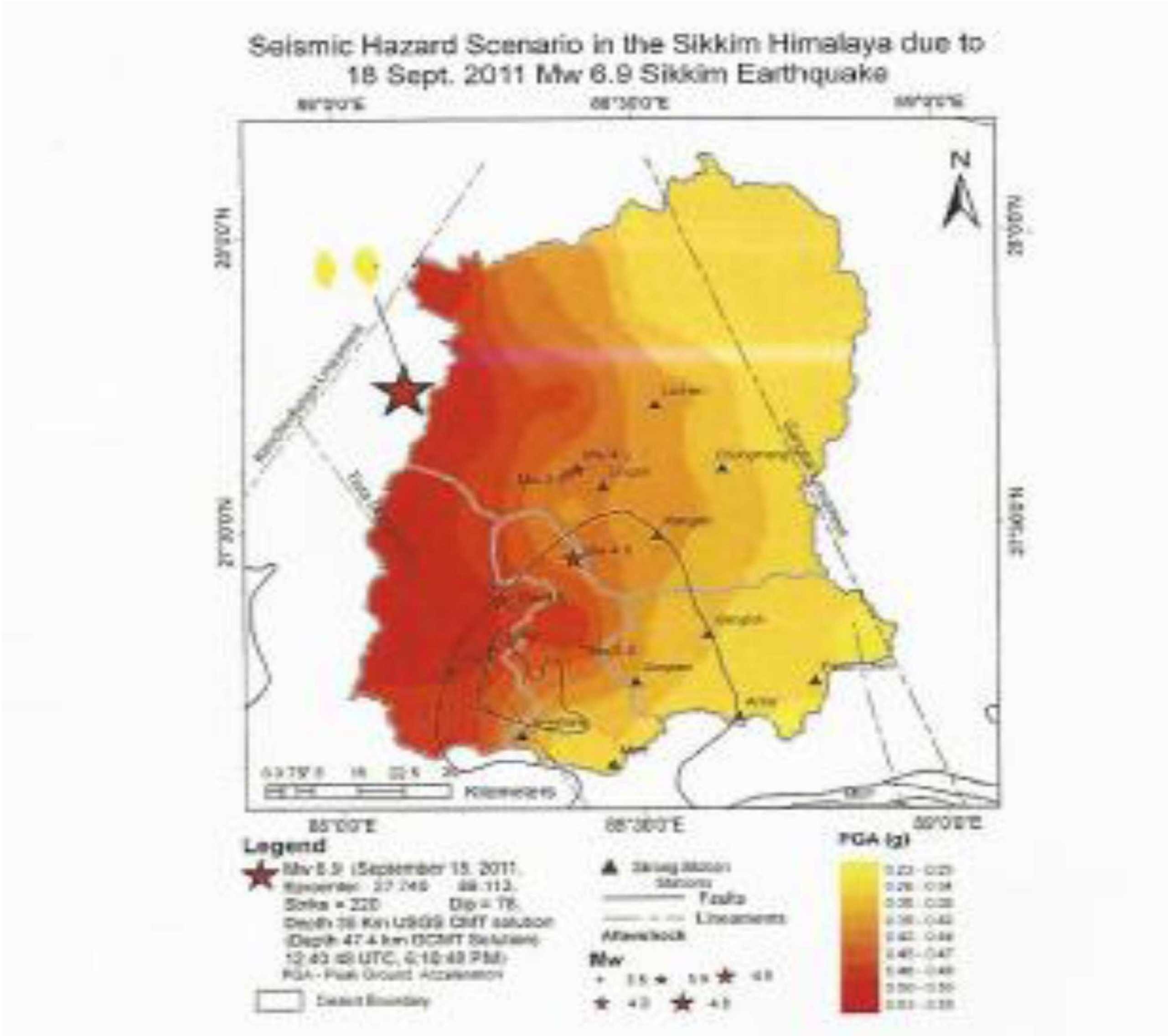


Fig 4: Showing Seismic Hazard Scenario in the Sikkim Himalaya due to the 18th Sept., 2011, Sikkim Earthquake of Mw 6.9

A comparative of MGA/EGA depiction by the Sikkim Strong Motion Array Triggered by 18thSept., 2011 Mw 6.9 Sikkim Earthquake at the back drop of the Seismic Micro zonation predicted hazard level are provided in table below:

Table 3- Comparative of MGA/EGA

Stations	Latitude	Longitude	Elevation in (m)	Epicentral Distance (km)	Operational/Triggered	Magnitude	Maximum ground Acceleration (MGA)S-wave envelope(g)			PGA(g)	Microzonation Predicted Probabilistie PGA (g) for Maximum Scenario
						(Mw)	Radial	Transverse	Vertical	Hazard Level	
Gangtok	27.32	88.61	1466	67.71	Triggered	6.9	0.36	0.26	0.08	0.37	0.75-0.80
Aftershock						4.8	0.17	0.12	0.06	0.19	-
						4.6	0.14	0.10	0.05	0.16	-
						4.2	0.11	0.05	0.03	0.12	-
Gezing	27.3	88.25	1879	50.57	Triggered	6.9	0.47	0.31	0.18	0.48	0.55-0.60
Singtam	27.24	88.49	555	66.78	Triggered	6.9	0.37	0.25	0.12	0.38	0.75-0.80
Melli	27.1	88.45	442	78.31	Triggered	6.9	0.28	0.14	0.08	0.29	0.55-0.60
Mangao	27.49	88.53	1137	49.74	Triggered	6.9	0.39	0.22	0.12	0.40	0.80-0.85
Chungthang	27.60	88.64	1570	54.41	Triggered	6.9	0.36	0.24	0.07	0.36	0.50-0.55

Mangan is located on the domain of MCT, and as per seismic map of India Mangan area lies in Zone- IV/V. Accordingly Seismic Loading will be considered as per Seismic Coefficient (Zone - V) with Importance – 1. The considered values taken as Horizontal Acceleration Coefficient 0.22, Vertical Acceleration Coefficient 0.12 for the extreme event.

5.0 Status and PresentStudies

Department of State Disaster Management Authority (SSDMA), land Revenue & Mines, Mineral Department (LR&DMD), detailed investigation for the preparation of Detailed Project Report (DPR) was initiated from 2013 to 2015, and subsequently DPR was prepared & submitted by the SSDMA & LR&DMD with the National Disaster Management Authority (NDMA) for their approval in 2015.

Some of the locations were identified as critical spots from the stability point of view by the Department of SSDMA and NDMA by jointly inspection after submission of the DPR in 2015. NDMA suggested SSDMA to revisit & addition of adequate treatments methodology. Based on advice of NDMA, SSDMA along with LR&DMD and DMMG, Sikkim Govt. appointed a consultantfor preparation of detail project report. After detail investigation a updated DPR has been submitted to NDMA in month of July, 2017. The experts committee of NDMA for review the DPR has been examined the DPR and gave some observation on the report (Observations enclosed as in Annexure).

Keeping in view of the above observations of the honourable committee, the revised DPR covers only following sites. These are

- Old Mangan bazaar & below SNT Complex & just adjacent to left bank of RaffongKhola in the lower reaches immediately below the SNT Complex landslide
- Lower reach of multi-storey parking area at RinzingNamgyalMarg
- Surrounding area of Senior-Secondary School and close to left bank of RaffongKhola

Accordingly, furthermore detail investigation has been performed to address all the concern raised by the committee.

5.1 Old Mangan bazaar & below SNT Complex & just adjacent to left bank of RaffongKhola

Old Mangan Bazar is close to the area to the left bank of RaffongKhola towards north of Mangan bazaar. The area is more vulnerable to failure in wet to surface runoff hydrological conditions. Some of the pictures are presented as below

Fig 5: Showing old Mangan Bazar left side of the slide zone below SNT complex.

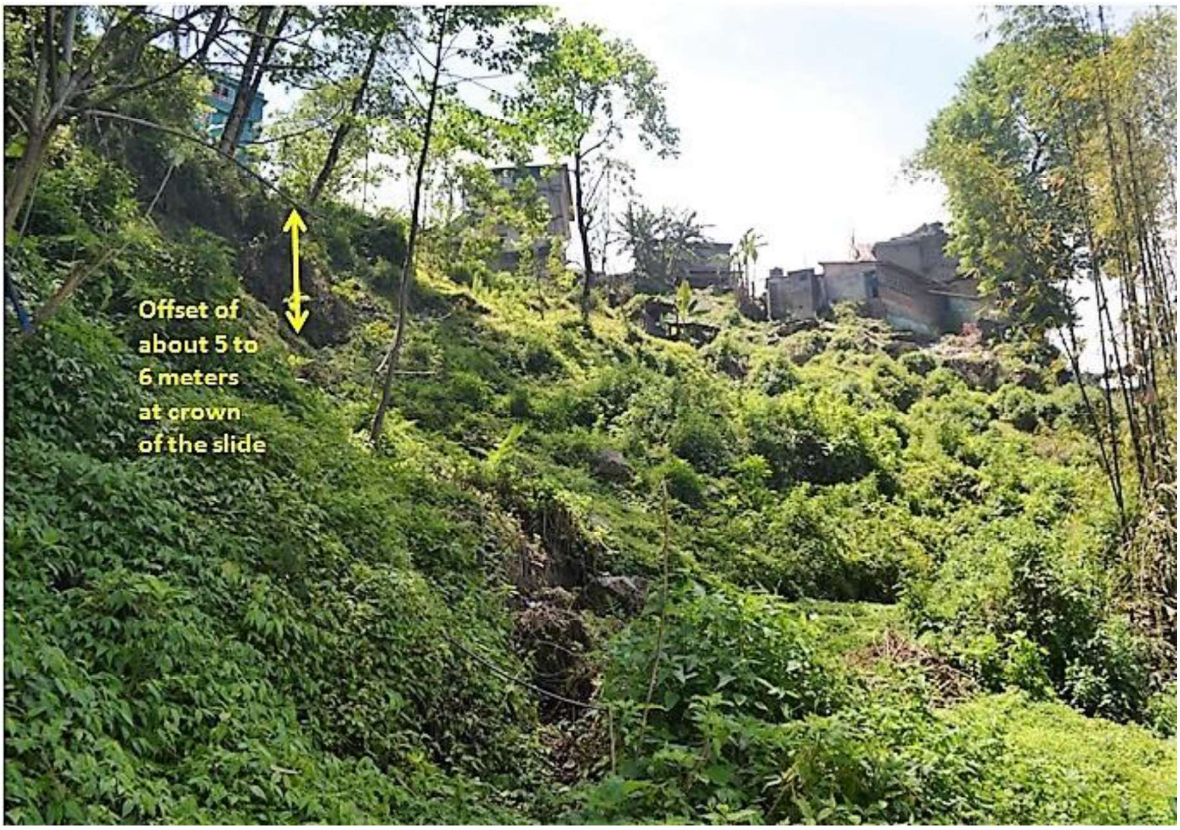


Fig 6: Showing crown portion of the slide zone below SNT complex.

Fig 7: Showing crown portion of the slide zone below SNT complex.

Fig 8: Showing right & left portion of the crown of slide zone below SNT complex

Fig 9: Showing cracks in the road in the slide zone below SNT complex

Fig 10: Showing downside view from left side of the slide zone below SNT complex

Fig 11: Showing steps due to sequential subsidence in the slide mass below SNT complex

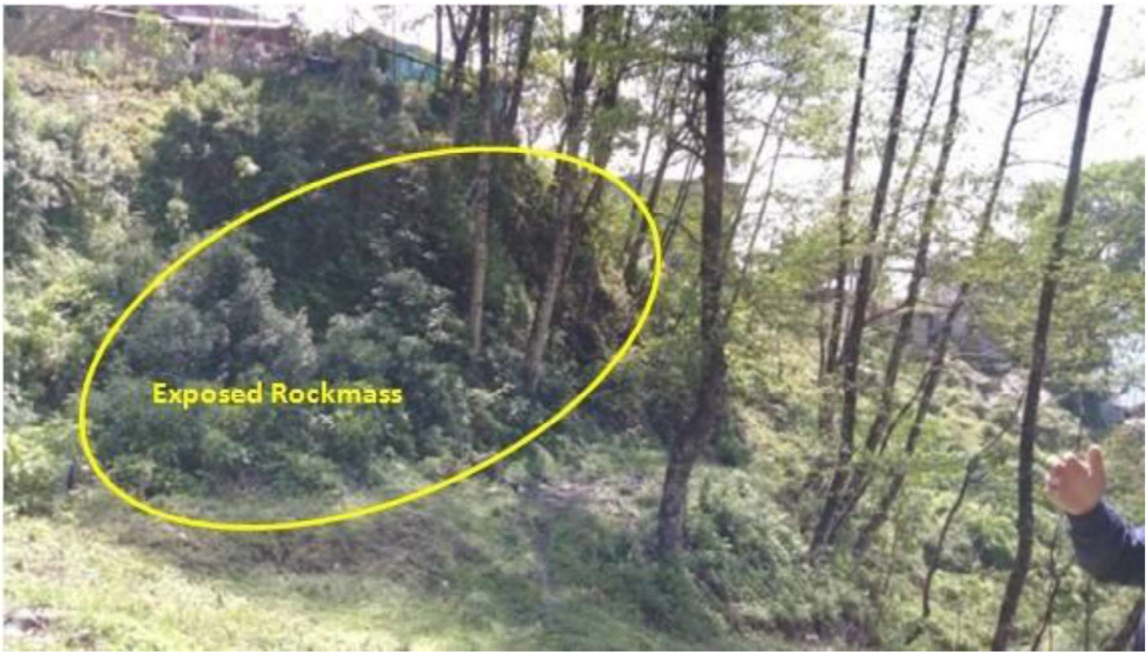


Fig 12: Showing exposed bed rock below SNT parking right side adjacent to slide mass

Fig 13: Showing exposed bed rock at right bank of raffongkhollajust upside or slide toe.

5.2 Mangan bazaar & Lower reach of multi-storey parking area at RinzingNamgyalMarg

The Mangan bazaar & Lower reach of multi-storey parking area at RinzingNamgyalMarg is densely habited. There many multistorey buildings constructed in these areas creating enormous pressure on the foundation. Simultaneously the domestic uses of these densely habited areas also dilate the foundation loose or weathered bed rock.

5.3 Surrounding area of Senior Secondary School and close to left bank of RuffongKhola

The study area surrounding area of Senior Secondary School and close to left bank of Ruffong Khola are mostly covered by loose overburden and slope wash debris composed of fragment crust bed rock of quartze biotite schist and phyllites with silty and clayey matrix. At places the area is saturated with rain and domestic used water that dilate the foundation. Thus at many place subsidence and slope movement is observed. There are some pictures of this area is here under.

Fig 14: Showing movement in slope wash material below road to school.

Fig 15: Showing slided scar in slope wash material below road to school.

5.4 Upper and lower reach of Raffong Khola Profile

Raffong khola is main drainage nalla adjacent to Mangan town of north Sikkim. The general gradient of raffong khola is very steed to moderate at few reaches. During rainy season and occasionally cloud bust conditions very big sized boulders rolled up from upper reaches to down in this nalla course. This nalla course is governed by fault (Source GSI). However, the signatures of fault plane are difficult to identify due to huge accumulation of slope wash material on both the banks. There are some pictures of this area is here under.

Fig 16: Showing upstream view of raffong khola from Sikkim Highway.

Fig 17: Showing downstream view of raffong khola from Sikkim Highway.

Fig 18: Upstream view of Raffong Nalla showing accumulation of huge boulder along Nalla below Sikkim highway.

Fig 19: Upstream view of Raffong Nalla showing exposed bed rock.

Fig 20: Upstream view of Raffong khola just above from slide toe below SNT complex.

6.0 Geological and Geotechnical conditions at the Mangan Slide area

The Mangan slide is located immediately north of Mangan town and at its toe, the area influenced by the slide, with the slide orientation being roughly NS, covering a length of –m and being –m at its widest extent, its toe lying at EL 990m and its apex at approx 1170m. In view of its location at the foot of the town any movement within the slide is bound to influence the foundation of buildings lying in the immediate periphery of the slide boundary, particularly its apex. The subsidence noted in some of the adjacent buildings is a mute testimony to the destructive factor inherent in such mass movements.The terrain of the slide area has a gentle slope varying from 25° to 35°,with marginally greater gradients towards its eastern margins where some rock exposures are noted. Three sets of tension cracks of varying lengths traverse the slide from east to west. It is apparent that settlements are generally more pronounced towards the head of the slide where gradients are slightly greater and close to the southern periphery or apex.

Mangan town area has a general slope from south to north with three perennial Kholas namely Devi Khola, Raffong khola and Ramet Kyong Khola aligned and flowing across the area from south to north andconfluence with the Teesta River at its northern most boundary

The Mangan area experiences heavy rain fall during the monsoon period. Presence of talus material and debris in a large part of the slope forming area with limited rock exposures allows infiltration of surface water, thus recharging the ground and resulting in subsidence and landslides. Evidence of subsidence and sinking are quite commonly exhibited on the surface. Based on the previous studies by GSI, SSDMA, areas vulnerable to sliding have been identified and demarcated for ascertaining their degree of susceptibility, from the above, the area in the proximity of Raffong khola has been identified as the most vulnerable area which needs to be taken up immediately on priority for evolving mitigation measures.

6.1 Geological Investigations*:* As a means of obtaining sufficient design inputs, it was considered prudent to carry out detailed surface and subsurface investigations of the concerned area, these are briefly detailed below.

6.2 Topographical survey and Geological mapping*:* In order to better understand the mechanics of sliding topographical survey on 1:1000 scale and thereafter systematic geological mapping of the slide area was taken up, the work included mapping of the slide boundary, demarcation of surface rock outcrops and characterization of overburden. Major topographical features such as nallas circumventing the slide zone were also delineated. Tension cracks and areas of subsidence were also noted and possible deductions made on the depth of the slip surface. A geological section along the long axis of the slide was developed to illustrate the depth of various lithological assemblages, demarcate the slip surface and show general terrain gradient, while also depicting the extent of subsidence along the tension cracks.(**referDrg No. Mangan/Sikkim/SSDMA-104 to 104A)**

6.3 Geological and structural setting of the area: Based on the geological mapping it is inferred that the slide area is overlain by overburden cover constituted by pebble to boulder grade rock fragments of BiotiteSchists, Phyllites and Quartzites in a generally coarse grained sandy matrix intermingled with dominantly micaceous material and ranging in depth from 15 to 25m. This material generally appears to be weathered and transported in origin, thus confirming its nature as talus / slope wash. Occasional large boulders are embedded within the matrix..The material constituting the matrix appears to exhibit moderately high permeability and porosity as is perceived by its retention capacity for water, and appears to be fully saturated possibly due to the continuous subsurface inflow it receives from the contributory nallas. This could be a major factor in contributing to the unstable nature of the hill slope.

The Litho-units around Mangan are a part of the lesser Himalayan zone and are represented by low grade metasedimentsviz, Quartz Biotite Schist / phyllite along with interbeds of quartzite. The litho-units have been correlated with the Gorubathan formation of Dalinggroup.The rocks in general show NW-SE to NNW-SSE foliation trends with dip varying from 25 ° to 60° towards NE to ENE.The study of the rock types reveals that the area has undergone different phases of deformation which is evident from the presence of open and moderately tight folds , open and tight vertical to sub-vertical joints and faults.The Channel courses of Raffong khola in the North and Ramet Kyong khola in the south of Mangan town are presumably fault planes. Furthermore, a NNW-SSE trending fault in the west of Mangan town probably passes through the sankalan bridge on the teesta river, this has been inferred from aerial photographs and geomorphological evidences of alignment of major channels in the area. Extremely limited outcrops are visible at the slide zone and that too confined to the eastern periphery of the zone.

6.4 Subsurface investigations: Investigations taken up in the slide zone comprise soil sampling and modal analysis, standard penetration tests (SPT), core drilling,seismic profiling, resistivity survey etc. The results of the soil investigations are summarized below

6.4.1 Grain size distribution of the matrix

Assessed from modal analysis of the undisturbed sample

1- Gravel 5%
2- Sand 65%
3- Silt 22%
4- Clay 09%
5- Generally sandy loam, GP and SP groups comprising poorly graded gravels and gravel sand mixes with little non plastic fines. Matrix characteristically contains sand with mica flakes.
6- Allowable Bearing pressure range varies from 46 to 442 KN / m2 (evaluated from SPT tests)
7- Moisture content: 40%
8- Liquid limits: 45 to 58% (also noted to be 30 to 40 %)
9- Plastic Limit: 37 to 43 %
10- Plasticity Index: 8 to 15 i.e. low to medium plasticity and compressibility.
11- Soil wet density: 2.07
12- Dry density: 1.99
13- Specific Gravity: 2.69 to 2.73

6.4.2 Exploratory core drilling

Two exploratory drill holes 01 and 02 , one of 30m and the other of 20m depth were carried out in the slide area , into bedrock. The drillhole logs are attached as **Annexure-01**. Drillhole 01 has encountered bedrock at 24m depth, while drill hole 02 has intercepted bedrock of mica schist with quartz veins at 12m depth. Fill material, probably representing talus or slope wash of

7.50m depth has been observed to overlie weathered mica schist at both locations;however the initial depth of the weathered medium also reflects presence of residual soil derived from in-situ weathering of bedrock. No water loss was recorded in either of the two drill holes. Nil to very low core recovery was noted in both the drill holes . From the above observations the following is inferred -

- The slide zone comprises of 7.5m deep debris material, which is in a saturated state. The bedrock depth ranges from 12 to 25m constituted by quartz biotite schist and in view of its low strength indicates deep in-situ weathering from which the intervening material is derived, however the intervening layer too consists of weathered and saturated material derived from the underlying bedrock and probably reflects residual soil which is a product of insitu weathering.
- The low core recovery also indicates deep weathering
- The low water loss also indicates complete saturation
- From the modal analysis it is apparent That the matrix comprises coarse sand with mica flakes which is in saturated state, this medium is acting like a confined aquifer which is not allowing the water to escape because of low flow conditions induced by the finer mica flakes intermingled with the matrix material which are blocking the interstitial pore spaces.
- The circumventing kholas are the source for the subterranean charging of the debrisresting on the bedrock.

6.4.3 Geophysical Survey:

a) **Seismic profiling:**The exploratory core drilling was supplemented by Geophysical studies to have corroboration of the parameters deciphered, As such four number seismic profiles were taken of in the Mangan town area, of which only one ie SRT 3 of 92m length was carried out transversely in the slide zone from west to east.

The aim of the investigation was to provide sub surface soil- rock profiles along the surveyed sections. The total length of the profile was 92m, with each geophone spacing at 4m. Evaluation of the seismic data depicts the presence of four distinct layers (refer annexure 02). The top layer depicts a compressional wave velocity of 55m/sec, the second layer a velocity of 1300m /sec, both the layers appear to represent top soil as per data obtained from the drill hole information too. The third layer represents a compressional wave velocity of 2700m/sec, depicting moderately weathered rock, while the fourth and final layer depicts a compressional wave velocity of 3900m/sec, representing competent rock and confirms to the bedrock levels deciphered from the drill hole data

b) **2D electrical resistivity survey:** Electrical resistivity profiling reveals subsurface geological and hydrological conditions such as movement of ground water, relief of bedrock and presence of water saturated zones, if any. Accordingly a two dimensional electrical resistivity survey was carried out in the subsidence area of the Mangan slide zone to gather information on the depth of the slip surface, depth of overburden, hydrological conditions , type of material present and its physical properties. Of the seven resistivity tomography profiles carried out, two numbers ie ERT 6 and ERT 7 were carried out in the subsidence area of the slide zone.

The profiles have provided reasonably accurate data to a depth of 27m. The interpreted data for both profiles is presented at annexures – and --. Perusal of the resistivity data for both profiles reveals that probe results are available till approx 27 to 30m depth ie till a recorded Elevation of 1067m approx. No observations exist for initial 5 to 7.5m, thereafter saturated soil is noted, followed by saturated and weathered biotite schist (probably residual soil from in-situ weathering of bed rock) with intermediate and isolated ground water occurrences. From the above it appears reasonably safe to assume that most of the ground ie top soil, intermediate weathered layer and bedrock all are in saturated state, which corroborates and supplements the conclusion that this could form a part of a confined aquifer.

6.5 Summary of Investigation

After detail geological, geophysical and geotechnical investigation of the study area, the summary is hereunder:

- The bed rock of the study area mostly quartz biotite schist.
- The bed rock is traversed by three principle set of joints. The joint details is hereunder

Joint Set	Dip Direction	Dip Amount	Persistenc e	Spacing	Opening/ Filling / surface condition
S1/ F	015^0-032^0	34^0 - 43^0	>10 m	Closely < 2 mm	Tightl / Smooth undulatory
S2	200^0-225^0	36^0- 54^0	5 to 8 m	2 to 5 m	Open / Nil / rough
S3	000^{0}-028^0	62^{0}-75^0	5 to 10 m	4 to 10 m	Open / Nil / rough

- There are three layer of material observed in study area these are
  - Top overburden & Slope wash material, mainly composed of crush fragmented bed rock, rock floor and silty clay. In general its depth varies from 2 to 15 meters depth.

- Highly weathered & fractured bed rock – In situ bed rock but almost crushed and in water contact it become almost slush. In general its depth varies from 6 to 25 meters depth.

- Fresh Bed rock mass – Quartz-Biotite Schist.

➢ There Engineering Parameters taken into consideration is as follows

S. No.	Material Type	GSI	C (Kpa)	Phi
1	Overburden	-	5 - 7	20^0 - 22^0
2	Highly Weathered & Crusted Bed rock mass	25 - 35	30 - 50	24^0- 26^0
3	Fresh Bed Rock Mass	40 - 50	120 - 160	36^0- 42^0

7.0 Geotechnical Evaluation

Review of all available input data from various surface and surface studies and investigations of the Mangan slide zone reveal the following factors:

1. The terrain has a general slope gradient of 25° to 30°, the slide orientation is almost due N-S with the northern boundary circumvented by the ramat kyong nallah flows at the base of the slide. With Mangan towns limits lying at the southern periphery of the slide, i.e. at its apex, hence any settlement within the slide area are bound to influence the lower slopes of the town area.

2. From the interpreted geological section prepared along the centre line of the slide and based on both core drilling and seismic profile data , it can be observed that an initial top layer of talus / slope wash debris of 7 to 8m depth is underlain by the in situ weathered rock mass , which could initially be comprising of residual soil produced as a consequence of insitu weathering of bedrock, followed by competent bedrock which would lie at considerable greater depths , but which outcrops at the eastern and southeastern periphery of the slide due to which the slope gradients are marginally steeper. Everywhere else the terrain is overlain by overburden, as deciphered from the geophysical profiling. The resistivity survey indicates complete saturation of all the constituents comprising the terrain at various levels, there appear to be no indications of surface drainage through the slide area thus conclusively suggesting that this in fact reflects a confined aquifer like condition.

3. It is also apparent that this ground mass lying at a lower level, at the base of the town, could have some subsurface channels by which it is being surcharged from a higher level.

4. The modal analysis of soil indicates almost 65% sand fraction, which would indicate moderately high permeability of the debris material, hence its water retention capacity should be reasonably greater than other medium, but the presence of considerable mica flakes would clog the inter granular spaces thus leading to restricted flow thru the mass and also explains its capacity to get waterlogged, which is indicated by the NIL water loss recorded during core drilling.

5. The more important aspect appears to be the toe erosion by the Nallah which flows along the base of the slide and which, appears to be a major contributory factor in the slope failure.

6. It has also been noted that, in general, terrains with dominant schist horizons, ie rocks of low competency and strength exhibit low surface gradients, however, the in-situ weathering is generally quite deep, particularly in tropical areas where rainfall is abundant. Steeper gradients would lead to greater slope failures due to low angle of repose of the debris material, especially in saturated state and with large boulders intermixed within the ground mass.

8.0 Design input

The limit equilibrium stability analysis has been performed using the software Phase2 developed by Rocscince. All type of soil and rock slopes, embankments, earth dams, pile sand retaining walls can be analyzed using this software.

Because the Mangan landslides consists of boulders in clay, the landslides at different places which are disrupting the local approaches and Sikkim highway and monitoring of these landslides have an issue due to the erosion instability of the unstable debris during heavy rainfall in repetitive intervals.

Mangan area landslides have multifarious causative reasons but soil and rock parameters are unique therefore mitigation and measured will be unique accept Raffong khola profile section. Mitigation and measure approach for Mangan bazaar, Sr. secondary school & Mangan bazaar Lower reach of multi-storey parking area can be treated with possible design approaches like Scaling of the debris, sub-surface / surface drainage system with pressure relief holes, enhancement of ground techniques such as bioengineering, piles, support structures etc.

Table 4: Soil and rock Engineering Parameters taken into consideration is as follows

S. No.	Material Type	Unit Wt. (Y) kN/m3	GSI	Cohesion (C) (Kpa)	Friction Angle Phi(Ø)
1	Overburden	19	_	5 - 7	200 - 220
2	Highly Weathered & Crusted Bed rock mass	20	25 - 35	30 - 50	240 - 260
3	Fresh Bed Rock Mass	18	40 - 50	120 - 160	360 - 420

8.1 The targeted safety factors are presented below:

Description	Global	
	Static	Seismic
Overall Slope Stability Check	1.30	1.00

Seismic Loading and pavement loading have been considered as under,

Seismic Coefficient (Zone - V) with Importance – 1

Horizontal Acceleration Coefficient = 0.22

Vertical Acceleration Coefficient = 0.12

Surcharge load (building etc) = 24 KPa

Pavement Loading (Live Load) = 22 KPa

8.2 Old Mangan bazaar & below SNT Complex & just adjacent to left bank of RaffongKhola

Profile section H-H' (**refer drg no. Mangan/Sikkim/SSDMA-105**) represent the area close to the left bank of RaffongKhola towards North-East of Mangan Bazar and below SNT Complex. The factor of safety, values of this area in dry, wet and surface run off hydrological conditions indicating that instability increases as wetness increases in the overburden mass along the profile section.

Area towards North-East of SNT building complex above El 1175 to El 1210 m along the Sikkim highway is stable and towards South-East area, buildings experienced cracks during 18th September, 2011 earth quake, specially the area. Area also experienced heavy rain fall during the monsoon period i.e. 19 – 23rd August of 2012. Presence of talus material and debris in the large part of the slope in this area with limited rock exposures and subsequently infiltration of surface water contributes to sinking and sliding in this area caused sizable area ofMangan –

Sungkalang bye pass road washed away. The evidence of the subsidence and sinking are quite commonly seen on the surface of the roads.

Based on the previous studies of GSI, SSDMA, present degree of susceptibility situations and identified areas is to demarcate which are more vulnerable to landslide.The thick over burden mass consistsof loose fragments and debris having high tendency to fall/slide during heavy rains which is always threat for the public transport particularly during monsoon season.

For the design approach all three sites 1 to 3 of phase -1 have same characters and soil parameters hence accept site no 4, Raffong khola upper and lower reaches. For Raffong khola design approach is considered as conventional treatment according to Soil and conservation manual, because Raffong khola have the special character of landslide it cannot be treated in one go, it requires multiple sequences of mitigation and measures.

From the previous studies and present studies even it will be appropriate if we consider it as torrential debris flow which carries huge mud water during the heavy rainfall flow with high order of velocities. Therefore, keeping in view of the criticality Raffong khola which is also identified as fault as per GSI Report. Design approach is adopted to retard the high velocity by putting the small conventional check dams and by making berms and proper drainage system in the catchment area of the Raffong khola. Design approach is discussed in below.

For the site no 1 to site no 3 following common type of approach has been envisaged by some minor changes in the individual profile sections. The Mitigation measures are as below:

1) Dressing of Top layer of scree and debris
2) Establishment of berms at different levels
3) Provision of catch drains
4) Consolidation grouting over highly fractured and weathered rock mass area
5) Ground Improvement using Multi Level Resistance of Pile System
6) Fully grouted rock anchors.
7) Provision of shot crete with wire mess
8) Pressure relief holes
9) Biotechnical stabilization / Geo-composites against erosion & weathering action
10) Non-woven Geo-textile for filtration and Separation
11) Provision of road edge protection towards Valley side
12) Protection work of Kholas/Jhoras in or around Mangan Town

- **Old Mangan bazaar & below SNT Complex & just adjacent to left bank of Raffong Khola**

1) Dressing of top layer of scree and debris:

As over burden layer of slide area comprising of scree and debris hence during the dressing of top layer utmost care shall be taken in terms of safety and security of the passers around the area. Keeping in view of dense habitation nearby, no blasting or use of any type of explosives should be permitted for dressing of top layer. However, little dressing of slope would be performed only by mechanical means. After dressing of this highly thick band, geological appreciation/ monitoring should be appraised by the expert geologist before starting the other relevant protection works and if any significant variation experienced the same should be brought into the knowledge of consultant, for review of the design and further modification accordingly.

Vegetation can be used as the slope surface cover in order to make the slope look as natural as possible. Where there is insufficient space at the crest to accommodate the cut back profile, structural supports such as hand dug caissons and retaining walls would be used to improve the stability of the slopes. For detail refer drg no. **Mangan/Sikkim/SSDMA/113**

2) Establishment of berms at different levels:

For the ease of the construction of the slope stability works, intermediate berms of suitable width and at suitable height shall be established. The width and height is variable suite to site condition which can be seen from drg no. **Mangan/Sikkim/ SSDMA /113.**

3) Provision of Catch Drains

A proper drainage system has been provided for the entire area of slide zone and a catch drain of size 1 m x 1 m is provided at the crown of cut slope to drain the rain & community water towards natural slope of the road and Raffong khola. Rest on all the benches, small collection drains of size 0.6 m x 0.6 m are also provided to collect the rain water in this area. These small collection drains finally feed its rain water to catch drain and raffong khola which further drained in the Teesta River slope. For details please refer drg no. **Mangan/Sikkim/EGE-SHEPL/113**

4) Consolidation grouting over highly fractured and weathered rock mass area

During the treatment of the surface a close monitoring is required from the Geological expert and wherever highly weak, fractured and weathered rock mass will observe after dressing of top loose debris in the whole slide area shall be treated with consolidated grouting as per the site requirements.

5) Ground Improvement using Multi Level Resistance of Pile System

For slope stability analysis using limit equilibrium methods, the soil displacement moving along a slip surface against the pile can be used to compute the axial and lateral resistance against sliding through the principles of superposition. An assumed soil displacement is applied against the pile from the ground to the slip surface. The direction of the applied soil displacement is tangent to the slip surface at the intersection of the pile. The axial and lateral components of the applied displacement are used to compute the axial and lateral resistances separately. The resultant pile resistance force at the slip surface intersection is used to satisfy force equilibrium for the selected limit equilibrium method.

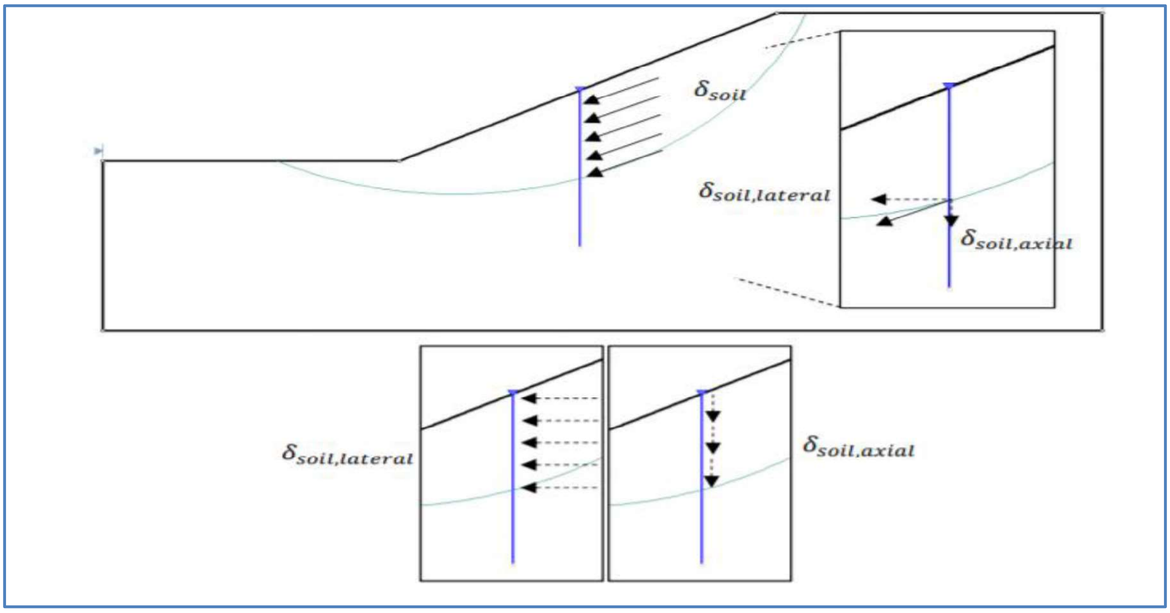


FIG 21: Mechanism of Soil Resistance by Pile System

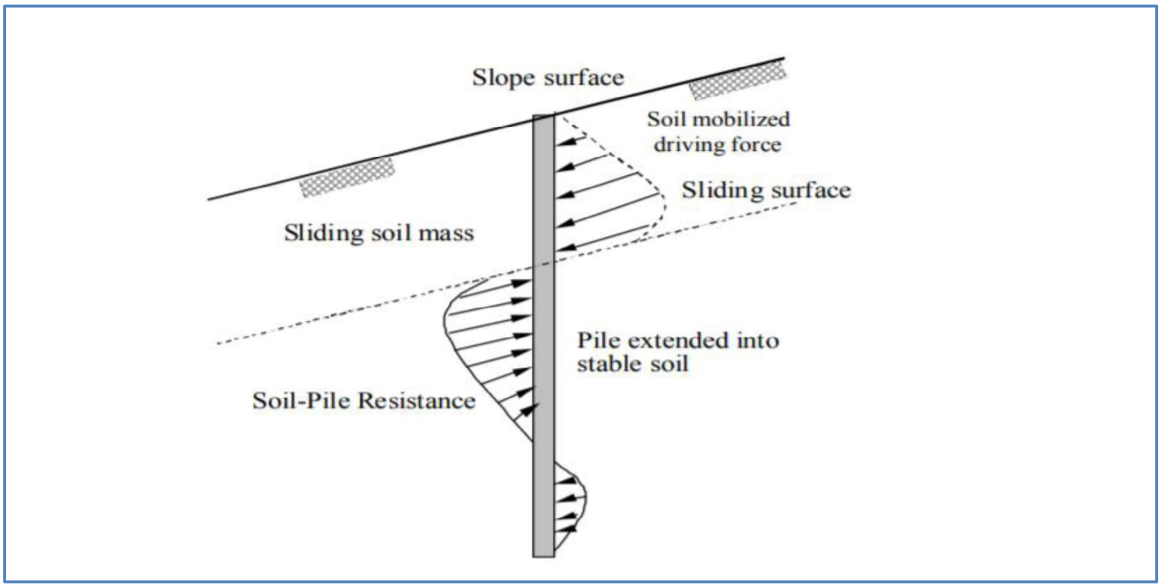


FIG 22: Driving force induced by the sliding soil mass above the sliding surface

The pile internal axial force at the sliding depth in response to the applied axial soil displacement is the axial resistance against sliding for that particular slip surface. Similarly, the internal shear force at the sliding depth in response to the applied lateral soil displacement is the lateral resistance for that particular slip surface.

The pile resistance is dependent on the depth and angle of the slip surface since this will affect the pile response from the applied displacement. As such, the pile resistance must be computed at a number of points along the pile varying the depth and angle of applied displacement at each point. Linear interpolation is used to obtain resistance values of intermediate sliding depths. The user may specify the maximum allowable soil displacement moving along any slip surface based on design tolerances to obtain the pile resistances. Alternatively, an ultimate pile resistance can be obtained by increasing the assumed soil displacement independently in the axial and lateral directions until the maximum resistances are reached.

6) Fully grouted rock anchors

Ground anchors are often used in combination with walls, horizontal beams or concrete blocks to stabilize slopes and landslides. Soil and rock anchors permit relatively deep cuts to be made for the construction of highways and can be used to provide a sufficiently large force to stabilize the mass of ground above the land slide or slip surface. This force usually considered is greater than that required to stabilize a vertical excavation for a typical highway retaining walls. Horizontal beams or concrete blocks may be used to transfer the ground anchors loads to the ground at the slope surface provided the ground does not “run” or compress and is able to resist the anchor to reaction forces at the excavated face.

In view of criticality & importance of the landslide area, 25 mm diameter 6 m long fully grouted, Rock Anchors is proposed on the slope of the landslide for proven safety aspects. The length of the rock anchor has been adopted according to IS 14448: 1997. The condition of rock is moderate to good one; hence the length of the rock anchor taken in staggered way covering overall slopes.

The diameter of the rock anchor has been envisaged as 25 mm confirming to Fe 415 grade steel as per IS : 1786. Suitable preventive measures shall be adopted to prevent corrosion depending upon aggressive nature of rock mass. For detail refer drgno.**Mangan/Sikkim/ SSDMA/113.**

7) Provision of shotcrete with wiremess

The purpose of the shotcrete with wiremess is to isolate degradable rock zones from ongoing weathering action. Shotcrete has not been considered as structural / strengthening item in the slope design for stabilization. The purpose of providing shotcrete with wire mess is to protect the exposed surface from weathering/ erosion and containing the ingress of rainwater into the rock mass to the possible extent. As the rock is of moderate nature with fractured and weathered surface, the shotcrete will help in protecting the slope from effects of local environmental variations. The minimum thickness of the shotcrete of 100 mm with wire mesh is provided as per the drg no. **Mangan/Sikkim/SSDMA/113.**

8) Pressure relief holes

Pressure relief/drainage holes will be drilled in lower slopes to prevent build up ground water pressure. Pressure relief hole shall be provided with perforated PVC pipes of size 50 mm diameter with length of pressure relief holes shall be 7 m long @ 6 m c/c both ways. For detail refer drg no. **Mangan/Sikkim/SSDMA/113**

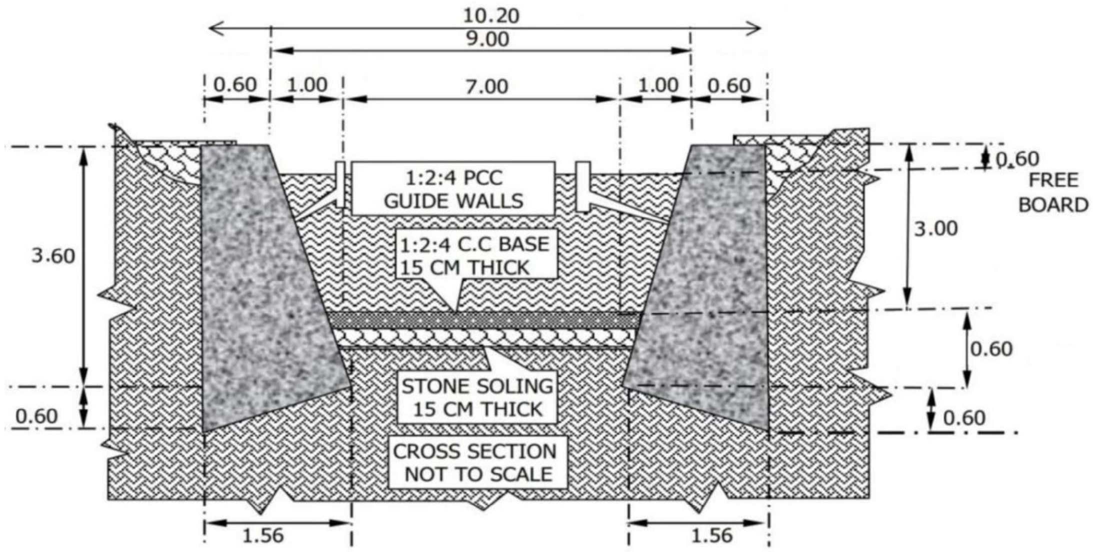
9) Biotechnical stabilization / Geo-composites against erosion & weathering action:

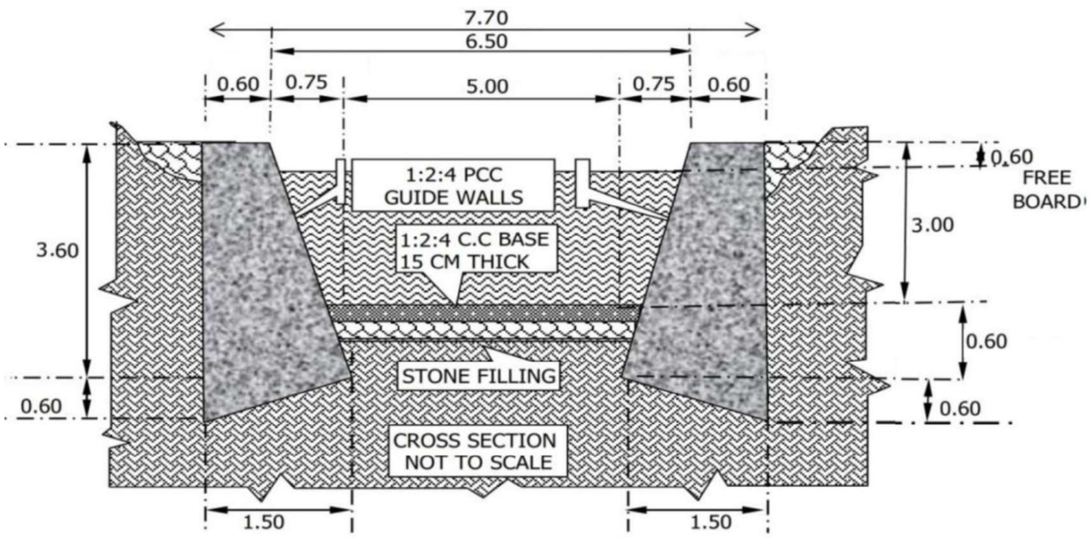
Against erosion & weathering action there are various combinations of geo-textiles, geo-grids, geo-membranes and/or other materials to serve all the primary functions with better performance. Most geo-synthetics are made from synthetic polymers such as polypropylene, polyester, polyethylene, polyamide, PVC, etc. These materials are highly resistant to biological and chemical Degradation. Natural fibbers such as cotton, jute, bamboo, etc., can be used as geo-textiles and geo-grids, especially for temporary applications. In contrast to the smooth surfaces that steel reinforcements usually have, most geo-synthetics have fabric-like surfaces (geo-textiles) or grid structures (geo-grids) that produce much better bonding between rock/soil mass and the reinforcement & installing of Geo-grids and growing vegetations. This application with suitable arrangement can be used with the approval of the site Engineer-in- charge with appropriate construction methodology suit to site conditions.

10) Protection work of Kholas/Jhoras in or around Mangan Town Design of Jhora training work at raffaong khoka

Protection of Raffong khola right from top El 1350 to about El 1100 m shall be treated where required suite to site condition and specific location shall be decided with consideration of site engineer in charge during the construction stage design.

Schematic drgs is presented as below:





5 nos check dam are considered in the Ist phase for with the delay time and retardation of the high velocity with the help of contour benching and systematic drainage system .this number can be reduced or increased during detailed design. Before detailed design proper study of design experts are required in terms of soil investigation and physical understanding.

Catchment Area of the proposed Jhora Site = 3.2 Km^2

a. As per Hydrology para 2.4.2(h) estimated peak discharge qp = 23.81 m^3/sec.

Keeping in view the factor of safety (FOS) under extreme circumstances =1.5

Adopted design flood Qp = 35.72 m^3 / sec.

b. Using Rational method $Q = \frac{API}{38}$

Where A = Catchment area in Sq. Km.

P = % of coefficient of run off (0.01 to 0,20 for forested area)

I = Intensity of rainfall in Cm/hr. in our case the maximum is 30 Cm/hr.

$$Q = \frac{3.2 \times 0.20 \times 30}{38}$$

= **0.50 cumecs**

Therefore, Design approach should be kept for extreme circumstances

Allowable safe velocity for flow in concrete lined channel 2.00 m / sec.

Discharge Q = A x V

$$A = \frac{Q}{V} = \frac{35.72}{2} = 17.86\ m^2$$

i.e. Cross-Sectional Area Required = 17.86 m^2

Assuming the width of water way 7.0 m of Trapezoidal section and side slopes taken as 1:1 according to site topography.

The height of water way is considered as 2.4 m.

Hence, considered water way channel area = 21.6 m^2

Therefore, adopted velocity V = 1.65 m /sec.

Free board of channel is considered 0.6 m

Total height of the side walls of the channel = 3.0 m

- **DESIGN FOR GUIDE WALL SECTION**

Height of wall = "H" = 2.4 + 0.6 =3.0 m

Top width of wall = 0.60 m

Unit weight of dry cohesion less back fill = "g" = 20 KN / m^3

Angle of shearing resistance = "f" = 30°

Assume the angle of friction of the wall and foundation soil as = 30

Angle of surcharge = "a" = 20°

Unit weight of stone masonry 24 KN / M^3

$$K_a = \cos\beta \times \frac{\cos\beta - \sqrt{\cos^2\beta - \cos^2\emptyset}}{\cos\beta + \sqrt{\cos^2\beta - \cos^2\emptyset}}$$

$$K_a = \cos 20° \times \frac{\cos 20° - \sqrt{\cos^2 20° - \cos^2 30°}}{\cos 20° + \sqrt{\cos^2 20° - \cos^2 30°}}$$

K_a= 0.42

$P_a = \frac{1}{2} K_a g H^2$

$P_a = \frac{1}{2} \times 0.42 \times 20 \times (3)^2$

$P_a = 37.8$ K N M

Overturning moment $M_o = 37.8 \times \frac{3}{3} = 37.8$ K N M

C,G. of the wall section AJ $= \frac{a2 + ab + b2}{3(a + b)} = \frac{(0.60)^2 + (0.60 \times 1.6) + (1.6)^2}{3 (0.60 + 1.6)}$

AJ $= \frac{3.88}{6.6} = 0.59$

	W	
1	24 x 0.60 x 3 =	43.2
2	24 x ½ x 1.3 x 3 =	36.0
	S W	79.2

MR = SW x (AB - AJ)
MR = 79.2 x (1.6 - 0.59)
MR = 80.0 KN M

F.S. against overturning $= \frac{MR}{M_O} = \frac{80}{37.8} = 2.12 > 1.50$ Hence safe

F.S. against sliding $= \frac{\mathbf{mw}}{P_a \, C_{os\ a}} = \frac{0.75 \ x \ 8}{37.8 \ x \ 0.94} = 1.69 > 1.50$ Hence safe

- **Check for tension in the masonry:**

Using the relation x $\frac{\mathbf{MR - M_o}}{\mathrm{SW}}$

Where X distance from toe at which resultant reaction acts

Therefore X $\frac{79.2 - 37.8}{79.2} = 0.52$

Now e $= \frac{AB}{2} - x$

$= \frac{1.6}{2} - 0.52$

$= 0.54 < \frac{AB}{2}$

HENCE SAFE

- **DESIGN OF DROP WALLS:**

We neglect the bed slope factor and compensate for the level difference with the help of drops at regular interval

Length of Jhora along the way = 500 m
Level Difference = (2) – (1) = 1000 m
Assuming average height of drop = 0.60 m

∴No. of drops required =833 Nos.

C/C between drops = $\frac{500}{1000}$= 0.5 Say = 0.5 m

Let scour depth be = 0.60 m
∴ Total height of the drops = 0.60 + 0.60 = 1.20 m

Let top width of drop will be = 0.60 m

Since the bed slope is negligible the drop will be designed for an surcharge condition.

Taking f = 30 °

$K_a = \frac{1 \quad -\sin f}{1 \quad + \quad \sin f} = \frac{1 \quad - \quad \sin \ 30^o}{1 \quad + \quad \sin \ 30^o} = 0.33$

P_a = ½ x K_a x g x H^2

= ½ x 0.33 x 18 $(1.20)^2$

= 4.28 KN/M

1.71 KN/M

Overturning moment M_O= 4.28 x $\frac{1.20}{3}$ = 1.71 KN/ M

CG of the wall section AJ = $\frac{a^2 + ab + b^2}{3\,(a+b)3} = \frac{(1.60)2 \; + (0.60x1.00) \; + (\; 1.00)}{3(0.60 \; + \; 1.00)2}$

= $\frac{0.36 \; + \; 0.60 \; + \; 1.00}{4.8} = \frac{1.96}{4.8}$

AJ = 0.41

	W	
1	24 x 0.60 x 1.20 =	17.28
2	24 x ½ x 0.40 x 1.20 =	5.76
	S W	23.04

MR = SW x (AB - AJ)
MR = 23.4 x (1.00 - 0.41)
MR = 13.63 KN M

F.S. against overturning =$\frac{MR}{M_O}$ = $\frac{13.63}{1.71}$ = 7.97 > 1.50 HENCE SAFE

F.S. against sliding =$\frac{mw}{P_a \, C_{os \ a}}$ = $\frac{0.75 \quad x \quad 23.04}{4.28 \quad x \quad 0.94}$= 4.30 > 1.50 HENCE SAFE

<u>Check for tension in the masonry</u>

Using the relation x $\frac{\mathbf{MR-M_o}}{SW}$

Where X distance from toe at which resultant reaction acts

Therefore X $\frac{13.63 - 1.71}{23.04}$ = 0.52

Now e = $\frac{AB}{2}$ – 0.52

= $\frac{1.00}{2}$ - 0.52

= - 0.02 < $\frac{AB}{2}$ = 0.17 HENCE SAFE

9.0 Design output

9.1 Analysis Report of Old Mangan bazaar & below SNT Complex & just adjacent to left bank of Raffong Khola

The analysis performed for slope protection at Mangan Town and adjoining area for different assumptions.

9.1.1 Overall slope stability Check cases in terms of Static and Seismic

Before presentation of result of analysis original slide geological section and after dressing of scree/ debris and excavated profile of slope with different level berms are placed below:

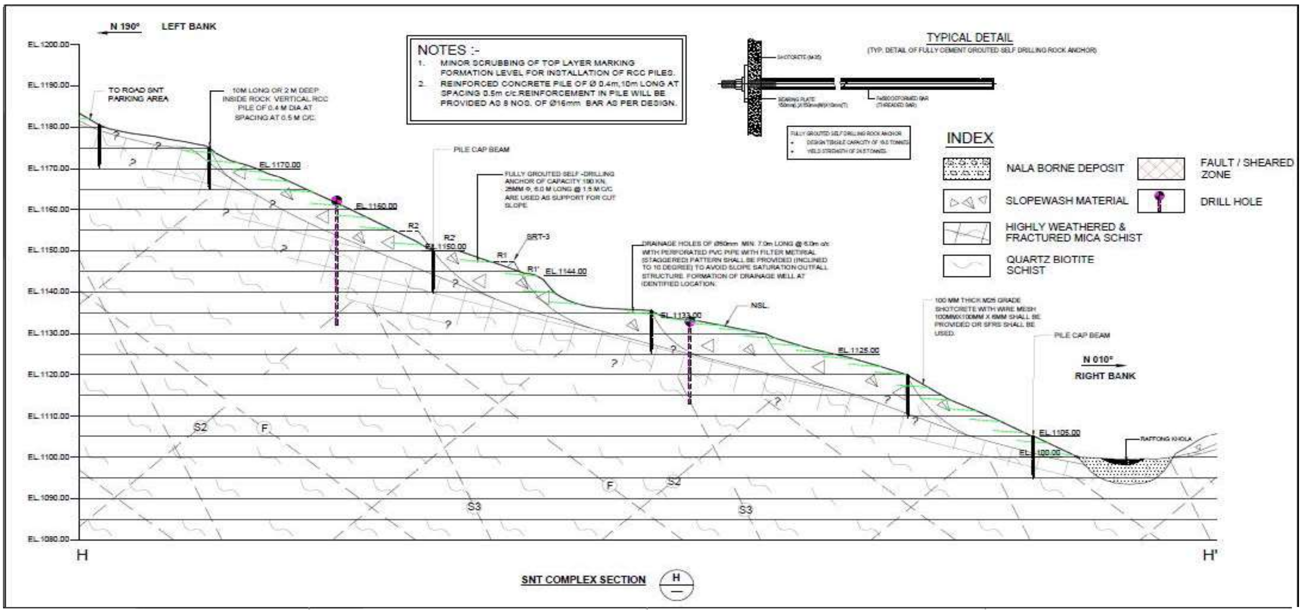


Fig. 23: Longitudinal Section of slided Area

9.1.2 ANALYSIS OF MANGAN SLIDE

The Shear Strength Reduction option in *Phase2* allows you to automatically perform a finite element slope stability analysis and compute a critical strength reduction factor for the model. The critical strength reduction factor is equivalent to the "safety factor" of the slope.

9.1.3 Overview of Method

The basic concept of the Shear Strength Reduction (**SSR**) method is actually quite simple.

1. The strength parameters of a slope are reduced by a certain factor (**SRF**), and the finite element stress analysis is computed.
2. This process is repeated for different values of strength reduction factor (**SRF**), until the model becomes unstable (the analysis results do not converge).
3. This determines the critical strength reduction factor (**critical SRF**), or safety factor, of the slope.
4. If your model includes support, note that the SSR analysis in *Phase2* is NOT applied to support properties (i.e. bolts or liners). Support strength parameters are NOT reduced during an SSR analysis and retain their original values.
5. If your model is multi-stage, note that the SSR analysis is only computed for the FINAL stage of your model. It is not computed for intermediate stages. If you want to perform the SSR analysis at an intermediate stage, you will have to reduce the Number of Stages in Project Settings to the desired stage number.
6. By default, the SSR analysis considers the stability of the entire model when the analysis is computed. However, there are circumstances when you may wish to focus on the stability of a particular area of the model. This can be accomplished with the SSR Search Area option, which allows you to apply the SSR analysis to a particular region of a model. You can also exclude regions with the SSR Exclusion Area option.
7. In general, the SSR analysis is only applicable for materials which have Material Type = Plastic.
8. When you define an SSR Search Area, what this does is effectively make the Material Type = Elastic for all finite elements which are outside of the SSR Search Area.

9. All finite elements within OR crossing an SSR Search area, are considered to be part of the SSR Search Area. Only elements which are entirely outside of a search area are given Elastic properties.

Therefore, failure can only occur within an SSR Search Area, during the SSR analysis, since all finite elements outside of the search area(s) are assumed to be Elastic.

Table 5: Material Properties Used in Analysis in Phase^2

Material Type	GSI	C kPa	φ
Overburden	-	5-7	20^0-22^0
Weathered Quartz Biotite Schist	25-35	30-50	24^0-26^0
Quartz Biotite Schist	40-50	120-160	36^0-42^0

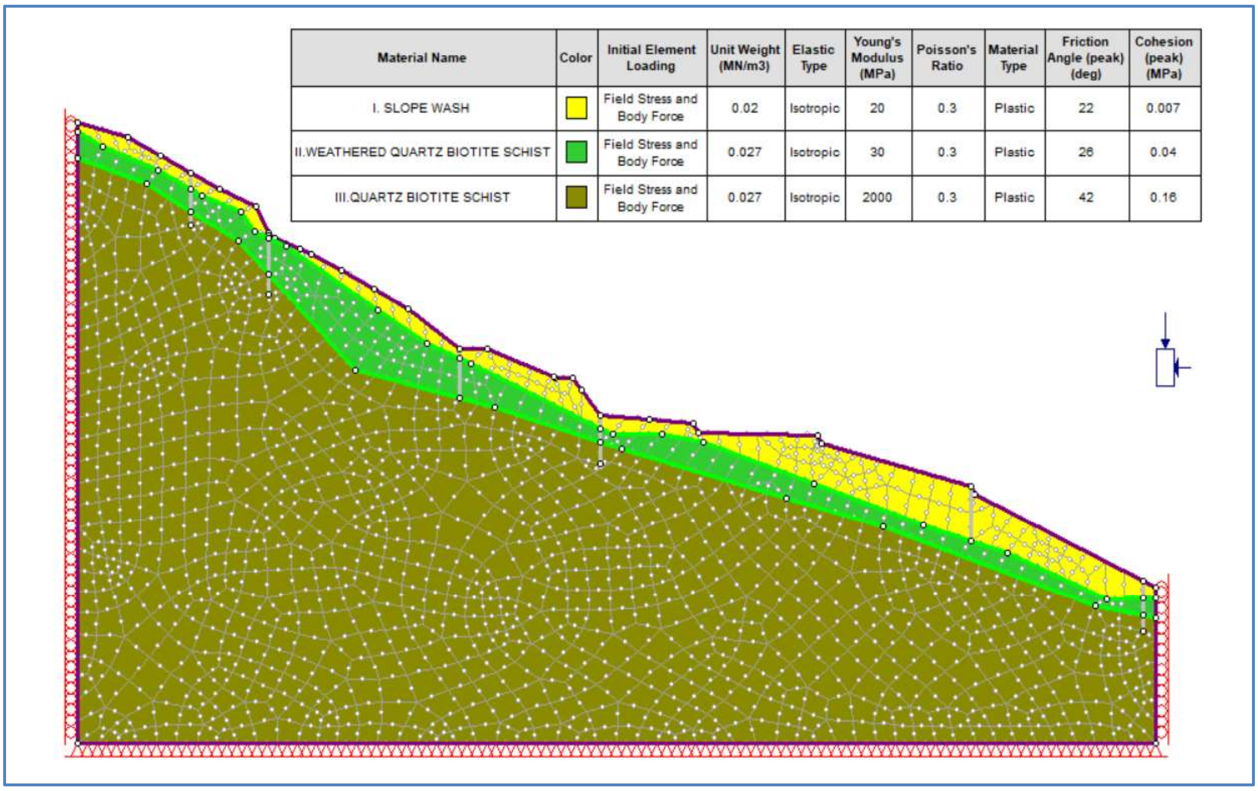


Figure 24: Discretised Model of Mangan Slide

Figure 25: FOS of Safety of Unsupported Section at Mangan (FOS=0.84)

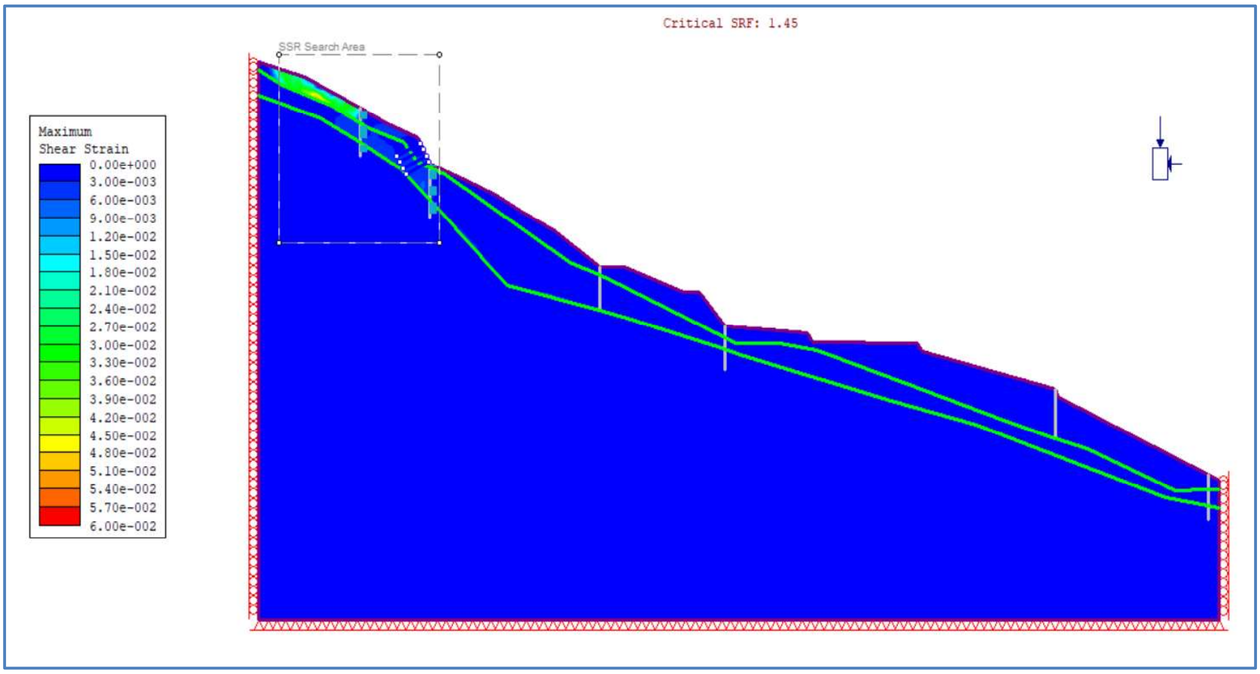


Figure 26: FOS of Safety of Mangan Slide Supported at First Level (FOS=1.45)

Support System: Support System used is 25 mm Dia, 6m long Self-Drilling Anchor along with vertical RCC pile of 0.4 m Dia at spacing at 0.5 m c/c.

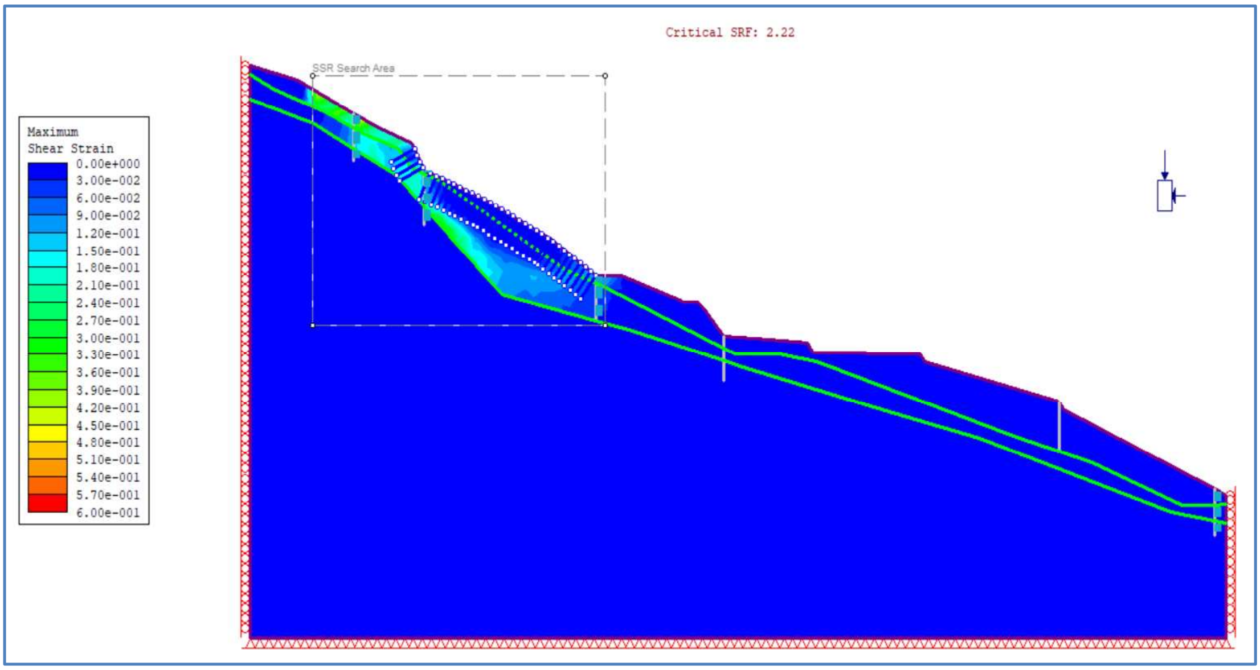


Figure 27: FOS of Safety of Mangan Slide Supported at Second Level (FOS=2.22)

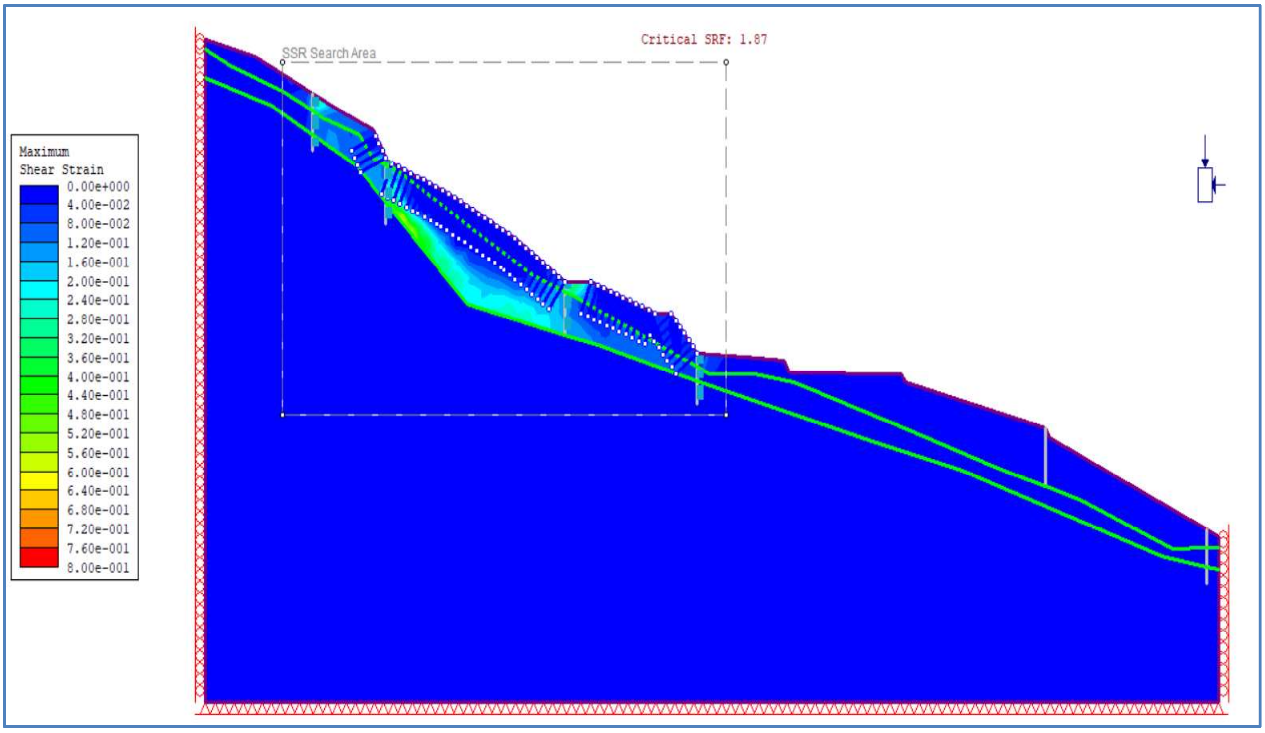


Figure 28: FOS of Safety of Mangan Slide Supported at Third Level (FOS=1.87)

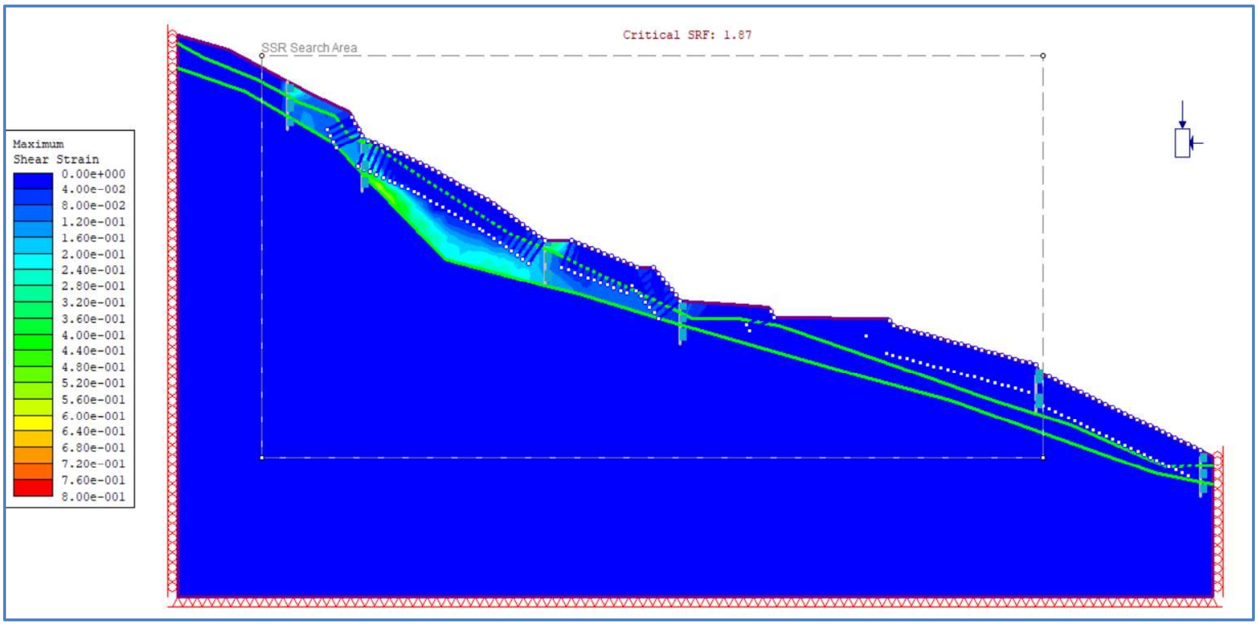


Figure 29: FOS of Safety of Mangan Slide Supported at Fourth Level (FOS=1.87)

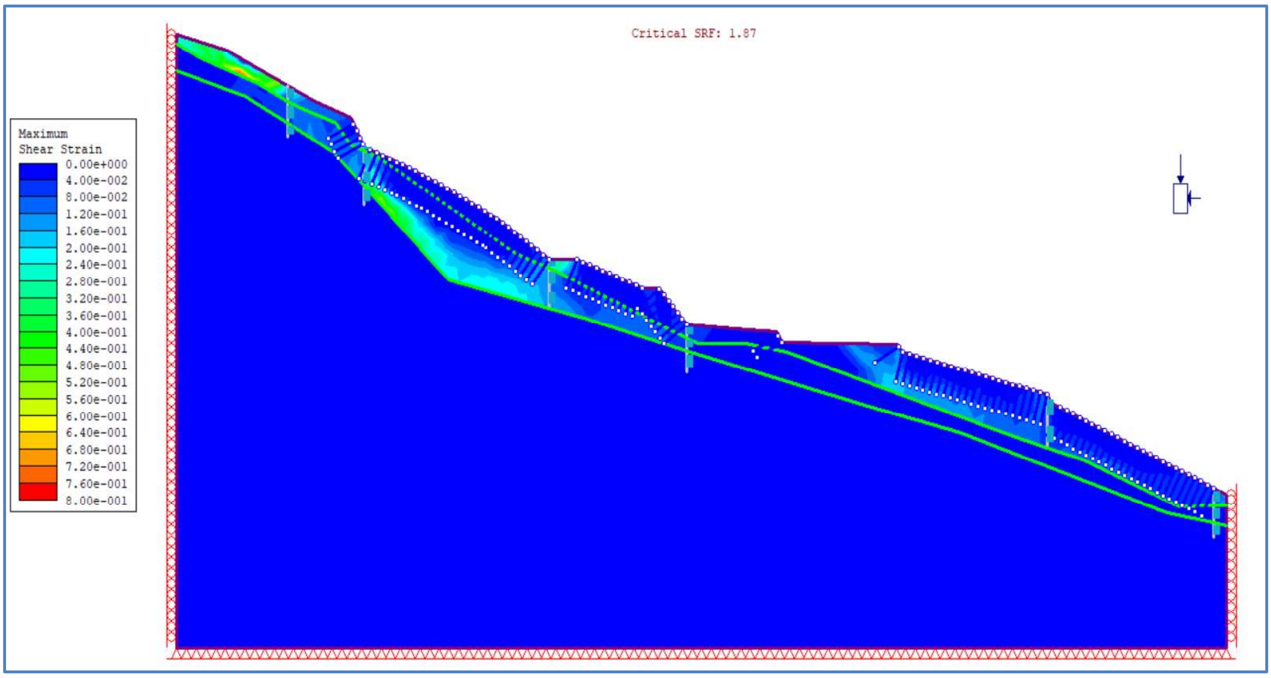


Figure 30: FOS of Safety of Mangan Slide Supported for Final Section (FOS=1.87)

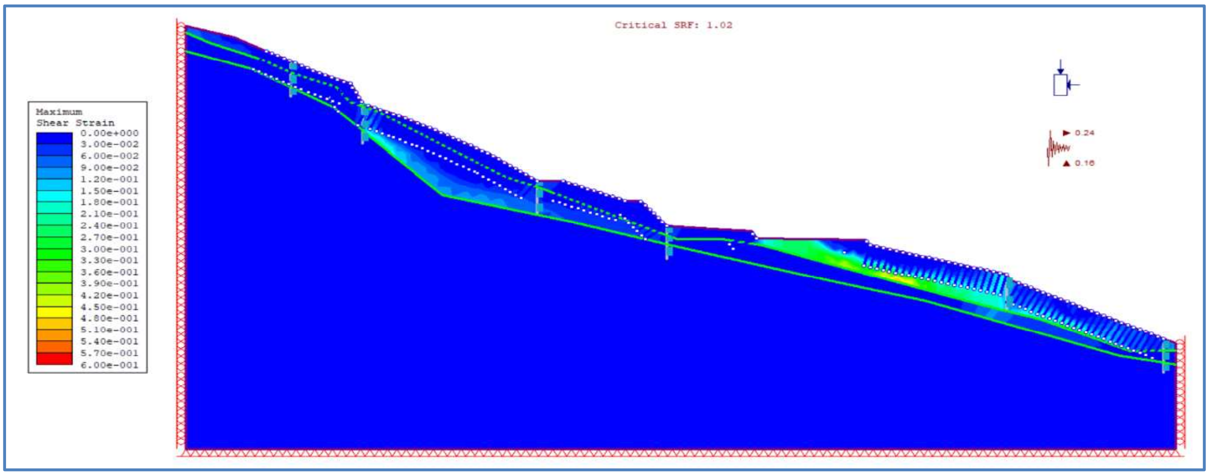


Figure 31: FOS of Safety of Mangan Slide Supported for Final Section -Seismic (FOS=1.02)

❖ **For Even Seismic case it is safe with provided support system.**

Table 6: Mangan Slide: Summary of Support recommendation

S No.	Support	Description
1	**Minor Dressing**	Minor Scrubbing of top layer marking formation level for Installation of RCC piles
2	**Self -Drilling Anchor**	Fully Grouted Self -Drilling Anchor of capacity 190 kN, 25mm Φ, 6.0 m to 8 m long staggered both ways @ 1.5 m c/c are used as support for cut slope.
3	**Shotcrete**	100 mm thick M25 Grade shotcrete with wire mesh 100mmx100mm x 6mm shall be provided or SFRS shall be used.
4	**Drainage**	Drainage holes of 50mm diameter Minimum, 7.0m long @ 6.0m c/c (staggered) shall be provided (inclined to 10 degree) to avoid slope saturation outfall structure. Formation of drainage well at identified location.
5	**RCC Pile with Pile Cap Beam**	Reinforced Concrete Pile of 0.4 m Diameter,10 m long or 2 m embedded in rock mass at spacing 0.5 m c/c. All pile shall be connected by pile cap beam of 0.6 m x0.4 m. Reinforcement in pile will be provided as 8 Nos of 16 mm Dia bar as per Design.

10.0 Cost Estimate

10.1 Introduction and Basis of Cost Estimate

The cost estimate has been presented for Mangan Landslide Area for below mentioned 4 Nos. of Sites:

i. Old Mangan bazaar & below SNT Complex & just adjacent to left bank of Raffong Khola
ii. Mangan bazaar &Lower reach of multi-storey parking area at Rinzing Namgyal Marg
iii. Surrounding area of Senior-Secondary School and close to left bank of Ruffong Khola
iv. Upper and lower reach of Raffong Khola Profile

The cost estimate has been framed broadly on the basis of "Standard Guidelines for preparation of estimate for Engineering Projects". Experience gathered during preparation of cost estimates of other projects has also been utilized to arrive at area list in cost estimate.

Cost estimate is inclusive of cost of further investigations at the project, land acquisition, camps and haulage roads required for the project, measures to mitigate impact on environment and other services and cost of civil structures. Based on investigations carried out so far as the project, designs including layout of the project have been prepared. These drawings form the basis of estimation of quantities to arrive at cost of civil structures. The rates for principal items used in the estimate have been analysed.

The rates are based on the following: -

Analysis of Rates

a) Analysis of hourly use rate of major construction equipment's which shall be used during execution of Project has been prepared on the basis of "Guidelines for preparation of project estimate for Engineering Projects" and on the basis of experience gathered during different projects.

b) Basic rates of construction materials and manpower are the basis of rate analysis of various items. Analysis for basic rates has been prepared on the basis of prevailing market rates. Transportation charges have been worked out considering the place of material supply and distance of the place of material supply from the project site.

10.2 Project Cost

Cost of the project has been estimated at January, 2015 price level is termed as present-day cost. The summary of present day cost in the form of major heads of expenditure has been provided in the abstract of cost, which is inclusive of Civil Works.

	ABSTRACT OF COST	
Sl. No.	**Item**	**Cost in INR (in Lakhs)**
A	Preliminary Works	65.00
B	Infrastructural works	50.00
	Sub Total (A)	**115.00**
	Main Civil Works	
C	Treatment works at old mangan bazaar & below SNT complex & just adjacent to left bank of raffongkhola.	826.32
D	Treatment works at Mangan bazaar & Lower reach of multi-storey parking area at RinzingNamgyal Marg.	59.61
E	Surrounding area of Senior Secondary School and close to left bank of RuffongKhola	478.181
	Sub Total (B)	**1364.111**
	Total of Works (A+B=C)	**1479.111**
	0.2% of total cost (C) is for Local Awareness**(D)**	**2.958**
	0.8% of total cost for training of locals and officials**(E)**	**11.833**
	Grand Total (C+D+E)	**1493.90**
	Rupees Forteen Crore Ninety Three Lakhs Ninety Thousand only	

A. Preliminary Works					
Sl. No.	**Description of work**	**Unit**	**Quantity**	**Price in INR**	**Amount in INR (in Lakhs)**
1	All type investigation including Topographical Survey, Geological, Geophysical and Geo-techical etc.	LS	1.00	32.85	32.85
2	Preparation of Pre Feasibility Report and DPR	LS	1.00	30.00	30.00
3	Establishment Expenses	LS	1.00	2.14	2.15
				Sub Total (A)	**65.00**

B. Infrastructural Works					
Sl. No.	**Description of work**	**Unit**	**Quantity**	**Price in INR**	**Amount in INR**
1	Temporary Haulage Roads in Project Area	LS	1.00	2.00	5.00
2	Temporary Building	LS	1.00	3.00	5.00
3	Construction of Store	LS	1.00	2.00	5.00
4	Compensation and welfare measures	LS	1.00	2.00	30.00
5	Environmental Purposes	LS	1.00	5.00	5.00
				Sub Total (B)	**50.00**

Main Civil Works					
C. TREATMENT WORKS AT OLD MANGAN BAZEER & BELOW SNT COMPLEX & JUST ADJACENT TO LEFT BANK OF RAFFONG KHOLA					
Sl. No.	**Description of work**	**Unit**	**Quantity**	**Price in INR**	**Amount in INR (in Lakhs)**
	Scaling & Dressing works				
a	Scaling&dressing of loose material in Soft rock	cum	2000	260	5.20
b	Scaling&dressing in Hard Rock in vertical wall etc.	cum	500	1400	7.00
	Landslide Treatment works				
c	32 R32N Self-Drilling Anchors anchors 6 m long complete in all respects	m	8400	2000	168.00
d	38 mm dia 6 m long pressure relief holes	m	10000	400	40.00
e	Consolidation grouting	m	650	1000	6.5
f	M25 Grade Concrete for Pile of 0.4m Dia.	Cum	3500	7000	245
g	Pile Cap Beam of 0.6 m x0.4 m	Cum	350	7000	24.50
h	Steel Reinforcement	MT	275	70/kg	192.50
i	Land scaping	LS			20.00
j	Catch Drain/Drainage System, Pits, Box culverts, RR stone masonry and concrete drains	LS	1	-	19.50
k	Provision of Shotcrete and other unforeseen site requirements, environmental budget	LS	1	-	5.00
l	Haulage Road/foot path and other misc. requirements	LS	1	-	8.00
m	T & P for slope scaling& protection measures including instrumentation.	LS	1	-	10.00
	Sub Total from (ato l)				**751.20**
n	Contingencies @ 2% of ato m	LS	1	-	15.024

o	PMC during execution @ 6% of ofato I				45.072
p	Quality & Post Monitoring cost including HM instruments @ 2% of A to I	LS	1	-	15.024
				Sub Total	**826.32**

D. TREATMENT WORKS AT MANGAN BAZAAR & LOWER REACH OF MULTI-STOREY PARKING AREA AT RINZING NAMGYAL MARG					
Sl. No.	**Description of work**	**Unit**	**Quantity**	**Price in INR**	**Amount in INR (in Lakhs)**
	Scaling & dressing works				
a	Scaling &Dressing in Soft rock	cum	4200	260	10.92
b	Excavation in Hard Rock in vertical wall etc.	cum	216	500	1.08
	Landslide Treatment works				
c	32 R32N Self Drilling Anchors anchors 6 m long complete in all respects	m	1000	2000	20.00
d	38 mm dia 6 m long pressure relief holes	m	300	400	1.20
e	Consolidation grouting	m	280	1000	2.80
	Treatment along Nala				
f	Plum concrete back filling (M7.5)	cum	20	3000	0.60
g	Concrete (M 10)	cum	40	4500	1.80
h	Plain concrete (M 15) for nalla treatment woks	cum	50	5600	2.80
i	Catch Drain/Drainage System, Pits, Box culverts, RR stone masonry and concrete drains	LS	1		5.00
j	Provision of Concrete and other unforeseen site requirements, environmental budget	LS	1	-	3.00
k	Haulage Road/foot path and other misc. requirements	LS	1	-	5.00

	Sub Total from				**54.20**
l	Contingencies @ 2% of a to k	LS	1	-	1.08
m	Quality & Post Monitoring cost including HM instruments @ 2% of a to k	LS	1	-	1.08
n	For PMC @ 6% of a to k	LS	1	-	3.25
				Sub Total	**59.61**

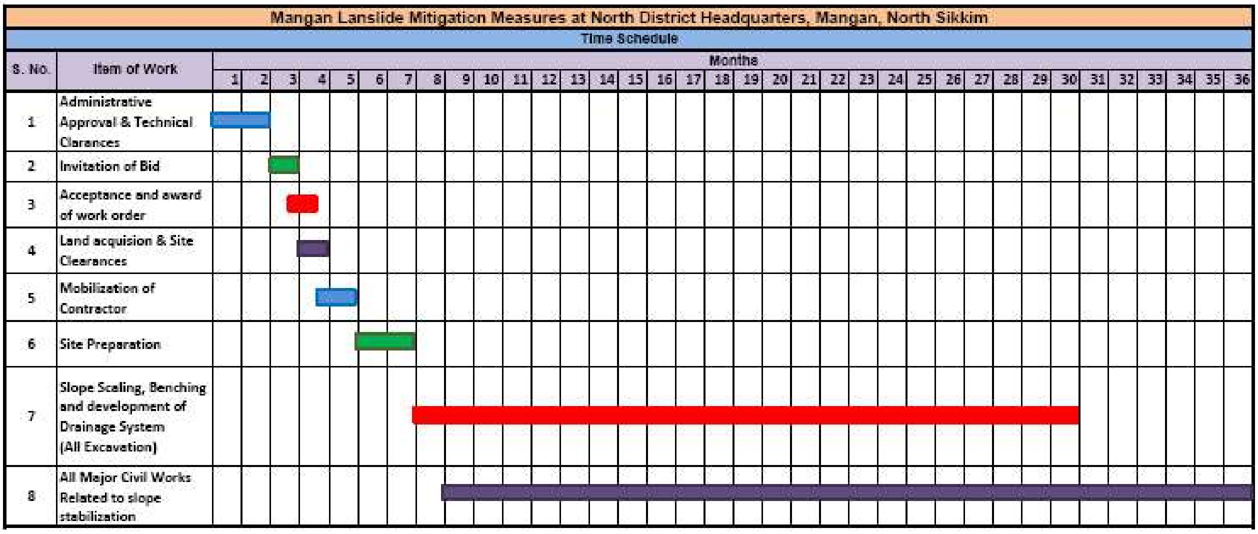
E. TREATMENT WORKS SURROUNDING AREA OF SENIOR-SECONDARY SCHOOL AND CLOSE TO LEFT BANK OF REFFONG KHOLA					
Sl. No.	**Description of work**	**Unit**	**Quantity**	**Price in INR**	**Amount in INR (in Lakhs)**
	Scaling & Dressing				
a	Scaling & Dressing in Soft rock	cum	8000	260	20.80
b	Scaling & Dressing in Hard Rock in vertical wall etc.	cum	300	500	1.50
	Landslide Treatment works				
c	32 R32N Self Drilling Anchors anchors 6 m long complete in all respects	m	1200	2000	24.00
d	38 mm dia 6 m long pressure relief holes	m	3200	400	12.80
e	Consolidation grouting	m	300	1000	3.00
f	M25 Grade Concrete for Pile of 0.4m Dia.	Cum	1500	7000	105.00
g	Pile Cap Concrete	Cum	150	7000	10.5
h	Steel Reinforcement	MT	160	70/kg	112.00
i	Land scaping	LS			20.00
j	Plum concrete back filling (M7.5)	cum	200	3000	6.00
k	Concrete (M 10)	cum	78	4500	3.51
l	Plain concrete (M 15)	cum	100	5600	5.60
m	Catch Drain/Drainage System, Pits, Box culverts, RR stone masonry and concrete drains	LS	1		75.00

n	Provision of Shotcrete and other unforeseen site requirements, environmental budget including intrumentation	LS	1	-	20.00
o	Haulage Road/foot path and other misc. requirements	LS	1	-	15.00
	Sub Total from (A to l)				**434.71**
p	Contingencies @ 2% of a to n	LS	1	-	8.6942
q	Quality & Post Monitoring cost including HM instruments @ 2% of a to n	LS	1	-	8.6942
r	For PMC @ 6% of a to n	LS	1	-	26.0826
					478.181

Note: The basic design of Rafong Khola is incorporated in detail project Report. However, as per the advice of honourable committee of NDMA, the treatment for raffong khola is not taken into consideration at this stage. Thus cost estimation is not included at this stage.

9.0 Time Schedule

The proposed time schedule is mentioned here under:



10. Construction Aspect

10.1 Access

The slide area/ rock slope excavation will require a co-ordinated set of activities between the contractor and relevant agency. To provide for stabilization as the removal/cuts of the slopes are incrementally brought down. These cyclic activities can be generalized as drill, shoot, excavation, stabilization and monitoring (if necessary).

As discussed with the contractor, there is no any specific road diversion scheme for the execution of the works at area. According to contractor the removal of debris/ scree will be carried out at night hours during which the traffic load on NH-58 remains in very low order, During the night hour works, existing NH-58 will be closed for the short time intervals for the management of removal and disposal works.

For the safety and security special manpower shall be deployed during the execution of works in day & night hours.

10.2 Monitoring

During the removal of slide material/ rock excavation and slope stabilization of the project and specific conditions during construction may differ from those observed during the site investigation. This can be the result of geological variability as well as the unpredictable success of scaling and rock excavation activities. The mitigation, designs herein included a reasonable percentage of contingency items that can be deployed to overcome such un-anticipated conditions.

To assist the region with these construction designs, it is recommended that the experienced professional Rock Slope Engineering personnel be periodically and regularly involved with the work.

10.3 Instruments & Monitoring

Monitoring of reinforced slope is essential for different parameters therefore required reasonably instruments can be installed with the permission of site Engineer- in-charge.

Selecting some specific type of site.

Data gathering and processing

Analysis data to understand the future result in the specific study area.

For landslide monitoring engineers should take surface and sub surface measurement. Surface monitoring are done with few survey pillar in the landslide zone and observed the rate of surface movement in pre monsoon, monsoon and post monsoon period.

While sub surface movement particularly shallow movement measured by installing flexible casings in boreholes through SGI rod inclinometers, Kirby's T-pegs etc, and deep surface movement are measured by chain deflect meters, single and multi point wire extensometers, insert type pipe strain meters etc. For little bit changes of landslide prone region the real time monitoring data is also essential.

Some of instruments are proposed in drgs no Mangan/Sikkim/SSDMA/114 & 115.

The early warning system can reduce the maximum losses of landslide hazard. It may possible with the inter cooperation of inhabitant, government authorities, scientific and technical communities, remote sensing techniques media and state disaster management authorities.

11. Human manpower Development Capacity Building

The challenging role of urban planners, geologist, geotechnical engineers, NGOs rescue workers, social scientist, Social workers, media and technicians are important to improve capacity building to fight against any natural calamities. For human power man power development or capacity buildings following steps are necessary:

(a) In the hilly terrain unscientific construction trigger landslide. Therefore, any construction activity should not be implemented without Government authority approval.

(b) Large sections of the society are detached from the school so government should arrange community education program free of Cost for 10 to 15 days. The specialist like the staff of SSDMA should be arranged training cum education program for inhabited like elderly, women, youth, physically challenged etc.

(c) The staffs of SSDMA are too short so it cannot reach everywhere quickly. Thus inhabited individuals, youth clubs, NGOs should encourage by the government to improve capacity building amount them to fight /self help during and after the landslide hazard.

(d) Another important step is up-gradation of capacity building among the SSDMA staffs, urban planners, architect, geological and geotechnical engineers, communication media staffs and decision makers of government bodies.

Proper land use Planning

Unscientific land use of study area also causes landslide several times. The study area belonged to geologically sensitive zone of India. But deforestation, urbanization, industrialization maximum use of resource, heavy building construction and engineering structural work etc. increases the landslide vulnerability in the study area day after day. Thus, proper scientific land use planning and Ban on non-biodegradable materials is necessary.

Landslide Management Education from School Level

Landslide Management including geo climatic region, landslide characteristics, landslide vulnerable zone, their participation in the times of landslide etc. of their own particular area should be taken as an academic compulsory subject for the local children's from primary school level education.

Village wise Training Programmed

Government should organize village wise training programmed in the study area for younger/elderly people, "What is the procedure to rescue yourself, your family and your neighbourhood in the time of landslide".

Warning Systems

Potential measure includes:

a. Landowner education on natural warning signs and self evacuation;
b. Low Level Early warning systems;
c. Regular monitoring and assessment of risk areas by qualified staff;

d. Active monitoring of rainfall forecasts and radar during events to detect any potential issues;
e. High Level Early warning systems – Low level Early warning systems plus;
f. Forwarding of all severe weather warnings to residents in risk areas (email and text alert)
g. Deployment of mobile radar to monitor areas of concern during major events;
h. Installation of wire sensors to measure land movement in all areas of high risk;
i. Rainfall sensors in all catchments;

(i) Low level event system
(a) Visual observation by residents in risk areas
(ii) High level event system
(a) Sensors connected to alarms placed in all areas with a high risk of potential landslide/debris flow
(b) Staff deployed to monitor specific sites during heavy rainfall events and warn residents if movement I slope detected.
(c) Evacuation procedures, including both formal and self evacuation.

Awareness
There is an immediate need to aware local people about the landslide to reduce losses. The State Government of Sikkim, Organization like Sikkim Disaster Management Authority (SSDMA), Local Schools, Local Hospital, Local Police, Electronic and Print Media each and every body should launch comprehensive awareness programme and campaign for the inhabited of landslide prone study areas. They do and highlight the following points:
a. They distribute handbills, posters in their regional language about the site specific details of landslide and what is the lesson they should learn from the past few landslide phenomena.
b. They prepared and display short video film, power point documentary for the local public about the importance of preparedness and mitigation method adopted by them before, during and after the landslide disaster.
c. The National Disaster Management Authority may launch power point presentation for Government organization, school and Hospital organization, local Police, NGO, Local nodal agencies, Local club, and local people. What is the role and responsibility before, during and after the landslide disaster.
d. The land and planner, urban planner should make understand the local people about the importance of land use planning. The scientist and engineer should arrange awareness camp to increase geological, geo-hydrological investigation practice for contractor. They also make understand local people about the importance and use of eco-friendly building materials in landslide prone area.
e. The State Government Universities, Colleges under the university should aware and encourage the students and research scholars to research about the new method to mitigate landslide in the hilly terrain of North Mangan District.
f. The state Government, local hospitals should aware and trained the Doctors, Nurses, all hospital staff and locals how to response in emergency period, what is the primary duty of the them etc.

Develop awareness among the inhabited about the disadvantage of non-biodegradable materials.

14.0 List of Drawings

Sr. No	Description	Drawing No.
1	Mangan Landslide Area Index / Location Map	Mangan/Sikkim/SSDMA-101
2	Mangan Landslide Area RaffongKhola Catchment Area Plan	Mangan/Sikkim/SSDMA -102
3	Mangan Landslide Area Drainage System Plan	Mangan/Sikkim/SSDMA -103
4	Mangan Landslide Area Geological Plan	Mangan/Sikkim/SSDMA -104
5	Mangan Landslide Area Geological Plan of landslide area below SNT Complex	Mangan/Sikkim/SSDMA -104A
6	Mangan Landslide Area Geological Section H-H at Old Mangan Bazar & SNT Complex Area	Mangan/Sikkim/ SSDMA -105
7	Mangan Landslide Area Geological Section J-J Mangan Bazar and below Multi-storey parking area.	Mangan/Sikkim/SSDMA -106
8	Mangan Landslide Area Geological Section G-G Surrounding Area of Sr. Secondary School	Mangan/Sikkim/SSDMA-107
9	Mangan Landslide Area Geological Section A-A along RaffongKhola from EL 2300 to EL 1820	Mangan/Sikkim/SSDMA-108
10	Mangan Landslide Area Geological Section A-A along RaffongKhola from EL 1820 to EL 1380	Mangan/Sikkim/SSDMA-109
11	Mangan Landslide Area Geological Section A-A along RaffongKhola from EL 1380 to EL 1000	Mangan/Sikkim/SSDMA-110
12	Mangan Landslide Area RaffangKhola Geological Cross Section at EL 2100 & EL 1800	Mangan/Sikkim/SSDMA-111
13	Mangan Landslide Area Geological Section at EL 1500, EL 1200 and EL 900	Mangan/Sikkim/SSDMA-112
14	Mangan Landslide Area, Old Mangan Bazar & SNT Complex- Mitigation measures Layout Plan	Mangan/Sikkim/SSDMA-113
15	Mangan Landslide Area Surrounding Area of Sr. Secondary School, Mitigation measures- Lay out plan	Mangan/Sikkim/SSDMA-114

16	Mangan Landslide Area, old Mangan Bazar & SNT Complex Mitigation Measures – Typical Plan	Mangan/Sikkim/SSDMA-114A
17	Mangan Landslide Area Surrounding Area of Sr, Secondary School Mitigation measures- L-section	Mangan/Sikkim/SSDMA-115
18	Mangan Landslide Area, Mangan Bazar and Below Multi-Storey Parking Area Mitigation measures- L-section	Mangan/Sikkim/SSDMA-116
19	Mangan Landslide AreaRaffongKhola Check Dam & Drainage System	Mangan/Sikkim/SSDMA-117
20	Mangan Landslide Area Typical Protection works details	Mangan/Sikkim/SSDMA-118
21	Mangan Landslide Area Typical Cross Sections of Drainage Systems	Mangan/Sikkim/SSDMA-119

15.0 References

- IS 1893 (Part 1) 2002, fifth edition, Indian Standard Criteria for Earthquake Resistant Design of Structures

- IS 14448 : 1997, Indian Standard Code for Practice for Reinforcement of Rock Slopes with Plane Wedge Failure

- IS 456 : 1978, Code of Practice for Plain and Reinforced Concrete (3rd Revision)

- IS 4031 (Part 5) : 1988, Method of Physical Test for Hydraulic Cement : Part 5 Determination of Initial and Final Setting Time (1st Revision)

- IS 11309 : 1985, Method for Conducting Pull Out Test for Anchor Bars and Rock Bolts

- AECOM Detailed Project Report on Geological Assessment Studies along the Project Road, September, 2014

- AECOM Detailed Project Report for Re-designing, Rehabilitation and Up-gradation to 2 Lane of NH-58 , September, 2015

- Rock Mass Rating system Table (After Bieniawski 1989)

- Hoek, E and Bray, J.W. (1974, 1977, 1981) Rock slope Engineering Institute of Mining and Metallurgy, London

- Practical Rock Engineering, by Dr. Evert Hoek (2007 ed.)

DRAWINGS

NOTE:

1. ALL DIMENSIONS AND LEVELS ARE IN METER.

DETAIL PROJECT REPORT (DPR) ON MANGAN LANDSLIDES MITIGATION AT NORTH DISTRICT HEADQUARTERS, MANGAN, NORTH SIKKIM

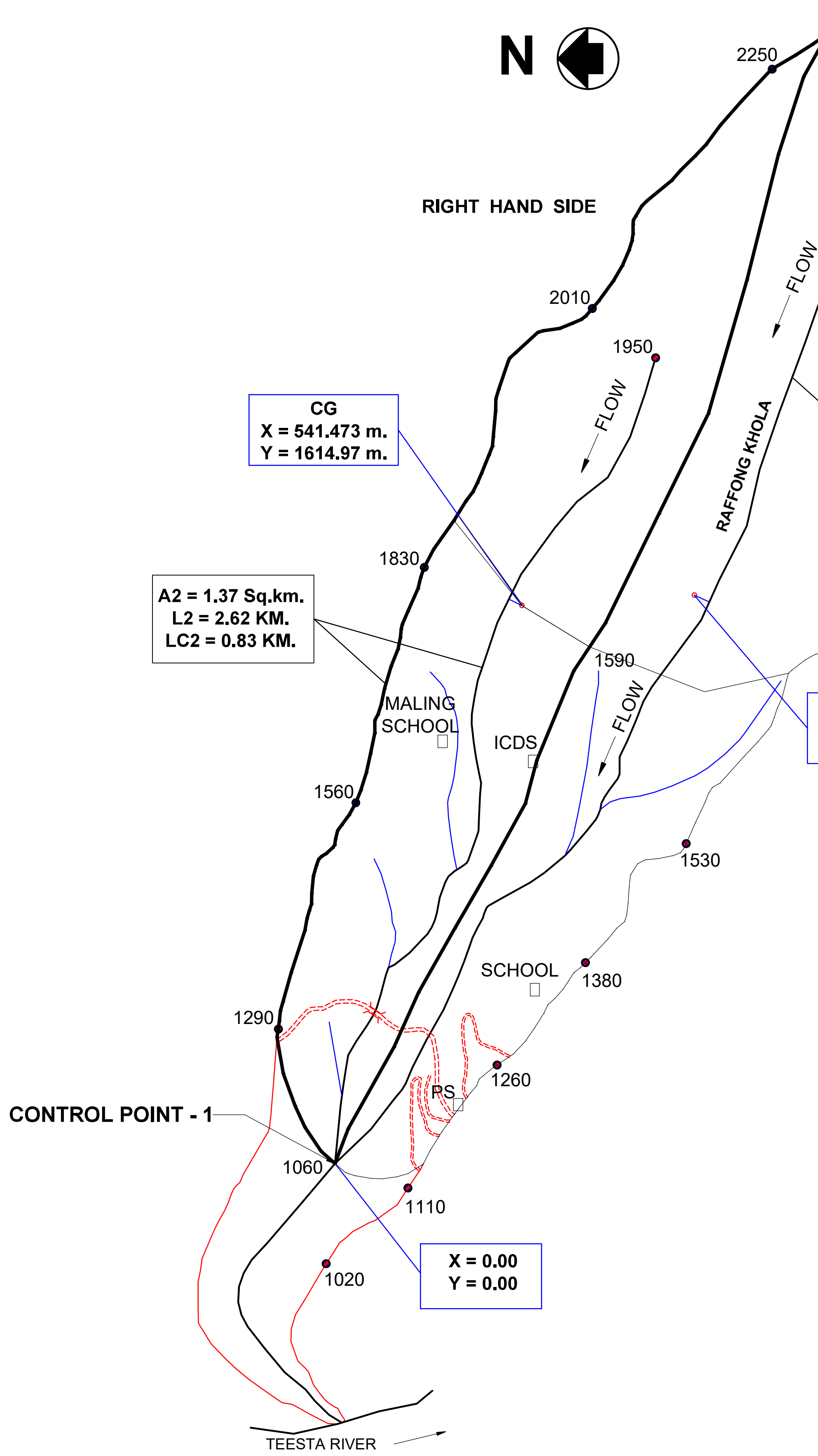
LAND REVENUE & DISASTER MANAGEMENT DEPARTMENT
GOVERNMENT OF SIKKIM

MANGAN LANDSLIDES AREA
INDEX / LOCATION MAP

SCALE: NTS

DATE	DESCRIPTION	DRAWN	SUBTD.	APPD.
30.05.2018				

DATE:	DRG.NO.	REV.
MAY, 2018	Mangan/Sikkim/SSDMA-101	



CONTROL POINT - 1 CATCHMENT AREA DETAILS:

S.NO	DESCRIPTION	AREA IN Sq.Km.
1.	LEFT SIDE FORK CATCHMENT AREA	1.57
2.	RIGHT SIDE FORK CATCHMENT AREA	1.37
3.	BELOW CONTROL POINT - 1 CATCHMENT AREA	0.26
4.	RAFFONG KHOLA TOTAL CATCHMENT AREA	3.20
5.	RAFFONG KHOLA LEFT & RIGHT FORK CONFLUENCE SITE CATCHMENT AREA AT CONTROL POINT SITE	2.94
6.	RIGHT HAND STREAM LENGTH AT CONFLUENCE	2.62 km.
7.	LEFT HAND STREAM LENGTH AT CONFLUENCE	3.70 km.
8.	RIGHT HAND LEVEL DIFFERENCE	1950 - 1060 = 890 m.
9.	LEFT HAND LEVEL DIFFERENCE	2340 - 1060 = 1280 m.

LEGENDS:

S.NO	DESCRIPTION	SYMBOL
1.	MAJOR NALA / MINOR NALA	
2.	MAIN ROAD	
3.	SPOT LEVEL	
4.	BRIDGE	
5.	VILLAGES	

NOTE:

1. ALL DIMENSIONS AND LEVELS ARE IN METER.

SCALE:

0 175 350 525 700 875 m.

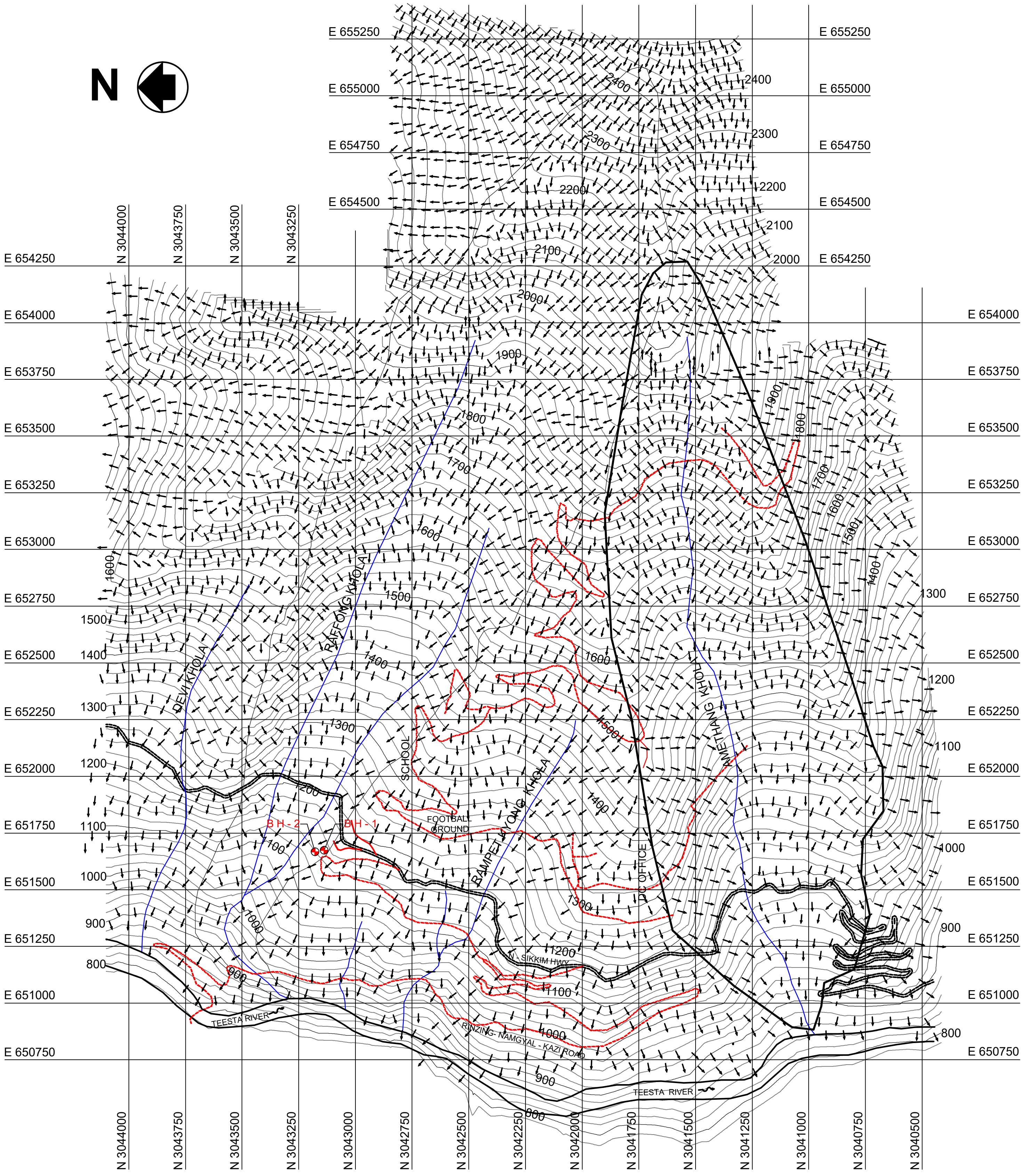
DATE	DESCRIPTION	DRAWN	SUBTD.	APPD.
30.05.2018				

DETAIL PROJECT REPORT (DPR) ON MANGAN LANDSLIDES MITIGATION AT NORTH DISTRICT HEADQUARTERS, MANGAN, NORTH SIKKIM

LAND REVENUE & DISASTER MANAGEMENT DEPARTMENT
GOVERNMENT OF SIKKIM

MANGAN LANDSLIDE AREA
RAFFONG KHOLA
CATCHMENT AREA PLAN

DATE:	DRG.NO.	REV.
MAY, 2018	Mangan/Sikkim/SSDMA-102	



SCALE:

0 250 500 750 1000 1250 m.

NOTE:

1. ALL DIMENSIONS AND LEVELS ARE IN METER.

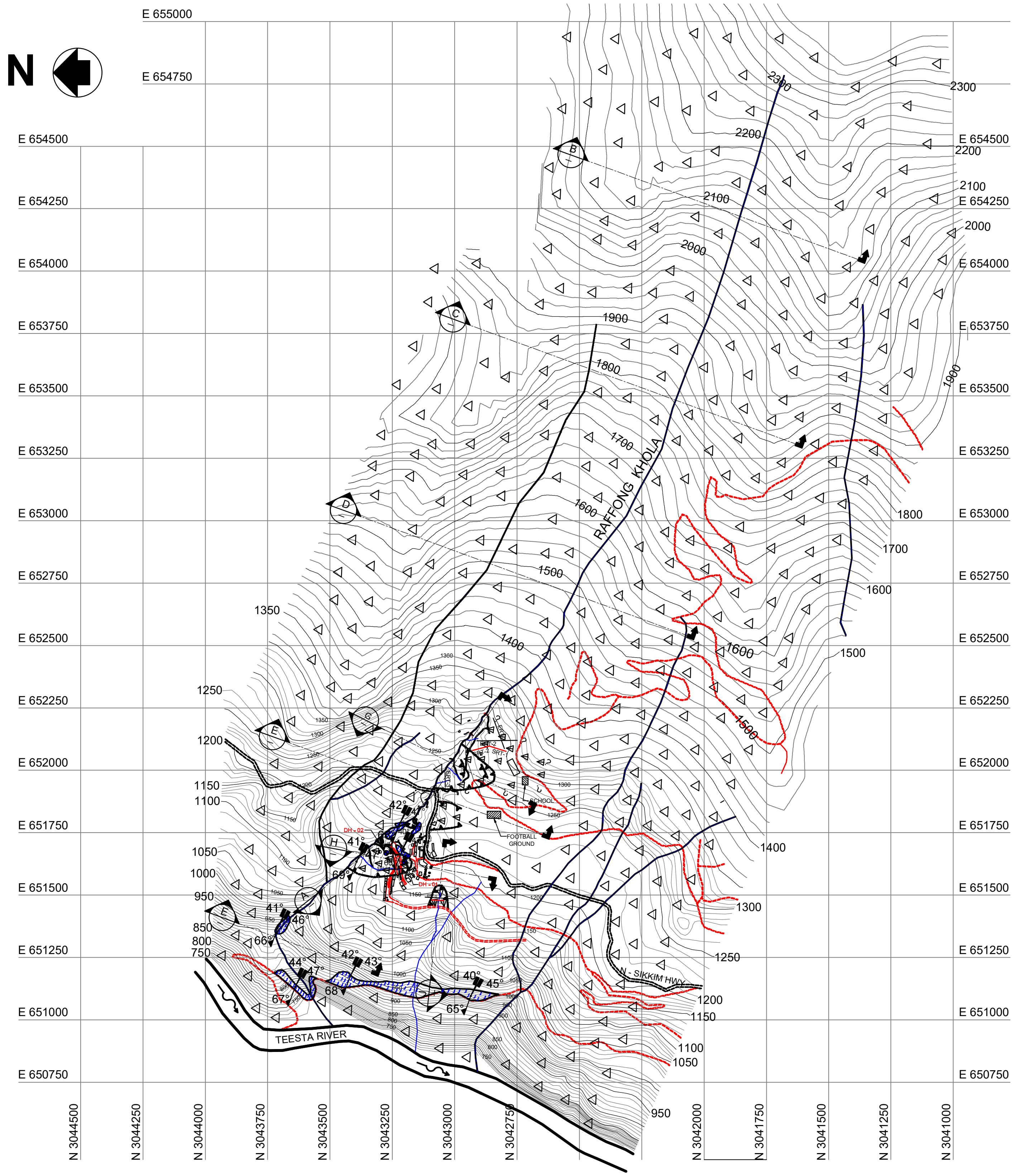
DATE	DESCRIPTION	DRAWN	SUBTD.	APPD.
30.05.2018				

DETAIL PROJECT REPORT (DPR) ON MANGAN LANDSLIDES MITIGATION AT NORTH DISTRICT HEADQUARTERS, MANGAN, NORTH SIKKIM

LAND REVENUE & DISASTER MANAGEMENT DEPARTMENT
GOVERNMENT OF SIKKIM

MANGAN LANDSLIDE AREA
DRAINAGE SYSTEM PLAN

DATE:	DRG.NO.	REV.
MAY, 2018	Mangan/Sikkim/SSDMA-103	



INDEX

- NALA BORNE DEPOSIT
- SLOPEWASH MATERIAL
- SLIDE DEBRIS
- QUARTZ BIOTITE SCHIST
- ROCK BOUNDARY
- JOINTS ORIENTATION (DIP & STRIKE)
- SLIDE ZONE
- NALA (KHOLA)
- ROAD
- SECTION LINE
- DRILL HOLE

NOTE:

1. ALL DIMENSIONS AND LEVELS ARE IN METER.

SCALE: 0 100 200 300 400 500 m.

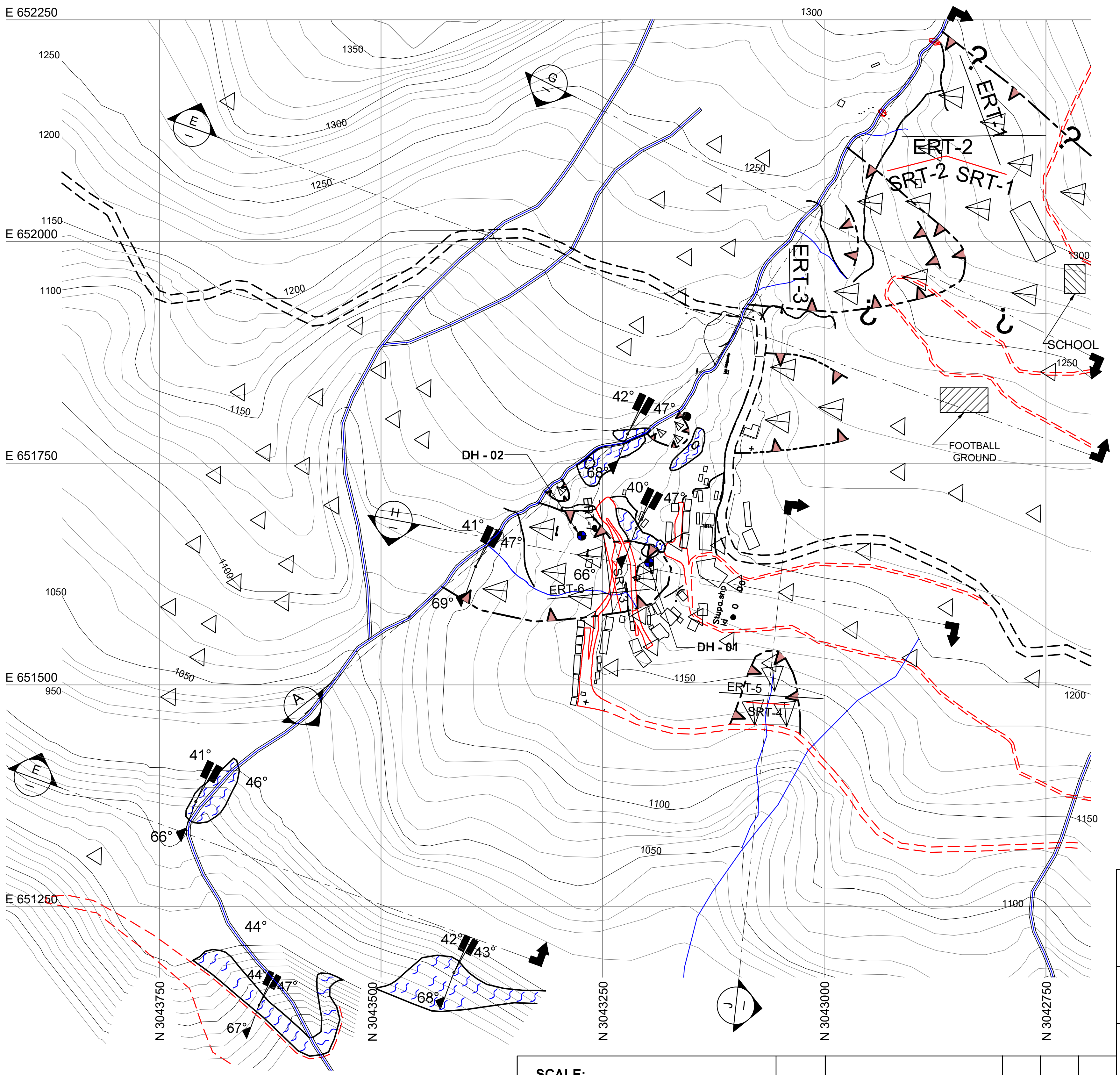
DATE	DESCRIPTION	DRAWN	SUBTD.	APPD.
30.05.2018				

DETAIL PROJECT REPORT (DPR) ON MANGAN LANDSLIDES MITIGATION AT NORTH DISTRICT HEADQUARTERS, MANGAN, NORTH SIKKIM

LAND REVENUE & DISASTER MANAGEMENT DEPARTMENT
GOVERNMENT OF SIKKIM

MANGAN LANDSLIDE AREA
GEOLOGICAL PLAN

DATE:	DRG.NO.	REV.
MAY, 2018	Mangan/Sikkim/SSDMA-104	



INDEX

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- SLOPEWASH MATERIAL
- SLIDE DEBRIS
- QUARTZ BIOTITE SCHIST
- ROCK BOUNDARY
- JOINTS ORIENTATION (DIP & STRIKE)
- SLIDE ZONE
- NALA (KHOLA)
- ROAD
- SECTION LINE
- DRILL HOLE

NOTE:

1. ALL DIMENSIONS AND LEVELS ARE IN METER.

SCALE: 0 50 100 150 200 250 m.

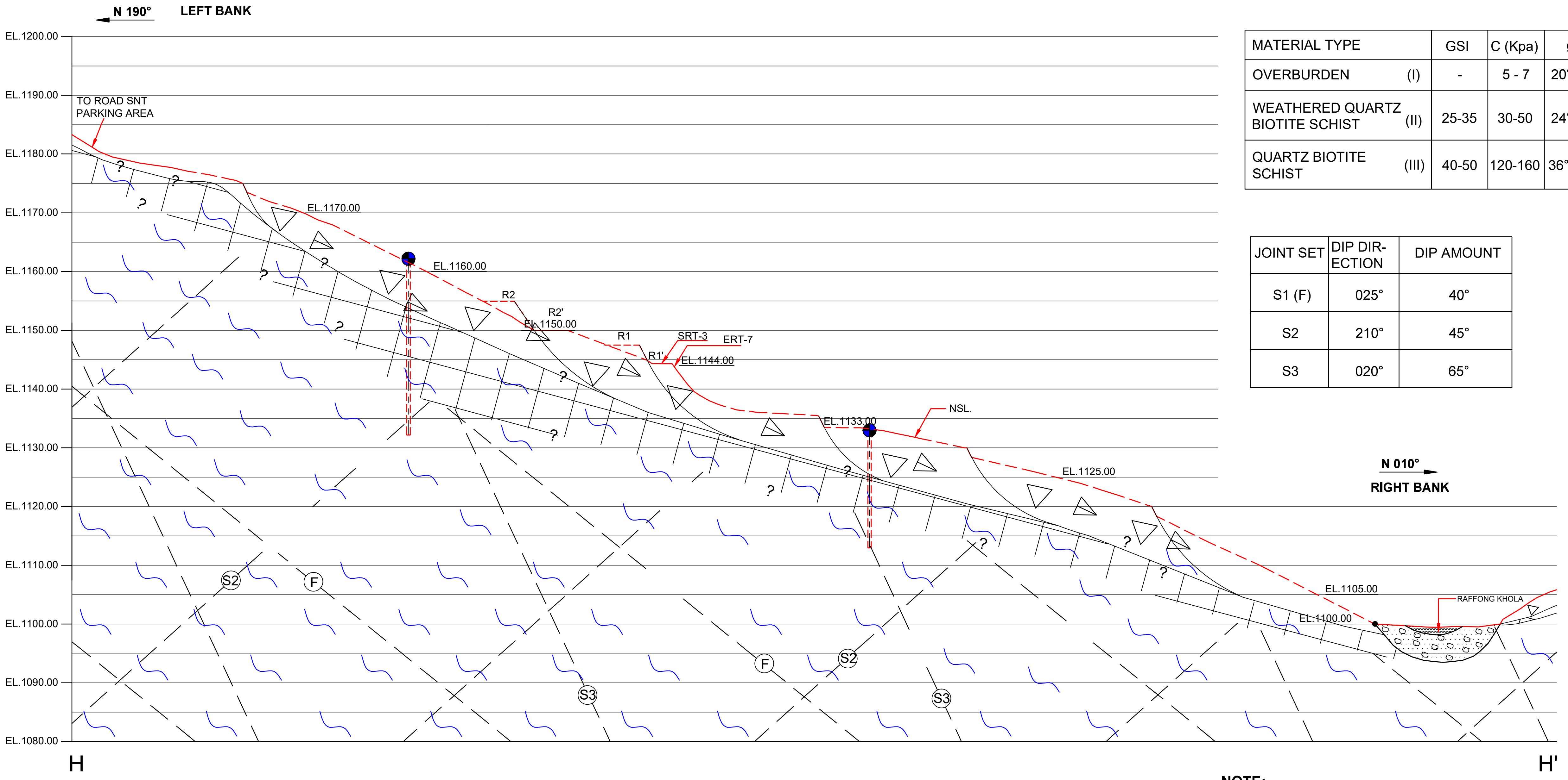
DATE	DESCRIPTION	DRAWN	SUBTD.	APPD.
30.05.2018				

DETAIL PROJECT REPORT (DPR) ON MANGAN LANDSLIDES MITIGATION AT NORTH DISTRICT HEADQUARTERS, MANGAN, NORTH SIKKIM

LAND REVENUE & DISASTER MANAGEMENT DEPARTMENT
GOVERNMENT OF SIKKIM

MANGAN LANDSLIDE AREA
GEOLOGICAL PLAN

DATE:	DRG.NO.	REV.
MAY, 2018	Mangan/Sikkim/SSDMA-104A	



MATERIAL TYPE		GSI	C (Kpa)	Ø
OVERBURDEN	(I)	-	5 - 7	20°-22°
WEATHERED QUARTZ BIOTITE SCHIST	(II)	25-35	30-50	24°-26°
QUARTZ BIOTITE SCHIST	(III)	40-50	120-160	36°- 42°

JOINT SET	DIP DIR-ECTION	DIP AMOUNT
S1 (F)	025°	40°
S2	210°	45°
S3	020°	65°

SNT COMPLEX SECTION H —

NOTE:

1. ALL DIMENSIONS AND LEVELS ARE IN METER.

INDEX

- NALA BORNE DEPOSIT
- SLOPEWASH MATERIAL
- HIGHLY WEATHERED & FRACTURED MICA SCHIST
- QUARTZ BIOTITE SCHIST
- DRILL HOLE

SCALE: 0 5 10 15 20 25 m.

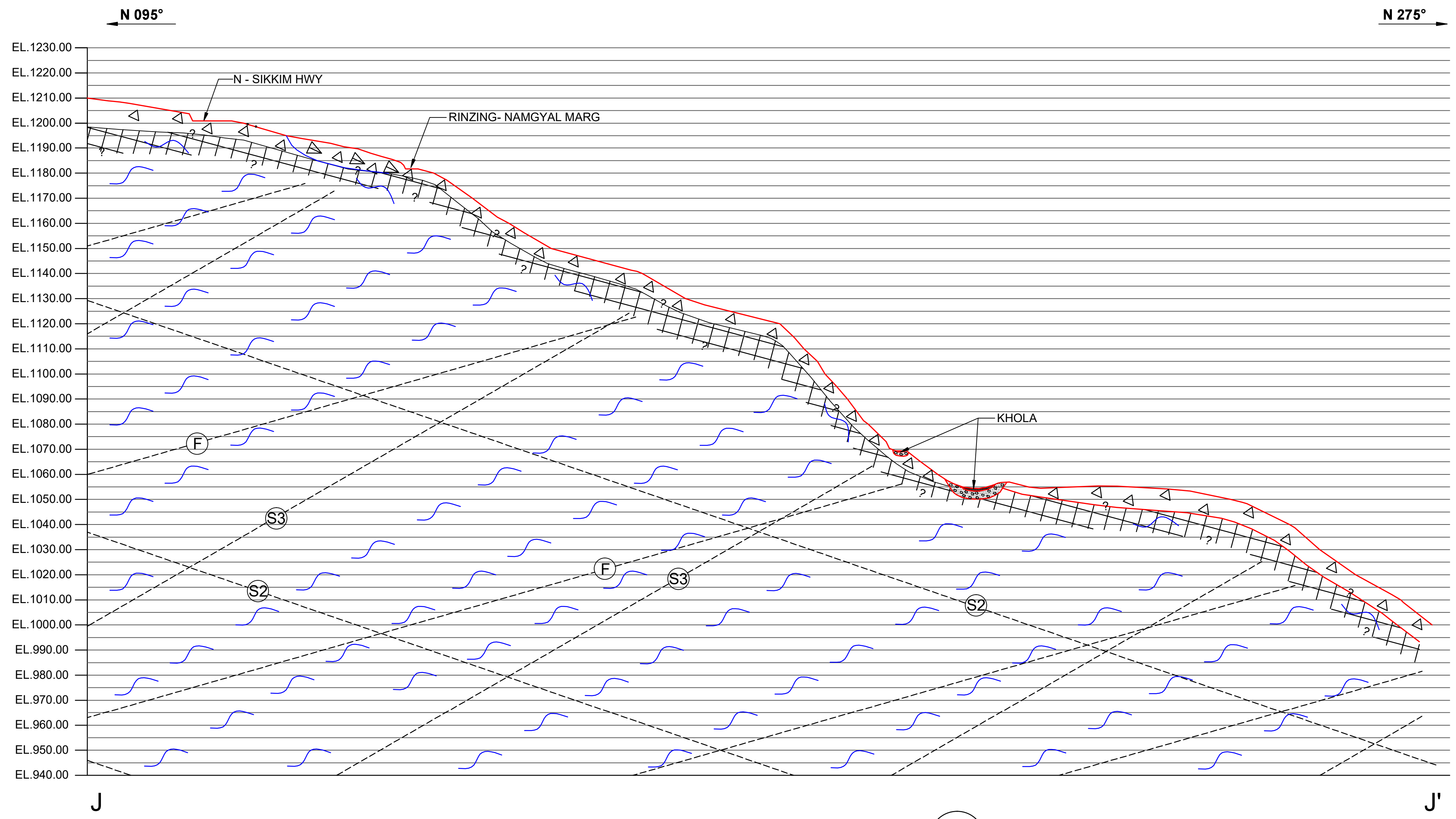
30.05.2018				
DATE	DESCRIPTION	DRAWN	SUBTD.	APPD.

DETAIL PROJECT REPORT (DPR) ON MANGAN LANDSLIDES MITIGATION AT NORTH DISTRICT HEADQUARTERS, MANGAN, NORTH SIKKIM

LAND REVENUE & DISASTER MANAGEMENT DEPARTMENT
GOVERNMENT OF SIKKIM

MANGAN LANDSLIDE AREA
GEOLOGICAL SECTION H-H
AT OLD MANGAN BAZAR & SNT COMPLEX AREA

DATE:	DRG.NO.	REV.
MAY, 2018	Mangan/Sikkim/SSDMA-105	



JOINT SET	DIP DIRECTION	DIP AMOUNT
S1 (F)	025°	40°
S2	210°	45°
S3	020°	65°

SECTION J

GEOLOGICAL SECTION BELOW PARKING AREA

NOTE:

1. ALL DIMENSIONS AND LEVELS ARE IN METER.

INDEX

- NALA BORNE DEPOSIT
- SLOPEWASH MATERIAL
- HIGHLY WEATHERED & FRACTURED MICA SCHIST
- QUARTZ BIOTITE SCHIST

MATERIAL TYPE		GSI	C (Kpa)	Ø
OVERBURDEN	(I)	-	5 - 7	20°-22°
WEATHERED QUARTZ BIOTITE SCHIST	(II)	25-35	30-50	24°-26°
QUARTZ BIOTITE SCHIST	(III)	40-50	120-160	36°- 42°

DETAIL PROJECT REPORT (DPR) ON MANGAN LANDSLIDES MITIGATION AT NORTH DISTRICT HEADQUARTERS, MANGAN, NORTH SIKKIM

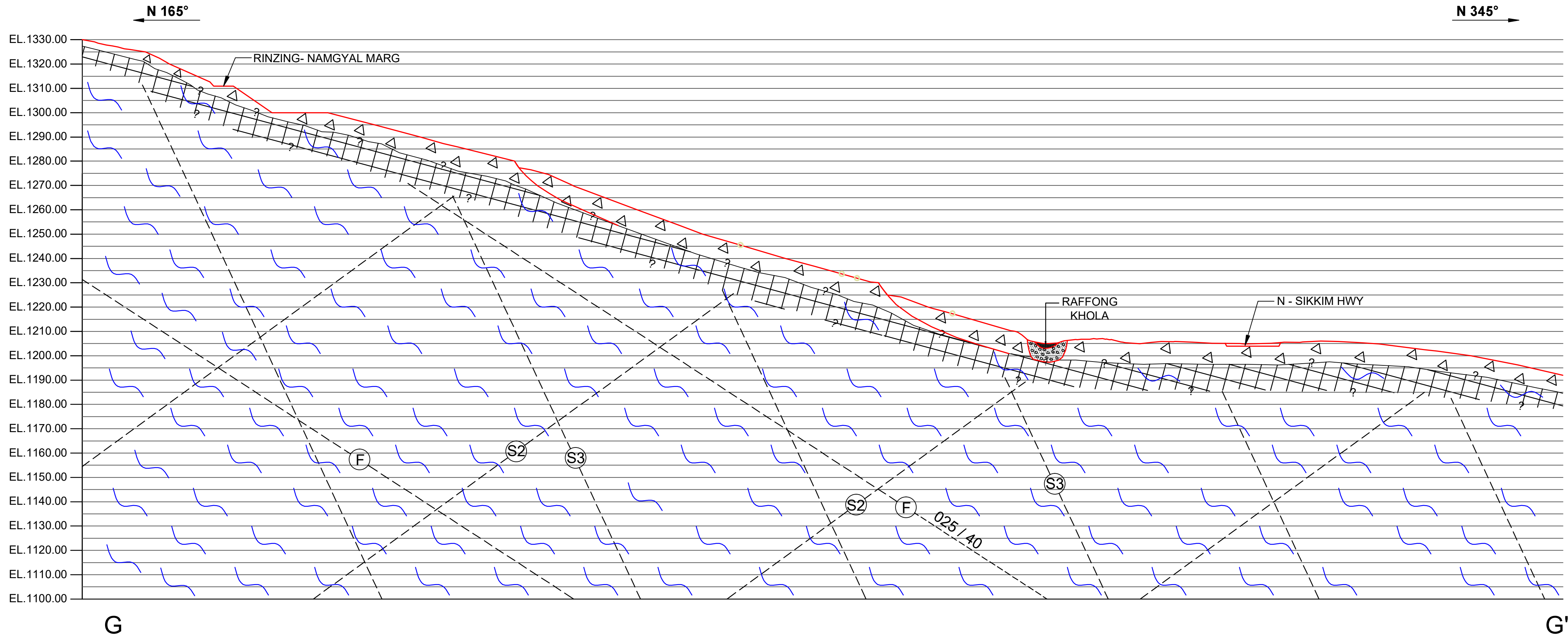
LAND REVENUE & DISASTER MANAGEMENT DEPARTMENT
GOVERNMENT OF SIKKIM

MANGAN LANDSLIDE AREA
GEOLOGICAL SECTION J-J
MANGAN BAZAR AND BELOW MULTI-STOREY PARKING AREA

SCALE: 0 10 20 30 40 50 m.

DATE	DESCRIPTION	DRAWN	SUBTD.	APPD.
30.05.2018				

DATE:	DRG.NO.	REV.
MAY, 2018	Mangan/Sikkim/SSDMA-106	



SECTION G

GEOLOGICAL SECTION
SR. SECONDARY SCHOOL

INDEX

- NALA BORNE DEPOSIT
- QUARTZ BIOTITE SCHIST
- SLOPEWASH MATERIAL
- HIGHLY WEATHERED & FRACTURED MICA SCHIST

NOTE:

1. ALL DIMENSIONS AND LEVELS ARE IN METER.

MATERIAL TYPE		GSI	C (Kpa)	Ø
OVERBURDEN	(I)	-	5 - 7	20°-22°
WEATHERED QUARTZ BIOTITE SCHIST	(II)	25-35	30-50	24°-26°
QUARTZ BIOTITE SCHIST	(III)	40-50	120-160	36°- 42°

JOINT SET	DIP DIR-ECTION	DIP AMOUNT
S1 (F)	025°	40°
S2	210°	45°
S3	020°	65°

SCALE: 0 10 20 30 40 50 m.

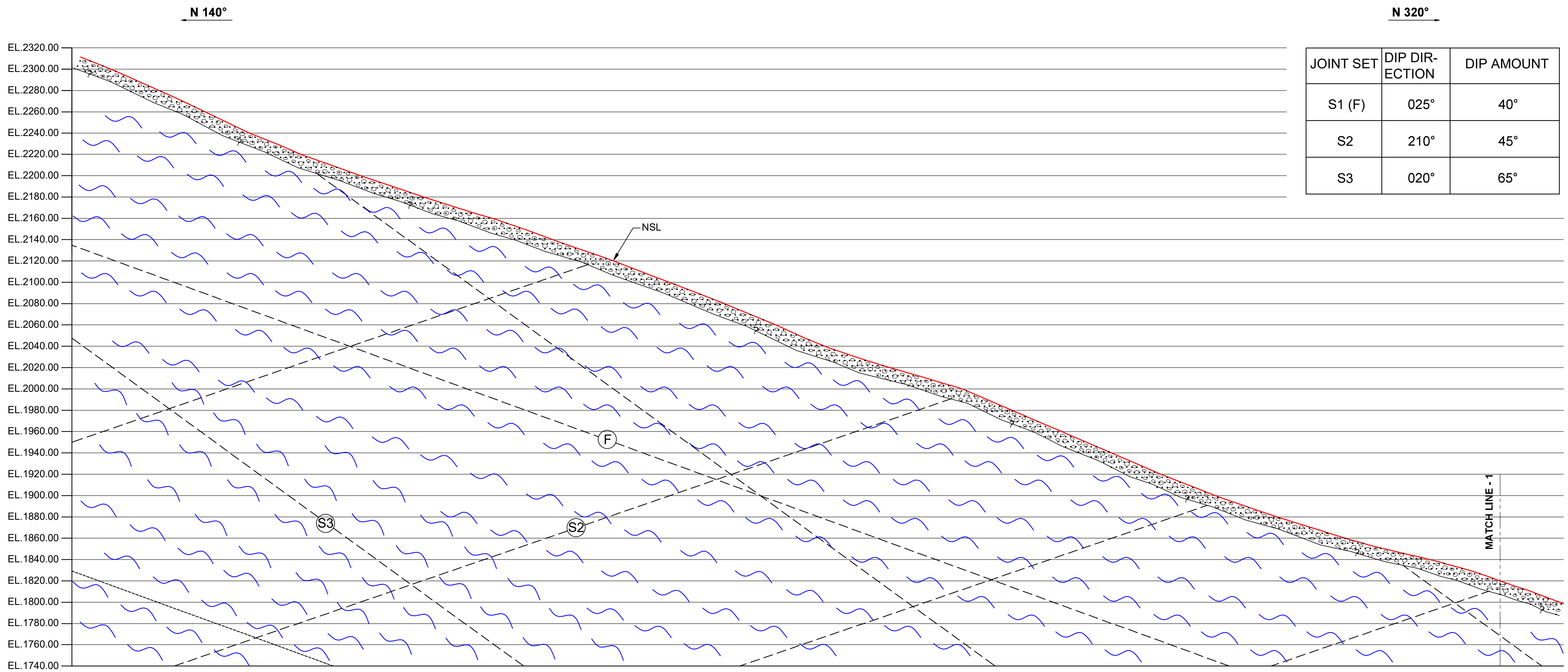
DATE	DESCRIPTION	DRAWN	SUBTD.	APPD.
30.05.2018				

DETAIL PROJECT REPORT (DPR) ON MANGAN LANDSLIDES MITIGATION AT NORTH DISTRICT HEADQUARTERS, MANGAN, NORTH SIKKIM

LAND REVENUE & DISASTER MANAGEMENT DEPARTMENT
GOVERNMENT OF SIKKIM

MANGAN LANDSLIDE AREA
GEOLOGICAL SECTION G-G
SURROUNDING AREA OF Sr. SECONDARY SCHOOL

DATE: **MAY, 2018** | DRG.NO. **Mangan/Sikkim/SSDMA-107** | REV.



JOINT SET	DIP DIR-ECTION	DIP AMOUNT
S1 (F)	025°	40°
S2	210°	45°
S3	020°	65°

SECTION A/—

GEOLOGICAL SECTION RAFFONG KHOLA

NOTE:

1. ALL DIMENSIONS AND LEVELS ARE IN METER.

INDEX

NALA BORNE DEPOSIT

QUARTZ BIOTITE SCHIST

MATERIAL TYPE		GSI	C (Kpa)	Ø
OVERBURDEN	(I)	-	5 - 7	20°-22°
WEATHERED QUARTZ BIOTITE SCHIST	(II)	25-35	30-50	24°-26°
QUARTZ BIOTITE SCHIST	(III)	40-50	120-160	36°- 42°

SCALE:

0 20 40 60 80 100 m.

DATE	DESCRIPTION	DRAWN	SUBTD.	APPD.
30.05.2018				

DETAIL PROJECT REPORT (DPR) ON MANGAN LANDSLIDES MITIGATION AT NORTH DISTRICT HEADQUARTERS, MANGAN, NORTH SIKKIM

LAND REVENUE & DISASTER MANAGEMENT DEPARTMENT GOVERNMENT OF SIKKIM

MANGAN LANDSLIDE AREA

GEOLOGICAL SECTION A-A

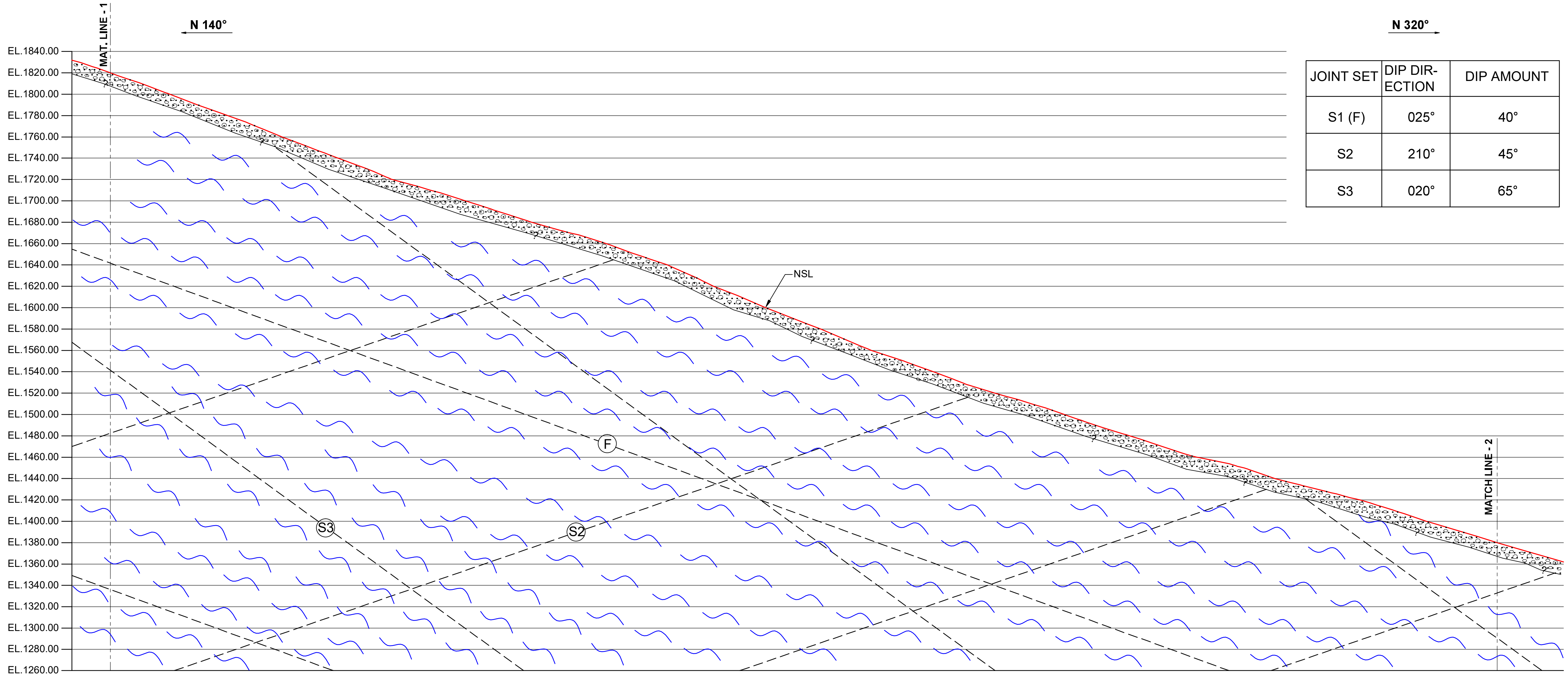
ALONG RAFFONG KHOLA FROM EL 2300 TO EL 1820

SHEET 1 OF 3

DATE: MAY, 2018

DRG.NO. Mangan/Sikkim/SSDMA-108

REV.



JOINT SET	DIP DIR-ECTION	DIP AMOUNT
S1 (F)	025°	40°
S2	210°	45°
S3	020°	65°

SECTION A

GEOLOGICAL SECTION
RAFFONG KHOLA

NOTE:

1. ALL DIMENSIONS AND LEVELS ARE IN METER.

INDEX

- NALA BORNE DEPOSIT
- QUARTZ BIOTITE SCHIST

MATERIAL TYPE		GSI	C (Kpa)	Ø
OVERBURDEN	(I)	-	5 - 7	20°-22°
WEATHERED QUARTZ BIOTITE SCHIST	(II)	25-35	30-50	24°-26°
QUARTZ BIOTITE SCHIST	(III)	40-50	120-160	36°- 42°

SCALE:

0 20 40 60 80 100 m.

DATE	DESCRIPTION	DRAWN	SUBTD.	APPD.
30.05.2018				

DETAIL PROJECT REPORT (DPR) ON MANGAN LANDSLIDES MITIGATION AT NORTH DISTRICT HEADQUARTERS, MANGAN, NORTH SIKKIM

LAND REVENUE & DISASTER MANAGEMENT DEPARTMENT
GOVERNMENT OF SIKKIM

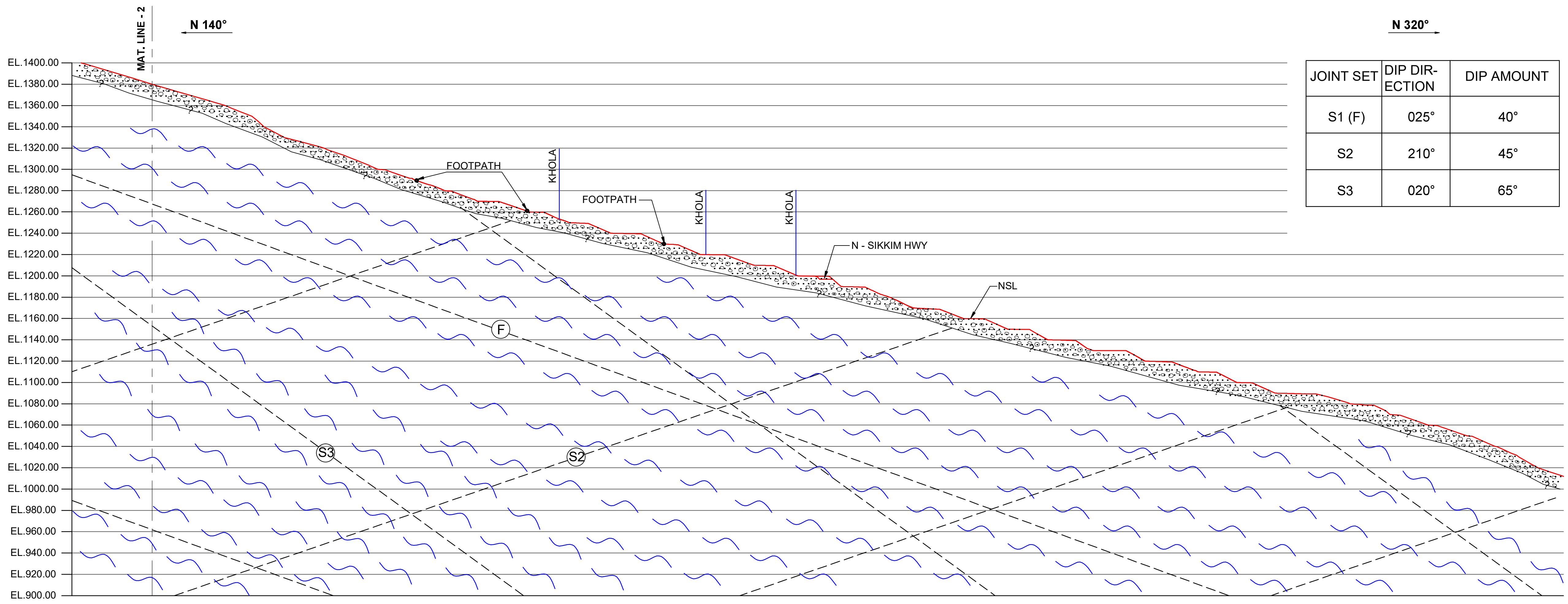
MANGAN LANDSLIDE AREA
GEOLOGICAL SECTION A-A
ALONG RAFFONG KHOLA FROM EL 1820 TO EL 1380

SHEET 2 OF 3

DATE: MAY, 2018

DRG.NO. Mangan/Sikkim/SSDMA-109

REV.



JOINT SET	DIP DIR-ECTION	DIP AMOUNT
S1 (F)	025°	40°
S2	210°	45°
S3	020°	65°

SECTION A

GEOLOGICAL SECTION
RAFFONG KHOLA

NOTE:

1. ALL DIMENSIONS AND LEVELS ARE IN METER.

INDEX

- NALA BORNE DEPOSIT
- QUARTZ BIOTITE SCHIST

MATERIAL TYPE		GSI	C (Kpa)	Ø
OVERBURDEN	(I)	-	5 - 7	20°-22°
WEATHERED QUARTZ BIOTITE SCHIST	(II)	25-35	30-50	24°-26°
QUARTZ BIOTITE SCHIST	(III)	40-50	120-160	36°- 42°

SCALE:

0 20 40 60 80 100 m.

DATE	DESCRIPTION	DRAWN	SUBTD.	APPD.
30.05.2018				

DETAIL PROJECT REPORT (DPR) ON MANGAN LANDSLIDES MITIGATION AT NORTH DISTRICT HEADQUARTERS, MANGAN, NORTH SIKKIM

LAND REVENUE & DISASTER MANAGEMENT DEPARTMENT
GOVERNMENT OF SIKKIM

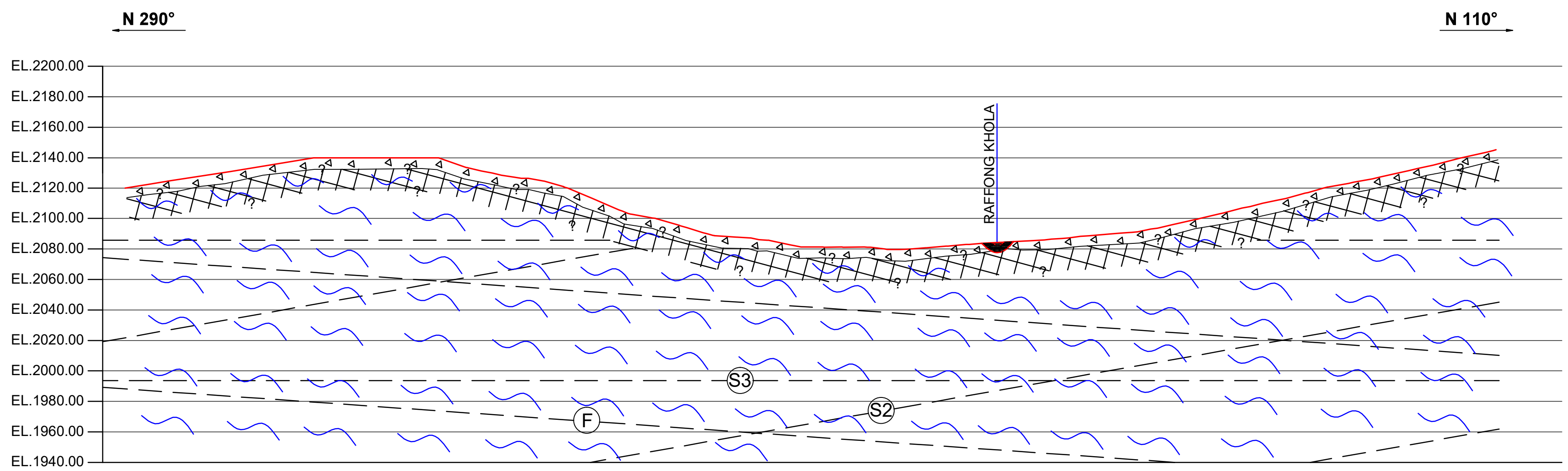
MANGAN LANDSLIDE AREA
GEOLOGICAL SECTION A-A
ALONG RAFFONG KHOLA FROM EL 1380 TO EL 1000

SHEET 3 OF 3

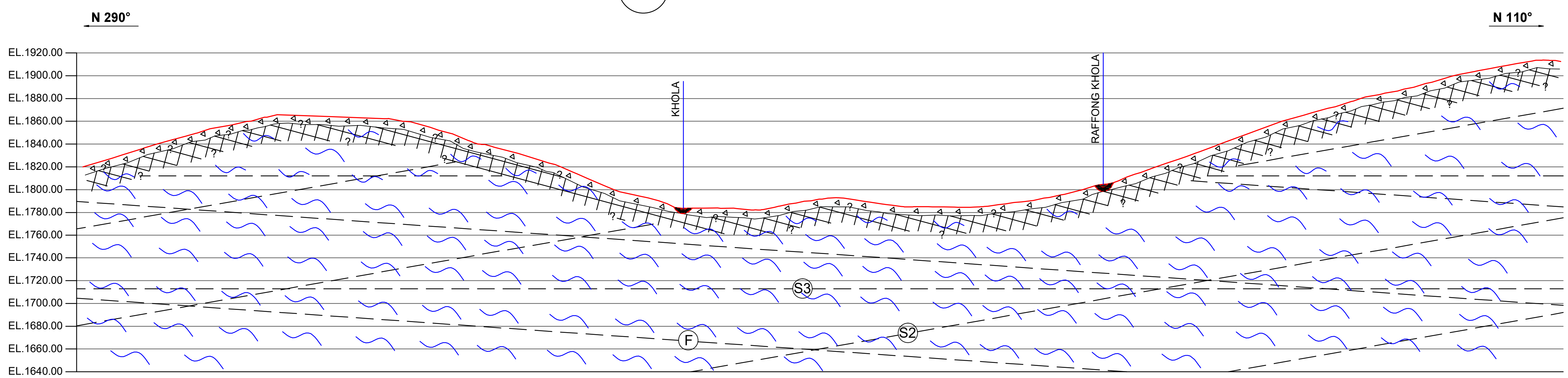
DATE: MAY, 2018

DRG.NO. Mangan/Sikkim/SSDMA-110

REV.



SECTION AT EL. 2100 (B)



SECTION AT EL. 1800 (C)

JOINT SET	DIP DIR-ECTION	DIP AMOUNT
S1 (F)	025°	40°
S2	210°	45°
S3	020°	65°

NOTE:

1. ALL DIMENSIONS AND LEVELS ARE IN METER.

INDEX

- NALA BORNE DEPOSIT
- SLOPEWASH MATERIAL
- HIGHLY WEATHERED & FRACTURED MICA SCHIST
- QUARTZ BIOTITE SCHIST

MATERIAL TYPE		GSI	C (Kpa)	Ø
OVERBURDEN	(I)	-	5 - 7	20°-22°
WEATHERED QUARTZ BIOTITE SCHIST	(II)	25-35	30-50	24°-26°
QUARTZ BIOTITE SCHIST	(III)	40-50	120-160	36°- 42°

SCALE:

0 20 40 60 80 100 m.

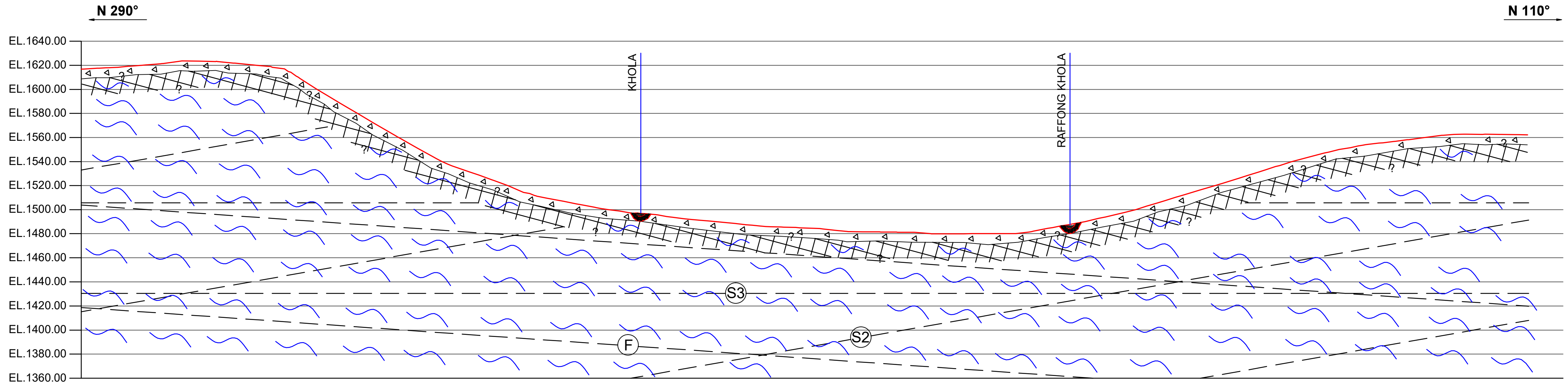
DATE	DESCRIPTION	DRAWN	SUBTD.	APPD.
30.05.2018				

DETAIL PROJECT REPORT (DPR) ON MANGAN LANDSLIDES MITIGATION AT NORTH DISTRICT HEADQUARTERS, MANGAN, NORTH SIKKIM

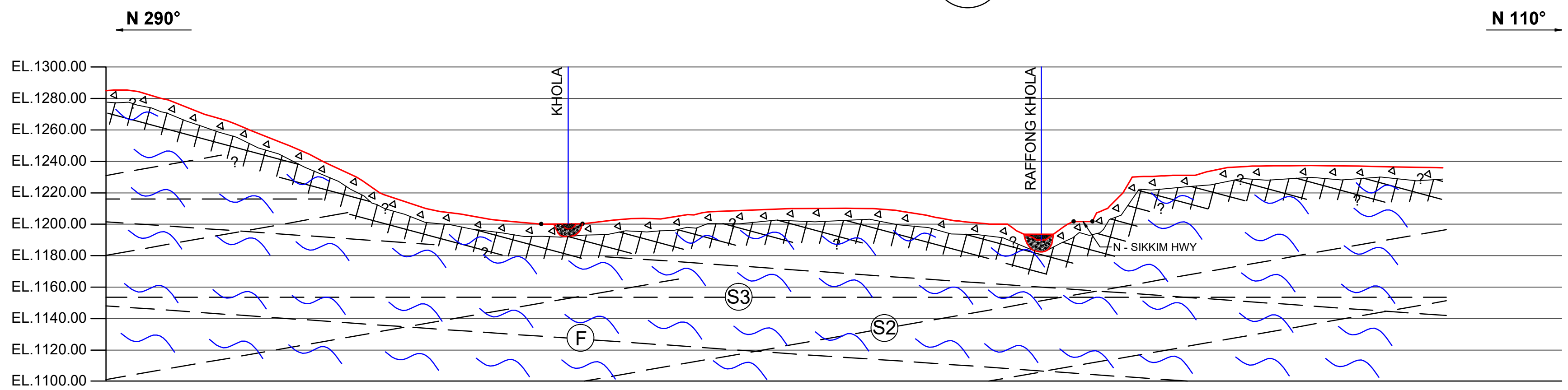
LAND REVENUE & DISASTER MANAGEMENT DEPARTMENT
GOVERNMENT OF SIKKIM

MANGAN LANDSLIDE AREA
RAFFONG KHOLA GEOLOGICAL CROSS SECTION
AT EL. 2100 & EL. 1800

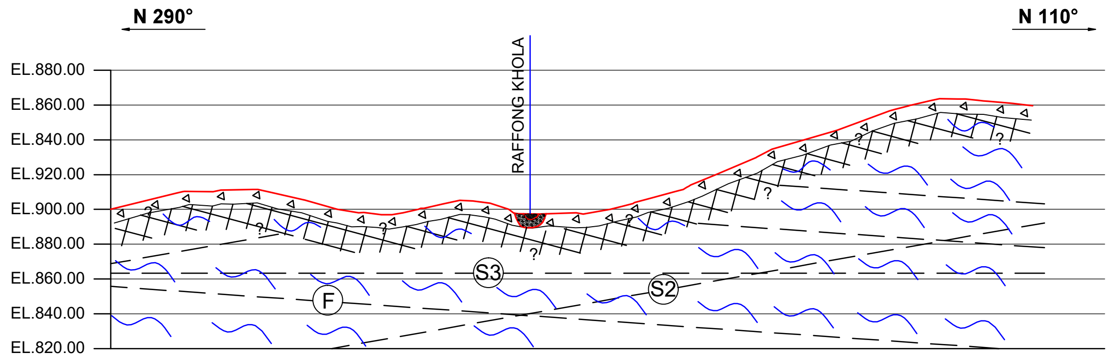
DATE:	DRG.NO.	REV.
MAY, 2018	Mangan/Sikkim/SSDMA-111	



SECTION AT EL. 1500 (D)



SECTION AT EL. 1200 (E)



SECTION AT EL. 900 (F)

MATERIAL TYPE		GSI	C (Kpa)	Ø
OVERBURDEN	(I)	-	5 - 7	20°-22°
WEATHERED QUARTZ BIOTITE SCHIST	(II)	25-35	30-50	24°-26°
QUARTZ BIOTITE SCHIST	(III)	40-50	120-160	36°- 42°

JOINT SET	DIP DIR-ECTION	DIP AMOUNT
S1 (F)	025°	40°
S2	210°	45°
S3	020°	65°

INDEX

- NALA BORNE DEPOSIT
- SLOPEWASH MATERIAL
- HIGHLY WEATHERED & FRACTURED MICA SCHIST
- QUARTZ BIOTITE SCHIST

NOTE:

1. ALL DIMENSIONS AND LEVELS ARE IN METER.

SCALE:

0 20 40 60 80 100 m.

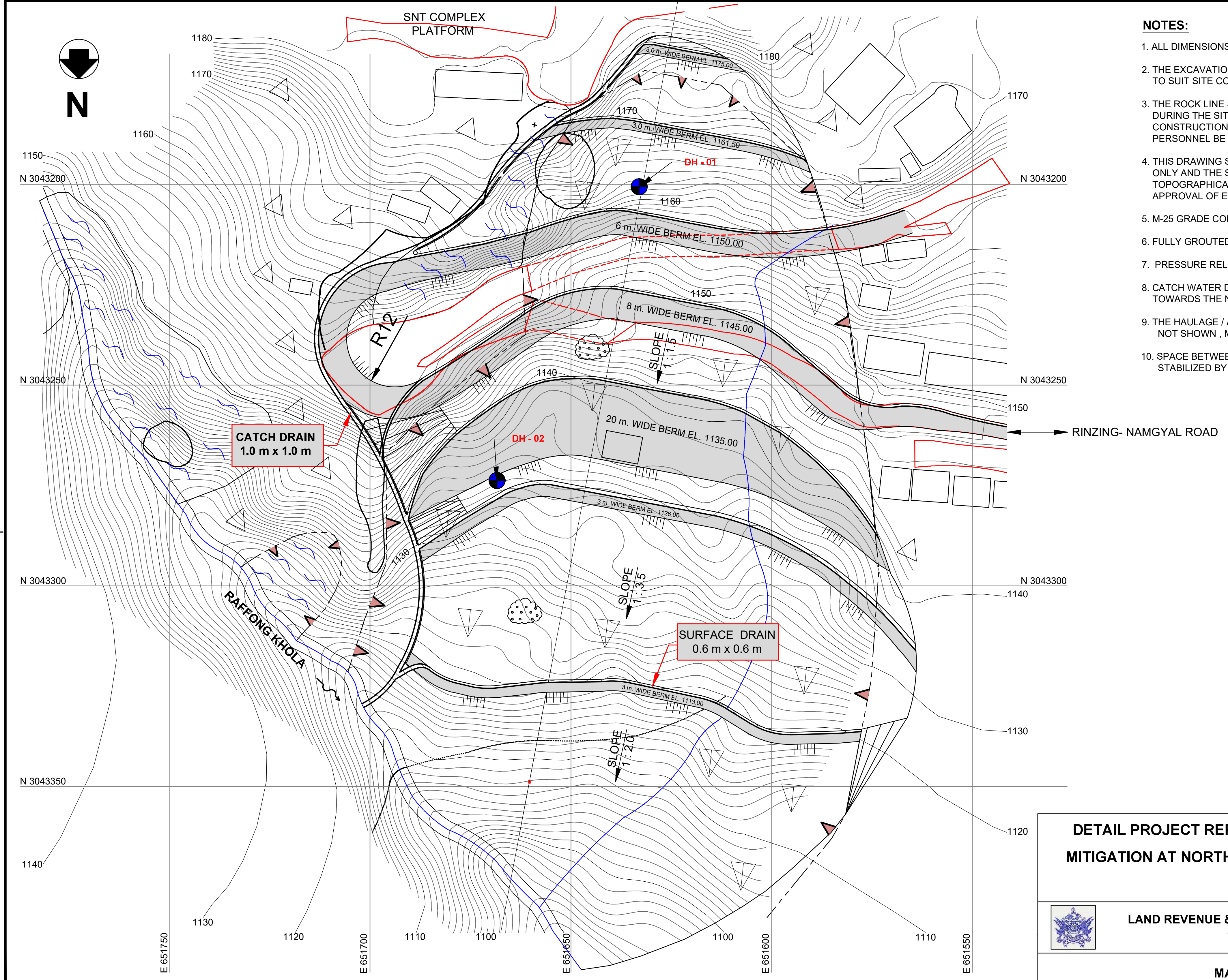
DATE	DESCRIPTION	DRAWN	SUBTD.	APPD.
30.05.2018				

DETAIL PROJECT REPORT (DPR) ON MANGAN LANDSLIDES MITIGATION AT NORTH DISTRICT HEADQUARTERS, MANGAN, NORTH SIKKIM

LAND REVENUE & DISASTER MANAGEMENT DEPARTMENT
GOVERNMENT OF SIKKIM

MANGAN LANDSLIDE AREA
RAFFONG KHOLA GEOLOGICAL CROSS SECTION
AT EL. 1500, EL 1200 & EL. 900

DATE: MAY, 2018
DRG.NO. Mangan/Sikkim/SSDMA-112
REV.



NOTES:

1. ALL DIMENSIONS AND LEVELS ARE IN METER.
2. THE EXCAVATION SLOPES ARE INDICATIVE AND MAY BE MODIFIED TO SUIT SITE CONDITIONS AND AS DIRECTED BY ENGINEER-IN-CHARGE.
3. THE ROCK LINE SHOWN IS INDICATIVE AND MAY DIFFER AS OBSERVED DURING THE SITE INVESTIGATION. TO ASSIST THE REGION WITH CONSTRUCTION DESIGN EXPERIENCED ROCK SLOPE ENGINEERING PERSONNEL BE PERIODICALLY & REGULARLY INVOLVED WITH THE WORK.
4. THIS DRAWING SHOWS THE PRINCIPLE OF EXCAVATION METHODOLOGY ONLY AND THE SAME MAY BE MODIFIED DEPENDING UPON ACTUAL TOPOGRAPHICAL AND GEOLOGICAL CONDITIONS AT SITE WITH THE APPROVAL OF ENGINEER-IN-CHARGE.
5. M-25 GRADE CONCRETE SHALL BE USED FOR THE WELL, PROTECTION WALLS
6. FULLY GROUTED ROCK ANCHOR SHALL BE OF 20 T WORKING CAPACITY.
7. PRESSURE RELIEF HOLES SHALL BE PROVIDED WITH PERFORATED PVC PIPES.
8. CATCH WATER DRAIN SHOWN IS INDICATIVE IT SHOULD BE SUITABLY ALIGNED TOWARDS THE NALAH / OR DEPRESSION ON EITHER SIDE OF THE HILL.
9. THE HAULAGE / APPROACH ROAD FOR FACILITATE TO CONSTRUCTION WORK NOT SHOWN , MAY BE SUITABLY ALIGN TO SUIT THE SITE CONDITIONS.
10. SPACE BETWEEN CATCH WATER DRAINS & TOP DRAINS SHALL BE SUITABLY STABILIZED BY CONCRETE CLADDING 100 mm. THK.

SCALE: 0 10 20 30 40 50 m.

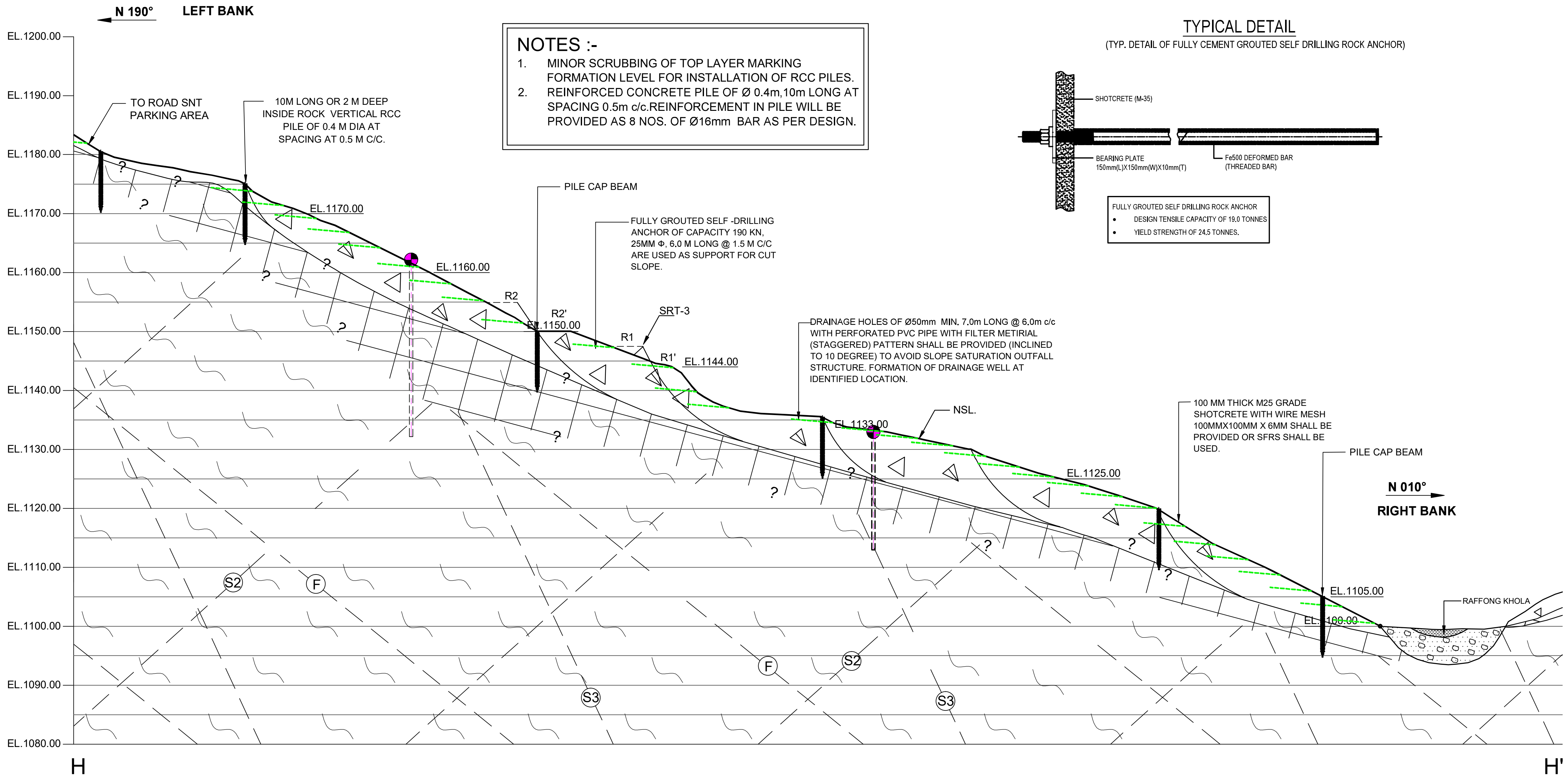
DATE	DESCRIPTION	DRAWN	SUBTD.	APPD.
30.05.2018				

DETAIL PROJECT REPORT (DPR) ON MANGAN LANDSLIDES MITIGATION AT NORTH DISTRICT HEADQUARTERS, MANGAN, NORTH SIKKIM

LAND REVENUE & DISASTER MANAGEMENT DEPARTMENT
GOVERNMENT OF SIKKIM

MANGAN LANDSLIDES AREA
OLD MANGAN BAZAR & SNT COMPLEX- MITIGATION MEASURES
LAYOUT PLAN

DATE: MAY, 2018 | DRG.NO. Mangan/Sikkim/SSDMA-113 | REV.



NOTES :-

1. MINOR SCRUBBING OF TOP LAYER MARKING FORMATION LEVEL FOR INSTALLATION OF RCC PILES.
2. REINFORCED CONCRETE PILE OF Ø 0.4m,10m LONG AT SPACING 0.5m c/c.REINFORCEMENT IN PILE WILL BE PROVIDED AS 8 NOS. OF Ø16mm BAR AS PER DESIGN.

TYPICAL DETAIL

(TYP. DETAIL OF FULLY CEMENT GROUTED SELF DRILLING ROCK ANCHOR)

FULLY GROUTED SELF DRILLING ROCK ANCHOR
- DESIGN TENSILE CAPACITY OF 19.0 TONNES
- YIELD STRENGTH OF 24.5 TONNES.

SNT COMPLEX SECTION (H)

INDEX

- NALA BORNE DEPOSIT
- SLOPEWASH MATERIAL
- HIGHLY WEATHERED & FRACTURED MICA SCHIST
- QUARTZ BIOTITE SCHIST
- FAULT / SHEARED ZONE
- DRILL HOLE

MATERIAL TYPE		GSI	C (Kpa)	Ø
OVERBURDEN	(I)	-	5 - 7	20°-22°
WEATHERED QUARTZ BIOTITE SCHIST	(II)	25-35	30-50	24°-26°
QUARTZ BIOTITE SCHIST	(III)	40-50	120-160	36°- 42°

JOINT SET	DIP DIR-ECTION	DIP AMOUNT
S1 (F)	025°	40°
S2	210°	45°
S3	020°	65°

SCALE: 0 — 7.5 — 15 — 22.5 — 30 — 37.5 m.

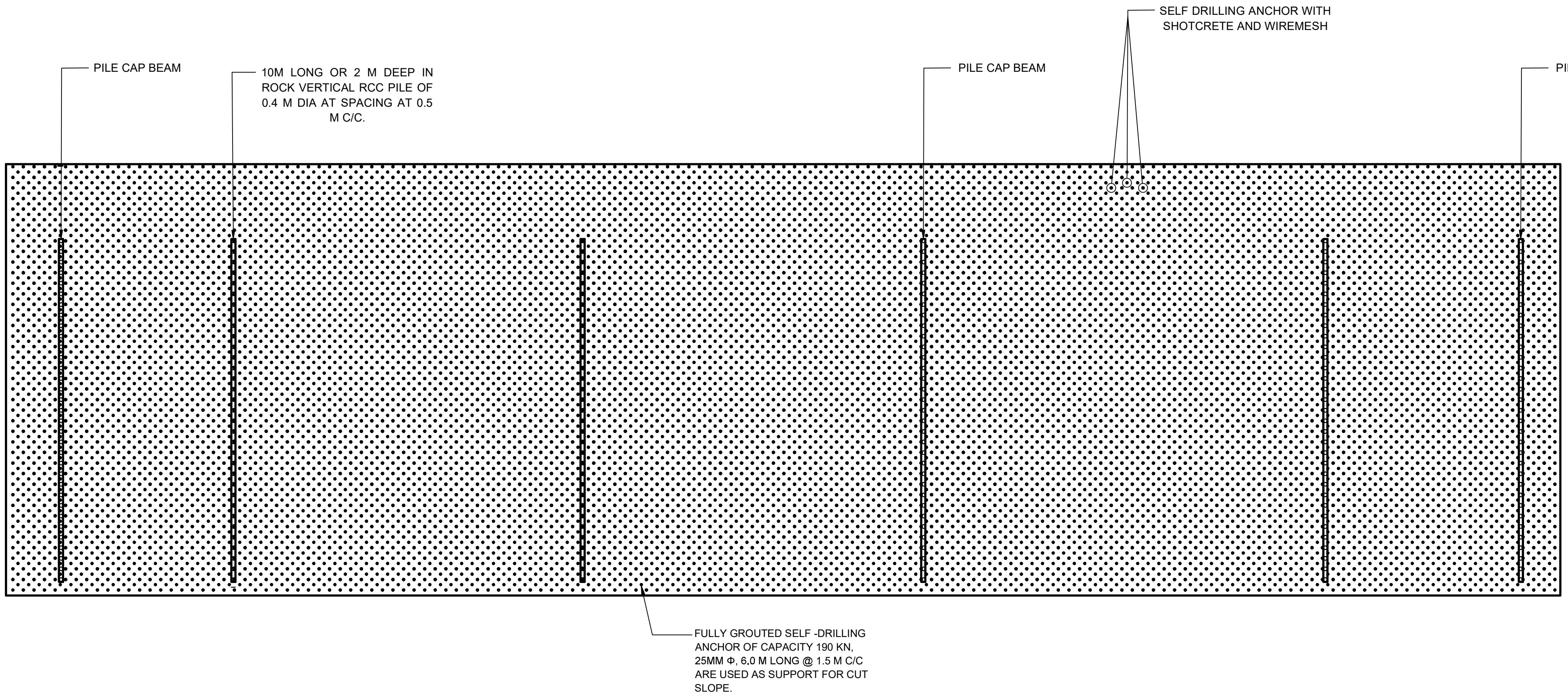
DATE	DESCRIPTION	DRAWN	SUBTD.	APPD.
01.07.2017				

DETAIL PROJECT REPORT (DPR) ON MANGAN LANDSLIDES MITIGATION MEASURES AT NORTH DISTRICT HEADQUARTERS, MANGAN, NORTH SIKKIM

LAND REVENUE & DISASTER MANAGEMENT DEPARTMENT
GOVERNMENT OF SIKKIM

MANGAN LANDSLIDES AREA
OLD MANGAN BAZAR & SNT COMPLEX- MITIGATION MEASURES
L- SECTION

DATE: JULY, 2017 | DRG.NO. Mangan/Sikkim/SSDMA-114 | REV.



TYPICAL PLAN

SCALE:

0 7.5 15 22.5 30 37.5 m.

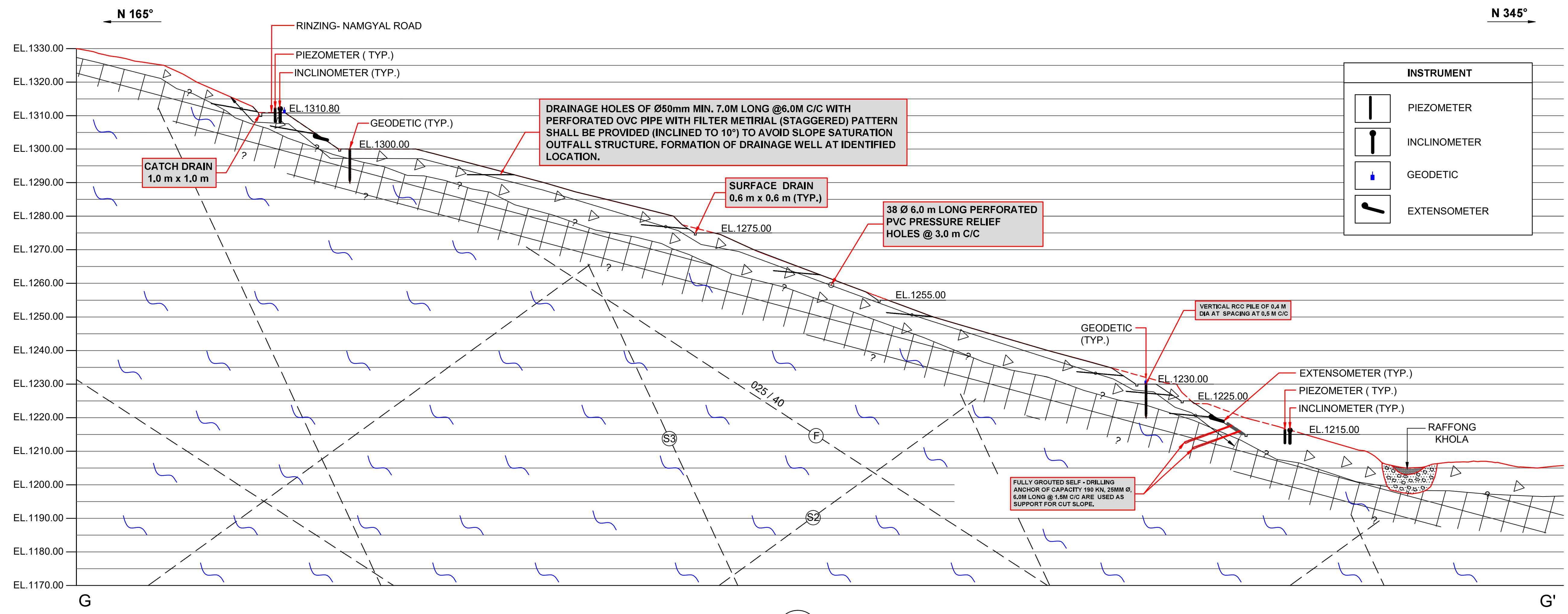
01.07.2017				
DATE	DESCRIPTION	DRAWN	SUBTD.	APPD.

DETAIL PROJECT REPORT (DPR) ON MANGAN LANDSLIDES MITIGATION MEASURES AT NORTH DISTRICT HEADQUARTERS, MANGAN, NORTH SIKKIM

LAND REVENUE & DISASTER MANAGEMENT DEPARTMENT
GOVERNMENT OF SIKKIM

MANGAN LANDSLIDES AREA
OLD MANGAN BAZAR & SNT COMPLEX- MITIGATION MEASURES
TYPICAL PLAN

DATE:	DRG.NO.	REV.
JULY, 2017	Mangan/Sikkim/SSDMA-114A	



SECTION G

GEOLOGICAL SECTION
SR. SECONDARY SCHOOL

INDEX

- NALA BORNE DEPOSIT
- QUARTZ BIOTITE SCHIST
- SLOPEWASH MATERIAL
- HIGHLY WEATHERED & FRACTURED MICA SCHIST

MATERIAL TYPE		GSI	C (Kpa)	Ø
OVERBURDEN	(I)	-	5 - 7	20°-22°
WEATHERED QUARTZ BIOTITE SCHIST	(II)	25-35	30-50	24°-26°
QUARTZ BIOTITE SCHIST	(III)	40-50	120-160	36°- 42°

JOINT SET	DIP DIR-ECTION	DIP AMOUNT
S1 (F)	025°	40°
S2	210°	45°
S3	020°	65°

NOTES:

1. ALL DIMENSIONS AND LEVELS ARE IN METER.
2. FOR OTHER NOTES REFER DRG. NO. Mangan/Sikkim/SSDMA-115.

SCALE: 0 12.5 25 37.5 50 62.5 m.

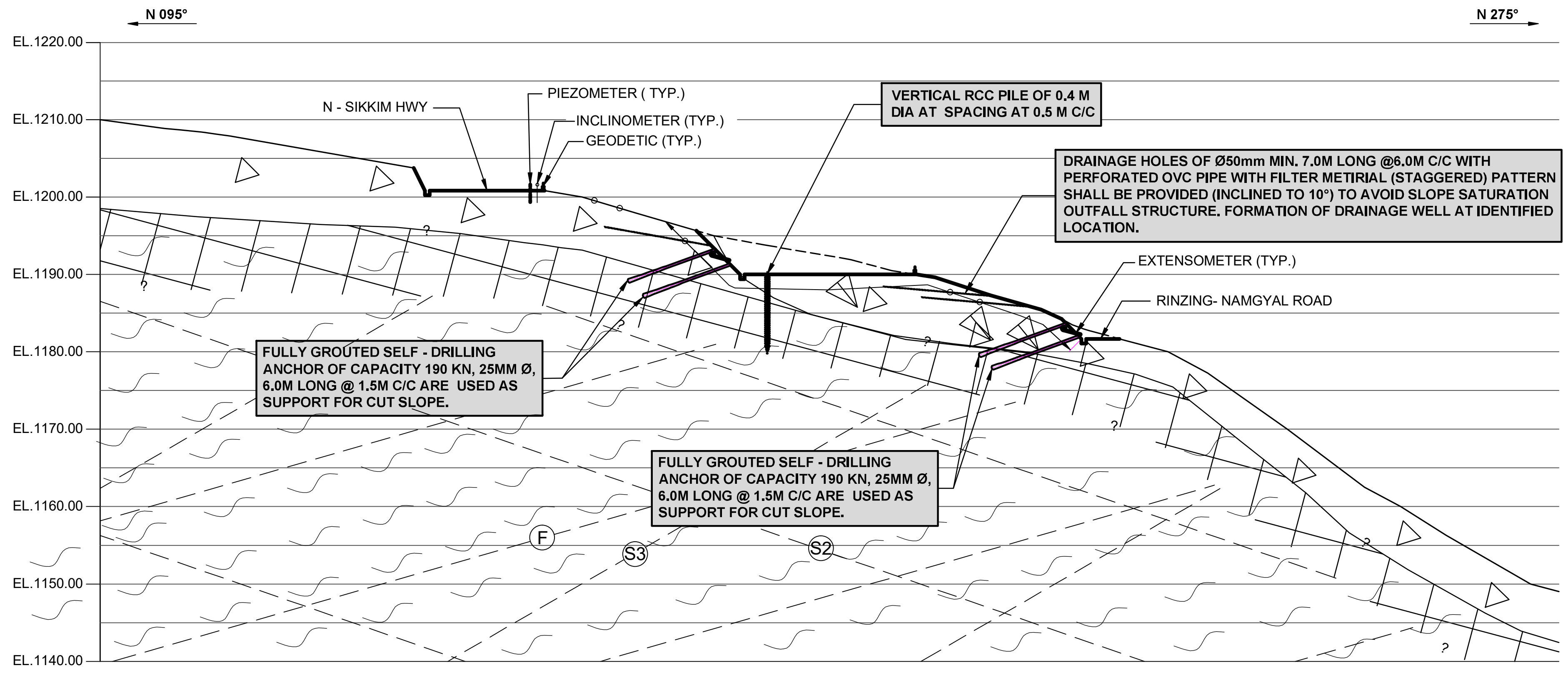
DATE	DESCRIPTION	DRAWN	SUBTD.	APPD.
30.05.2018				

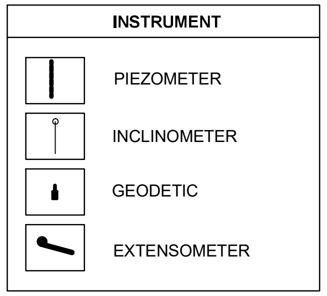
DETAIL PROJECT REPORT (DPR) ON MANGAN LANDSLIDES MITIGATION AT NORTH DISTRICT HEADQUARTERS, MANGAN, NORTH SIKKIM

LAND REVENUE & DISASTER MANAGEMENT DEPARTMENT
GOVERNMENT OF SIKKIM

MANGAN LANDSLIDE AREA
SURROUNDING AREA OF SR. SECONDARY SCHOOL
MITIGATION MEASURES
L- SECTION

DATE:	DRG.NO.	REV.
MAY, 2018	Mangan/Sikkim/SSDMA-115	





SECTION J

GEOLOGICAL SECTION BELOW PARKING AREA

NOTES:

1. ALL DIMENSIONS AND LEVELS ARE ARE IN METER.
2. FOR OTHER NOTES REFER DRG. NO. Mangan/Sikkim/SSDMA-115.

MATERIAL TYPE		GSI	C (Kpa)	Ø
OVERBURDEN	(I)	-	5 - 7	20°-22°
WEATHERED QUARTZ BIOTITE SCHIST	(II)	25-35	30-50	24°-26°
QUARTZ BIOTITE SCHIST	(III)	40-50	120-160	36°- 42°

JOINT SET	DIP DIR-ECTION	DIP AMOUNT
S1 (F)	025°	40°
S2	210°	45°
S3	020°	65°

INDEX

- NALA BORNE DEPOSIT
- SLOPEWASH MATERIAL
- HIGHLY WEATHERED & FRACTURED MICA SCHIST
- QUARTZ BIOTITE SCHIST

SCALE:

0 7.5 15 22.5 30 37.5 m.

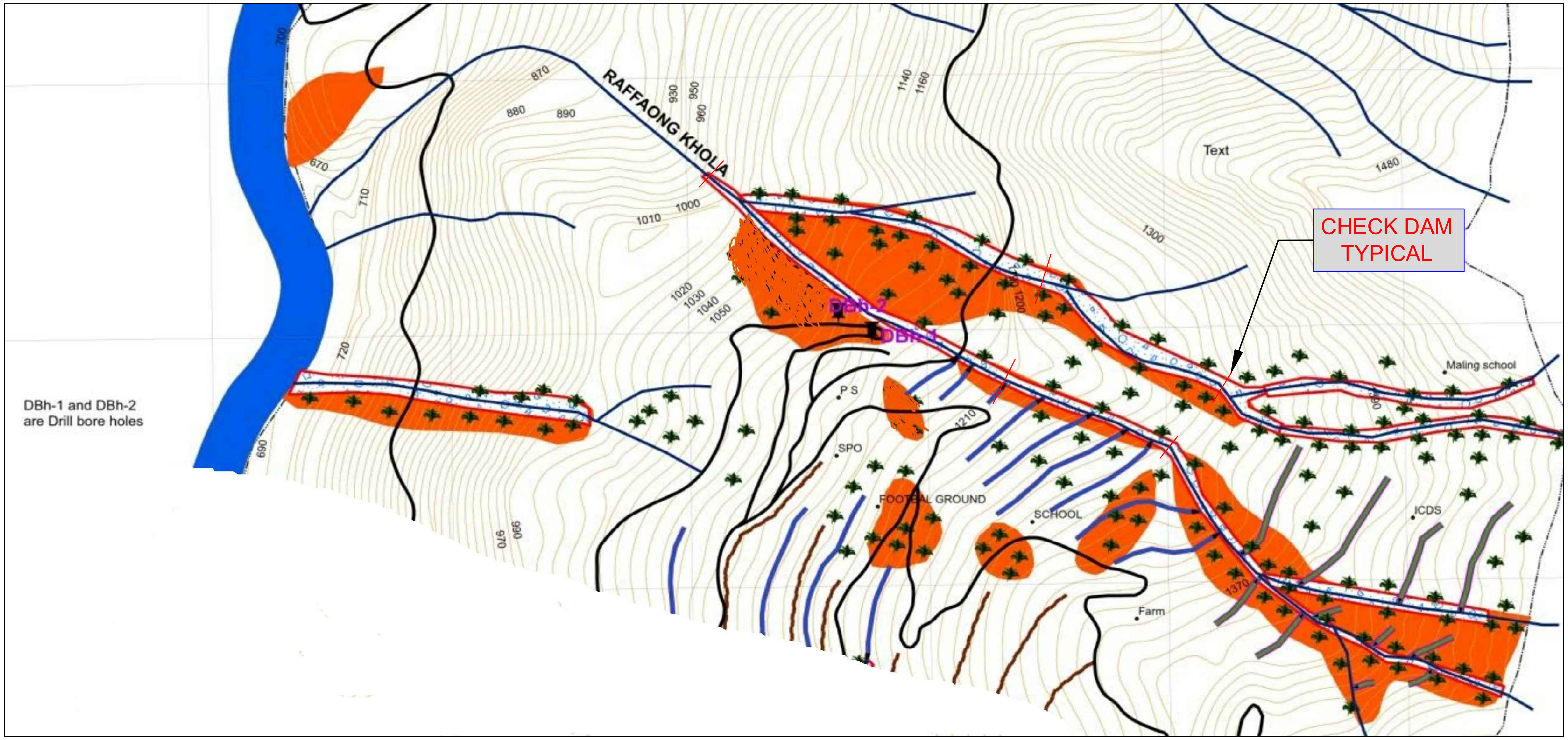
DATE	DESCRIPTION	DRAWN	SUBTD.	APPD.
30.05.2018				

DETAIL PROJECT REPORT (DPR) ON MANGAN LANDSLIDES MITIGATION AT NORTH DISTRICT HEADQUARTERS, MANGAN, NORTH SIKKIM

LAND REVENUE & DISASTER MANAGEMENT DEPARTMENT
GOVERNMENT OF SIKKIM

MANGAN LANDSLIDE AREA
MANGAN BAZAR AND BELOW MULTI-STOREY PARKING AREA
MITIGATION MEASURES
L-SECTION

DATE: **MAY, 2018** DRG.NO. **Mangan/Sikkim/SSDMA-116** REV.



NOTE:-

1. ALL DIMENSIONS AND LEVELS ARE IN METER.

30.05.2018				
DATE	DESCRIPTION	DRAWN	SUBTD.	APPD.

SCALE:

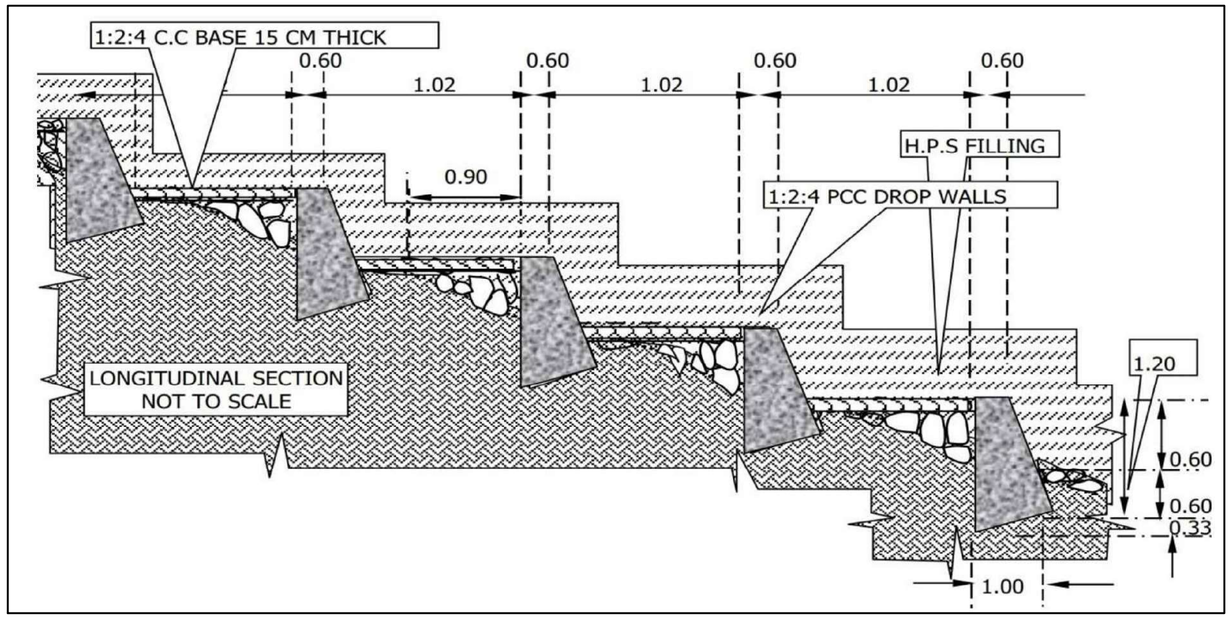
NTS

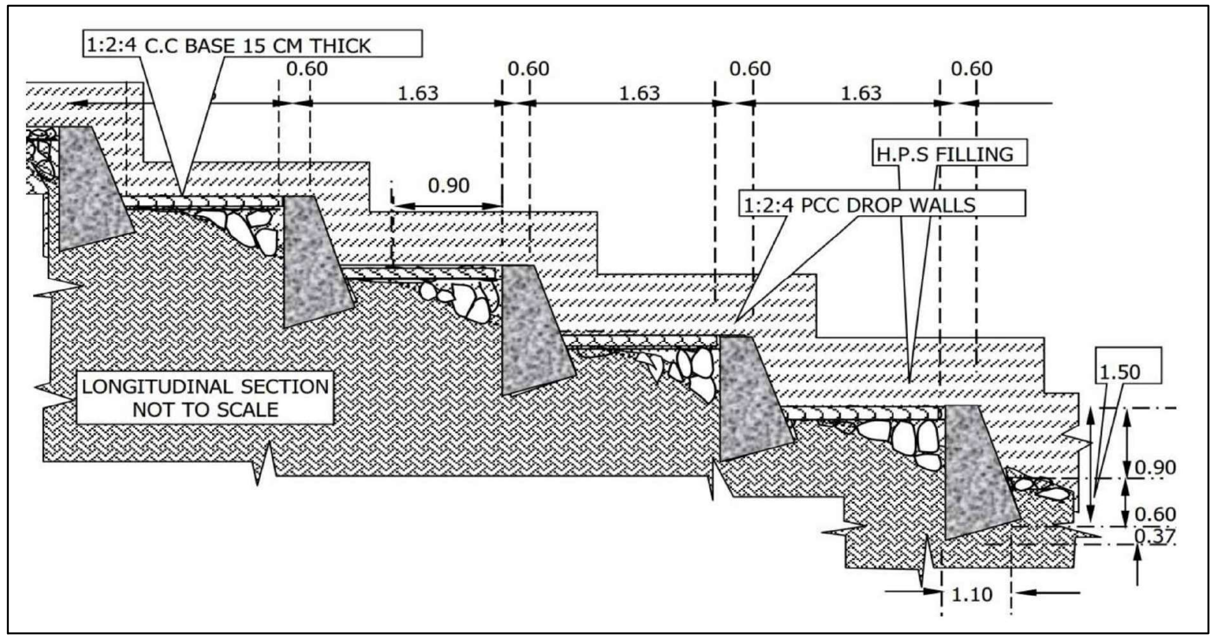
DETAIL PROJECT REPORT (DPR) ON MANGAN LANDSLIDES MITIGATION AT NORTH DISTRICT HEADQUARTERS, MANGAN, NORTH SIKKIM

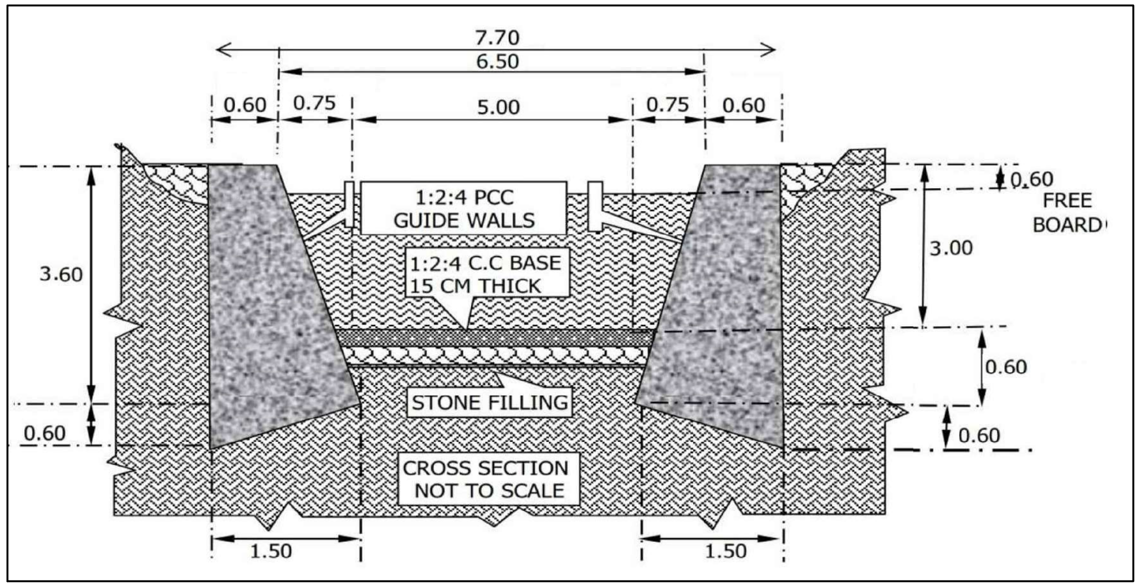
LAND REVENUE & DISASTER MANAGEMENT DEPARTMENT
GOVERNMENT OF SIKKIM

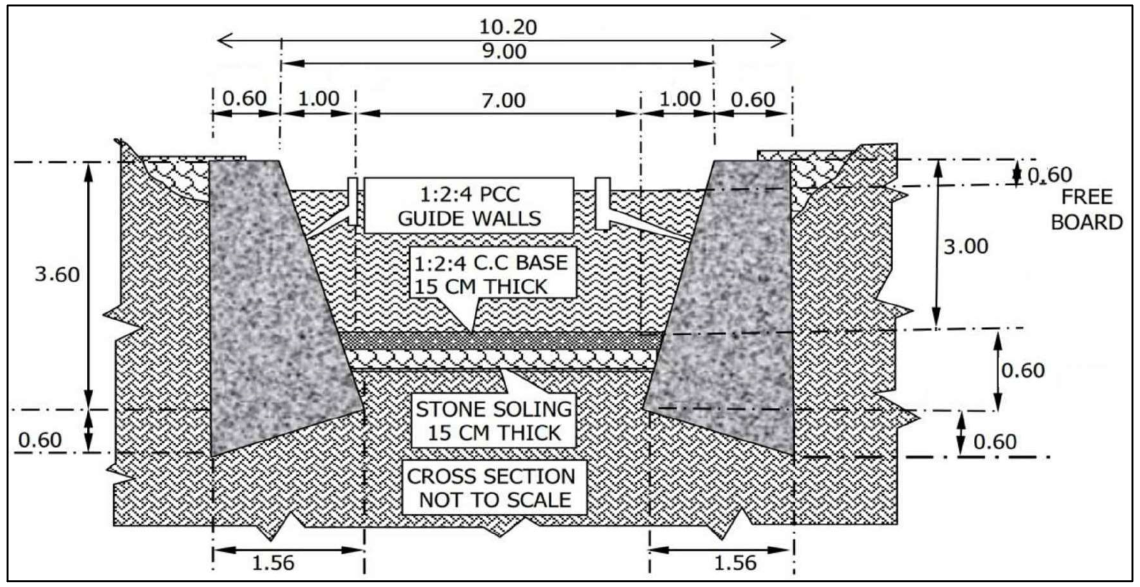
MANGAN LANDSLIDES AREA
RAFFONG KHOLA
CHECK DAM & DRAINAGE SYSTEM

DATE:	DRG.NO.	REV.
MAY, 2018	Mangan/Sikkim/SSDMA-117	









NOTE:

1. ALL DIMENSIONS AND LEVELS ARE IN METER.

DETAIL PROJECT REPORT (DPR) ON MANGAN LANDSLIDES MITIGATION AT NORTH DISTRICT HEADQUARTERS, MANGAN, NORTH SIKKIM

LAND REVENUE & DISASTER MANAGEMENT DEPARTMENT
GOVERNMENT OF SIKKIM

MANGAN LANDSLIDE AREA
MITIGATION MEASURES
TYPICAL PROTECTION WORKS DETAILS

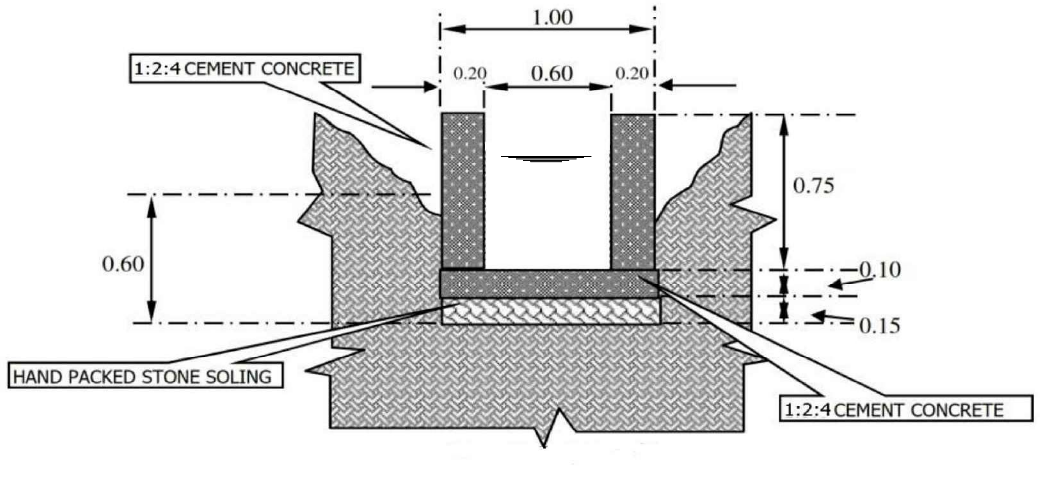
SCALE: NTS

DATE	DESCRIPTION	DRAWN	SUBTD.	APPD.
30.05.2018				

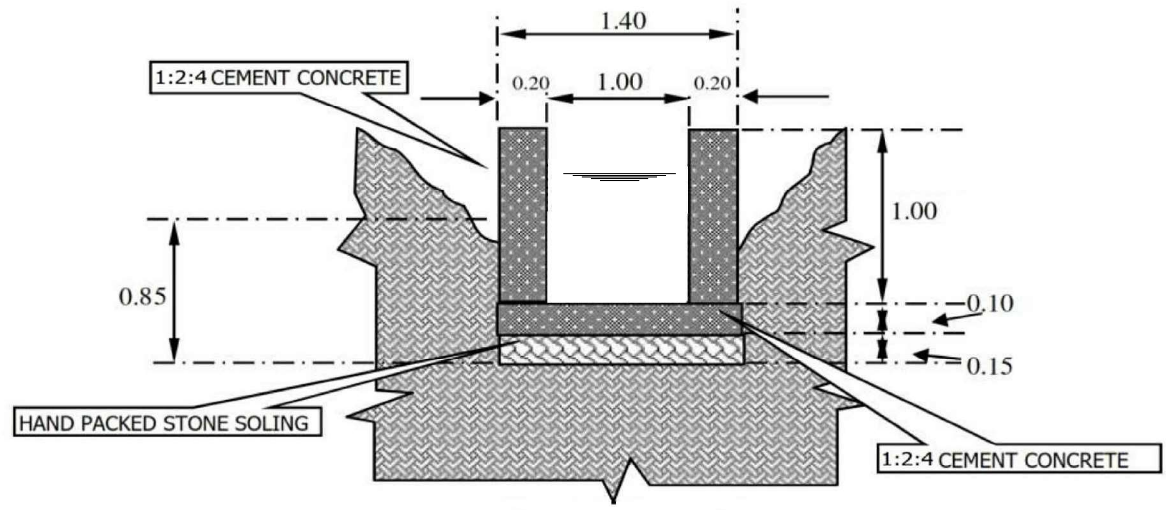
DATE: MAY, 2018

DRG.NO. Mangan/Sikkim/SSDMA-118

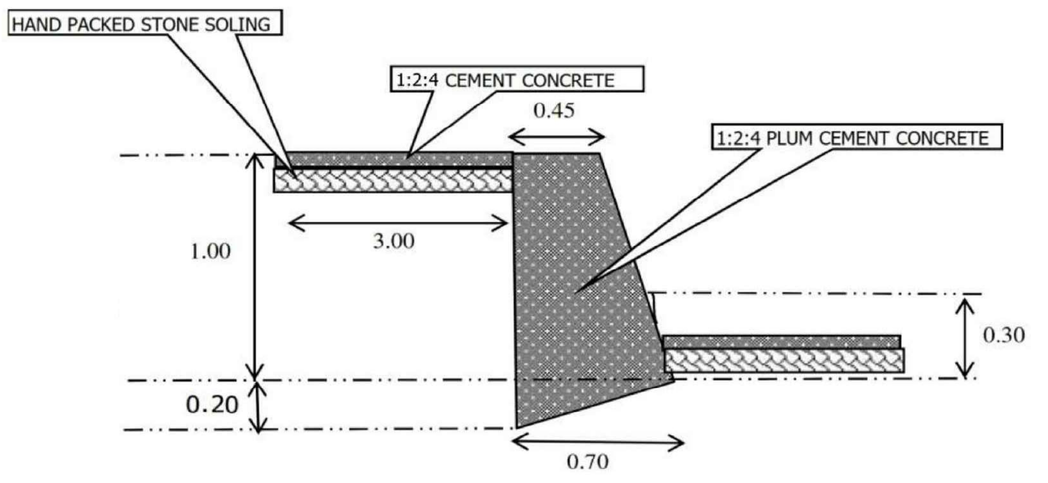
REV.



CROSS SECTION OF DRAIN



CROSS SECTION OF DRAIN



CROSS SECTION OF D/WALL

NOTE:

1. ALL DIMENSIONS AND LEVELS ARE IN METER.

DETAIL PROJECT REPORT (DPR) ON MANGAN LANDSLIDES MITIGATION AT NORTH DISTRICT HEADQUARTERS, MANGAN, NORTH SIKKIM

LAND REVENUE & DISASTER MANAGEMENT DEPARTMENT
GOVERNMENT OF SIKKIM

MANGAN LANDSLIDE AREA
MITIGATION MEASURES
TYPICAL CROSS SECTION OF DRAINAGE SYSTEMS

SCALE: NTS	DATE	DESCRIPTION	DRAWN	SUBTD.	APPD.	DATE:	DRG.NO.	REV.
	30.05.2018					MAY, 2018	Mangan/Sikkim/SSDMA-119	

ANNEXURE-1

DRILLHOLE LOGS

Mines, Minerals & Geology Department
Government Of Sikkim,Gangtok.

SITE: Mangan bazaar, Near SNT complex, North Sikkim.										JOB NO.: 01
DRILLING EQUIPMENT: Diamond drilling with Single tube barrel										
DRILLING METHOD: Rotary					**DRILLING DIAMETER:** BX,NX Size					**CASHING DIAMETER**: NX Size
DRILL HOLE NO.: 01								**SHEET NO.:** 01		R.L. (m): 1134m amsl
ORIENTATION: Vertical down								**CO-ORDINATE: N27^{0} 30.207', E 88^{0} 32.132'**		
DETAILS OF SAMPLES:								**DETAILS OF DRILL HOLE:**		
RUN (mts.)		**Depth (in mts.)**	**Log**	**Type of sample in(mts.)**	**Core Reco v-ery (%)**	**Core Loss (%)**		**Water loss**	**Allowable bearing capacity/ Rock Strength**	**Rock Type**
From	**To**									
0.00	1.50	1.50		slush	00.00 %	100.00 %		No loss		Filling Materials
1.50	3.00	1.50		slush	00.00 %	100.00 %		No Loss		Filling Materials
3.00	4.50	1.50		Slush	0.00 %	100.00 %		No loss		Filling Materials
4.50	6.00	1.50		Slush	0.00 %	100.67 %		No Loss		Filling Materials
6.00	7.50	1.50		Slush	00.00 %	100.00 %		No loss		Filling Materials
7.50	9.00	1.50		slush	00.00 %	100.00 %		No Loss		Weathered Mica schist with quartz veins
9.00	10.50	1.50		Slush	00.00 %	100.00 %		No loss		Weathered Mica schist with quartz veins
10.50	12.00	1.50		Slush	00.00 %	100.00 %		No Loss		Weathered Mica schist with quartz veins
12.00	13.50	1.50		slush	0.00 %	100.00 %		No loss		Weathered Mica schist with quartz veins
13.50	15.00	1.50		slush	0.00 %	100.00 %		No Loss		Weathered Mica schist with quartz veins
15.00	16.50	1.50		Slush	00.00 %	100.00 %		No loss		Weathered Mica schist with quartz veins
16.50	18.00	1.50		Slush	00.00 %	100.00 %		No Loss		Weathered Mica schist with quartz veins
18.00	19.50	1.50		Slush	00.00 %	100.00 %		No loss		Weathered Mica schist with quartz veins
19.50	21.00	1.50		slush	00.00 %	100.00 %		No Loss		Weathered Mica schist with quartz veins
21.00	22.50	1.50		Slush	0.00 %	100.00 %		No loss		Weathered Mica schist with quartz veins
22.50	24.00	1.50		Slush	0.00 %	100.00 %		No Loss		Weathered Mica schist with quartz veins
24.00	25.50	1.50		Core	08.00 %	92.00%		No loss		Mica schist with quartz veins
25.50	27.00	1.50		Core	11.00 %	89.00%		No Loss		Mica schist with quartz veins
27.00	28.50	1.50		Core	07.00 %	93.00%		No loss		Mica schist with quartz veins
28.50	30.00	1.50		Core	10.00 %	90.00%		No Loss	145.60T/m^{2}	Mica schist with quartz veins

SITE: Mangan bazaar, Near SNT complex, North Sikkim.									JOB NO.: 02	
DRILLING EQUIPMENT: Diamond drilling with Single tube barrel										
DRILLING METHOD: Rotary					**DRILLING DIAMETER:** BX,NX Size				**CASHING DIAMETER:** NX Size	
DRILL HOLE NO.: 02								**SHEET NO.:** 01	R.L. (m): 1127m amsl	
ORIENTATION: Vertical down								**CO-ORDINATE: N27^{0} 30.229', E 88^{0} 32.128'**		
DETAILS OF SAMPLES:								**DETAILS OF DRILL HOLE:**		
RUN (mts.)		**Depth (in mts.)**	**Log**	**Type of sample**	**Core Recov-ery**	**Core Loss**		**Water loss**	**Allowable bearing capacity/ Rock Strength**	**Rock Type**
From	**To**			**in(mts.)**	**(%)**	**(%)**				
0.00	1.50	1.50		slush	00.00%	100.00%		No loss		Filling Materials
1.50	3.00	1.50		slush	00.00%	100.00%		No Loss		Filling Materials
3.00	4.50	1.50		Slush	0.00%	100.00%		No loss		Filling Materials
4.50	6.00	1.50		Slush	0.00%	100.67%		No Loss		Filling Materials
6.00	7.50	1.50		Slush	00.00%	100.00%		No loss		Filling Materials
7.50	9.00	1.50		slush	00.00%	100.00%		No Loss		Weathered Mica schist with quartz veins
9.00	10.50	1.50		Slush	00.00%	100.00%		No loss		Weathered Mica schist with quartz veins
10.50	12.00	1.50		Slush	00.00%	100.00%		No Loss		Weathered Mica schist with quartz veins
12.00	13.50	1.50		Core	6.00%	94.00%		No loss		Mica schist with quartz veins
13.50	15.00	1.50		Core	12.00%	88.00%		No Loss	218.4T/m^{2}	Mica schist with quartz veins
15.00	16.50	1.50		Core	7.00%	93.00%		No loss		Mica schist with quartz veins
16.50	18.00	1.50		Core	8.00%	92.00%		No Loss		Mica schist with quartz veins
18.00	19.50	1.50		Core	5.00%	95.00%		No loss		Mica schist with quartz veins
19.50	20.00	0.50		Core	20.00%	80.00%		No Loss	445.00T/m^{2}	Mica schist with quartz veins

ANNEXURE-2

GEOPHYSICAL REPORT

Geo–physical investigation by 2D– Electrical Resistivity Survey/Tomography at subsidence areas of Mangan, North Sikkim.

Background:

Electrical resistivity determination is usually made by injecting a specified amount of electric current electrodes and with the aid of a pair of potential electrodes. The potential difference between any two points at the surface caused by the flow of the electric current in the sub-surface is measured. From the measured current (I) and the voltage (V) values the ensuing resistivity is determined.

The approach of geophysical study is to reveal the sub-surface characteristics materials based on the subsurface geology and hydrological conditions. Geophysical investigation provides us the in situ subsurface conditions, which can be translated into geo-technical information, which provides complete understanding of physical behavior of a sub-surface geology. Feasibility of various direct and indirect geophysical techniques resolve details of sub-surface masses present there on, such as movement of ground water, thickness, relief of bed rock, water saturated zone (Bogoslovsky et al.1977; Mills.1990; Caris and Van Asch,1991; Hermann et al. 2000). Recently, the role of Electrical Resistivity Tomography (ERT) or electrical imaging (I.B osazuwa and E. Chii Chii 2010) in Lake/overburden Investigations is on wide practice, due to cost, time and other parameters.

Electrical resistivity surveys with vertical electrical soundings (Schlumberger method) which provides characteristics of sub surface layer, depths and resistivities at a single place. Furthermore 2D resistivity imaging techniques provide 2D and even 3D high resolution electrical images of sub surfaces (Griffiths and Baker 1993).

Objectives:

A two-dimensional electrical resistivity survey was carried out at the subsidence areas of mangan, North Sikkim, Seven nos. of 2D profile were prepared with an aim of following objectives:

1. **To investigate the sub-surface seepage of water/moisture content/depth of slip surface if any.**
2. **Depth of overburden/transported materials deposit.**

3. **Type of materials present/inferred geological condition.**
4. **Approximate Depth of rock and their physical properties.**

Methodology:

Electrical Resistivity Tomography Method

Two–dimensional (2D) electrical imaging surveys are widely used to map areas of moderately complex geology where conventional resistivity sounding and profiling techniques are inadequate. The data from such surveys are plotted in the form of a pseudo–section which gives an approximate and sub–surface geology is slightly distorted. The data collected in dried–up lake/ saturated zone of study areas were interpreted by 2D Resistivity Imaging software. Integrated Geo–Instrumentation Service resistivity meter model **SSR–MP1**, is used to obtain the resistivity data to reasonable depths of 20– 30 m (depth of investigation depends on local geological conditions) from the ground surface of the area. For a good lateral, vertical and horizontal resolution, **Hybrid Wenner–Schlumberger profiling is preferred**. A multi–electrode resistivity imaging technique were used in the area. A GARMIN makes GPS was used for the position location of electrodes along the profile.

Resistivity data were collected using **Wenner–Schlumberger** (Vertical Electrical Sounding) array configuration with electrode separation 2–5 m. Topographic corrections and 2D inversion model were carried out using **Res2Divn GEOTOMO Software**. This resistivity inversion software based on the least-square method proposed by Locke and Barker (1996) is used during the investigation. In all inversion 9 attempts of iteration was kept.

A total of seven resistivity tomography profile were carried out in the area, Profile–01,02 and 03 was conducted around the Mangan Senior secondary school comples, towards Rafong khola section. Profile – 04 and 05 was conducted below SNT complex, Profile–06 and 07 was conducted below Mangan car parking (towards southern end). The depth of information in the tomography is upto 25meters maximum. All the profile sections are shown in the location map. The adopted contour colour code provides the key information on parameters of deposited material like presence of low resistivity clayey/silty sand horizons, wet sandy soil horizons and the depth of bed rock. Tentative true resistivity versus subsurface depth are inferred from geological literature (Telford et al.1990). The data so obtained are used in the preparation of subsurface lithological sections along each profile and also inferred geo–hydrological regimes were carried out.

Profile section – 01 At North of Mangan sr. Sec. school:

Site Geology: Mangan School complex consists of thick soil overburden and few outcrops are exposed along Raffong Khola section. The rocks are dominated by Biotite Schist with weathering. The overburden Biotite schist material consists 80% of mica flakes and 20% sandy material. It do not contain clayey material and very low on cohesion. The water absorption capacity of soil is high and has low frictional resistance; as a result the area is characterized by high water regime. The depth wise inferred geology is formulated in the table1.

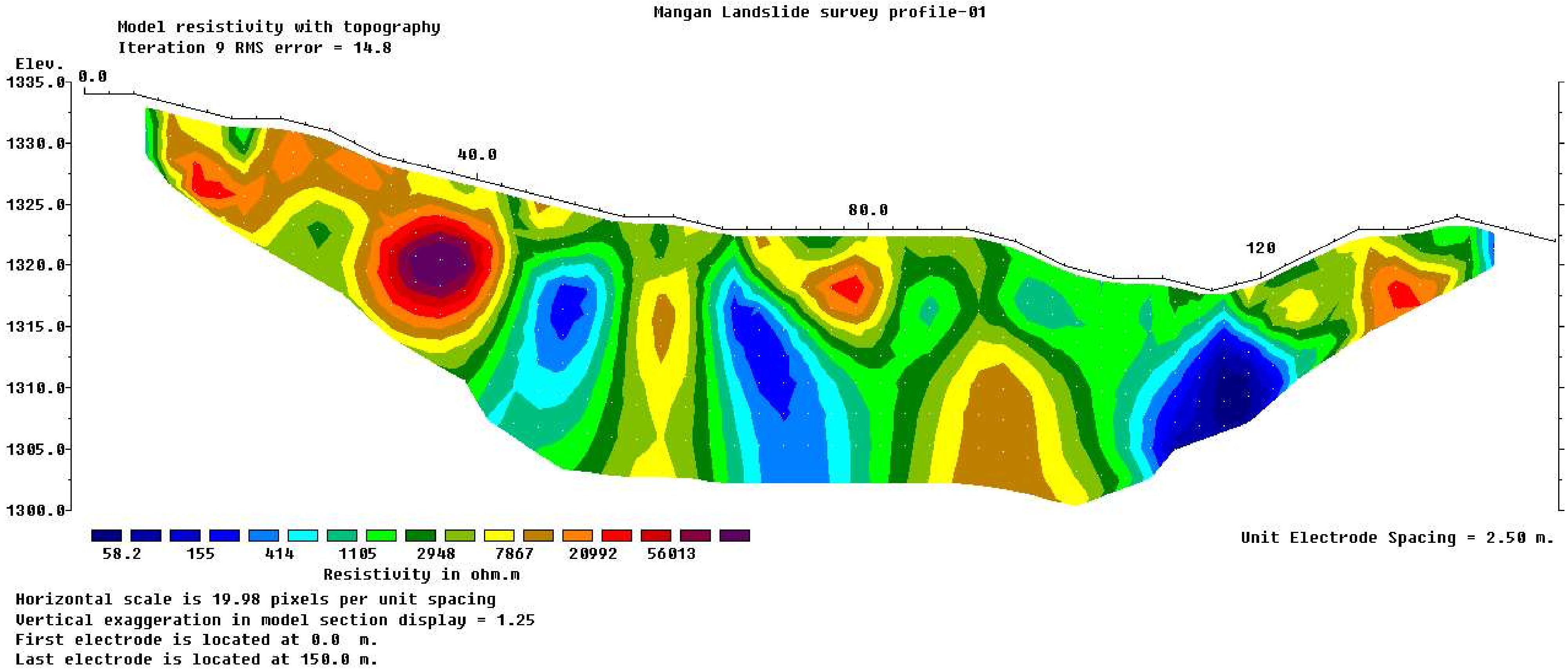


Fig: Electrical resistivity Tomography of Profile section–01 near Mangan Sr. Sec. School, North Sikkim

Table: 1 showing the inferred geology of sub–surface at profile section–01.

Sl. No.	PS–01 (0.0mts. – 150mts.)	Depth (m)	Resistivity (ohm–meter)	Inferred geology/ type of materials Present
1	**0m – 7.5m**	–	–	*Field Data Gap(no information)*
2	**7.5m – 8m**	1332m – 1326m	1500 Ωm –7000 Ωm	*Slightly weathered mica schist overlain by thick soil cover.*
3.	**8m–15m**	1332m–1322m	7000 Ωm -8000 Ωm	*Fresh schistose rock.*
4.	**15m–18m**	1332m–1329m	1500 Ωm –7000 Ωm	*Slightly weathered mica schist overlain by thick soil cover*
		1329m–1321m	7000 Ωm-8000 Ωm	*Slightly weathered mica schist overlain by thick soil cover*
5.	**18m – 42m**	1330m–1312m	7000 Ωm-8000 Ωm	*Slightly weathered mica schist overlain by thick soil cover*
6.	**42m – 57m**	**1328m – 1325m**	1500 Ωm –7000 Ωm	*Slightly weathered mica schist overlain by thick soil cover*
		1325m – 1318m	400 Ωm –1500 Ωm	*Weathered mica schist overlain by thick soil overburden.*
		1318m – 1308m	*50 Ωm – 400 Ωm*	*Ground water.*
		1308m–1304m	400 Ωm – 800 Ωm	*Saturated weathered mica schist*
7	**57m – 68m**	**1328m – 1302m**	3000 Ωm –8000 Ωm	*Relatively fresh schistose rock.*
8.	**68m – 70m**	**1328m – 1325m**	1500 Ωm–3000 Ωm	*Slightly weathered mica schist*
		1325m – 1322m	400 Ωm –1500 Ωm	*Weathered mica schist overlain by thick soil overburden*
		1322m – 1302m	*50 Ωm – 400 Ωm*	*Ground water.*
	70m – 85m	**1328m – 1318m**	3000 Ωm-4000 Ω*m*	*Semi weathered mica schist overlain by soil cover*
		1318m – 1302m	1000 Ωm – 3000 Ωm	*Slightly weathered mica schist rock*
	85m – 95m	**1328m –1322m**	3000 Ωm–4000 Ωm	*Semi weathered mica schist overlain by soil cover*
		1322m – 1302m	2000 Ωm–4000 Ωm	*Semi weathered mica schist overlain by soil cover*
	95m – 115m	**1322m – 1314m**	1000 Ωm –2000 Ωm	*Slightly weathered mica schist rock*
		1314m–1310m	400 Ωm–1000 Ωm	*Weathered mica schist overlain by thick soil overburden.*
		1310m–1302m	*50 Ωm – 400 Ωm*	*Ground water.*
	115m –	**1320m –**	3000 Ωm – 7000	*Relatively fresh schistose rock.*

	127m	**1310m**	Ωm	
	127m – 135m	**1321m – 1310m**	6000 Ωm–7000 Ωm	*Slightly weathered mica schist overlain by thick soil cover*
	135m–140m	**1322m–1311m**	1000 Ωm – 3000 Ωm	*Slightly weathered mica schist rock*
	140m–142.5m	**1322m–1312m**	*50 Ωm – 400 Ωm*	*Ground water*
12	**142.5m–150m**	**–**	–	**Field Data Gap(no information)**

<u>Profile section –02 at towards north east of Managn Sr. Sec. school ground.</u>

Site Geology: The area under study is dominated by three rock types namely Quartz–biotite schist, Biotite schist and Garnitiferrous mica schist. The rocks are mainly exposed along nala section, road cuttings and ridges. The shear strength of these rocks varies with rock composition. The general trend of rock shows NW–SE strike dipping 30° to 50° towards NE. Two sets of prominent joint, besides the foliation plane are mapped in the area. Mica Schist unit under the influence of surface and sub surface water are susceptible to weathering. As result, the area dominated by these rocks forms gentle slope and gullies. These rocks are exposed in around Mangan School, along nala section of Raffong Khola, play ground area around Goskhan and lower Mangan. They show intense weathering and ground area activites are high. Also these areas have thick soil over burden.The depth wise inferred geology is formulated in the table 2.

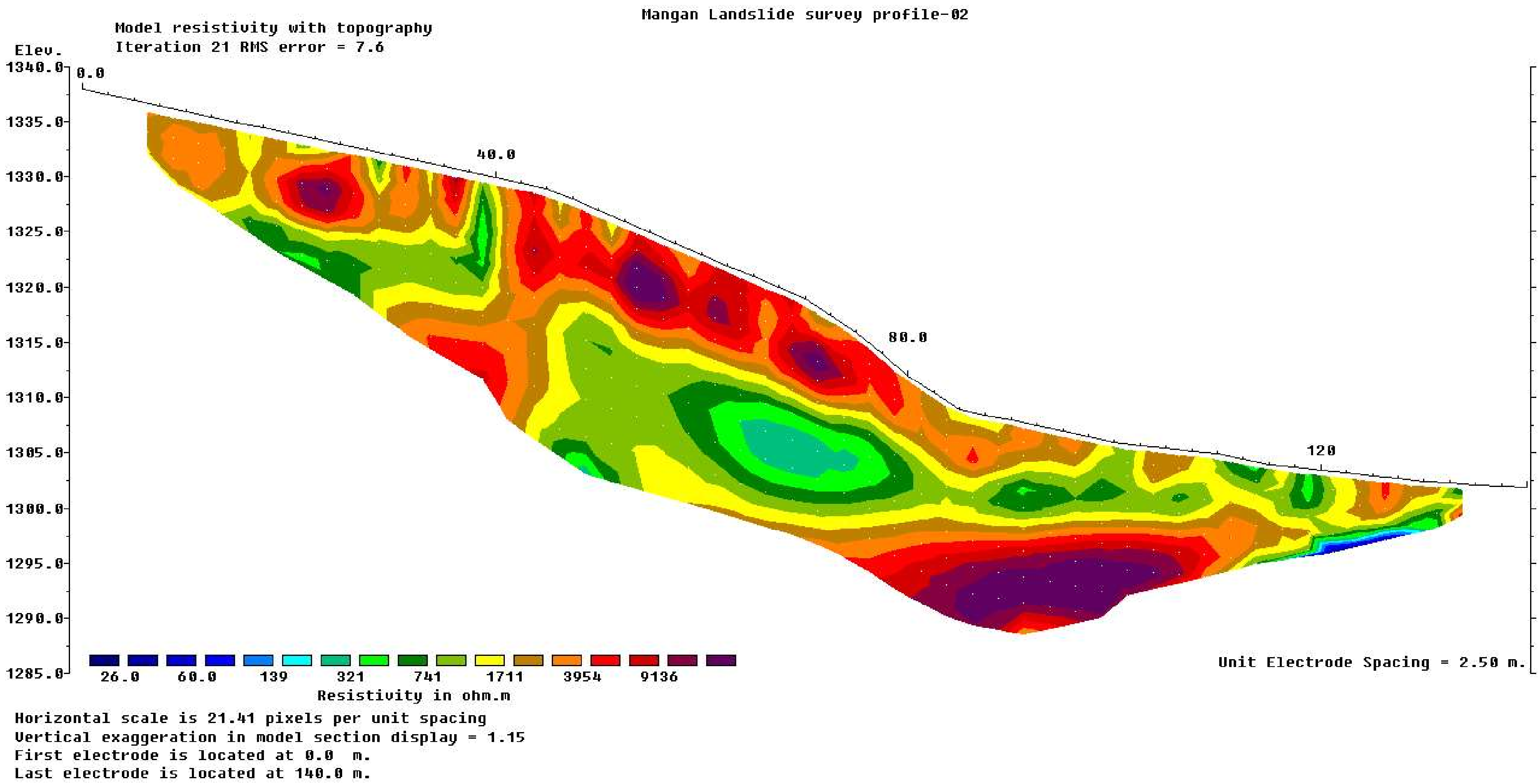
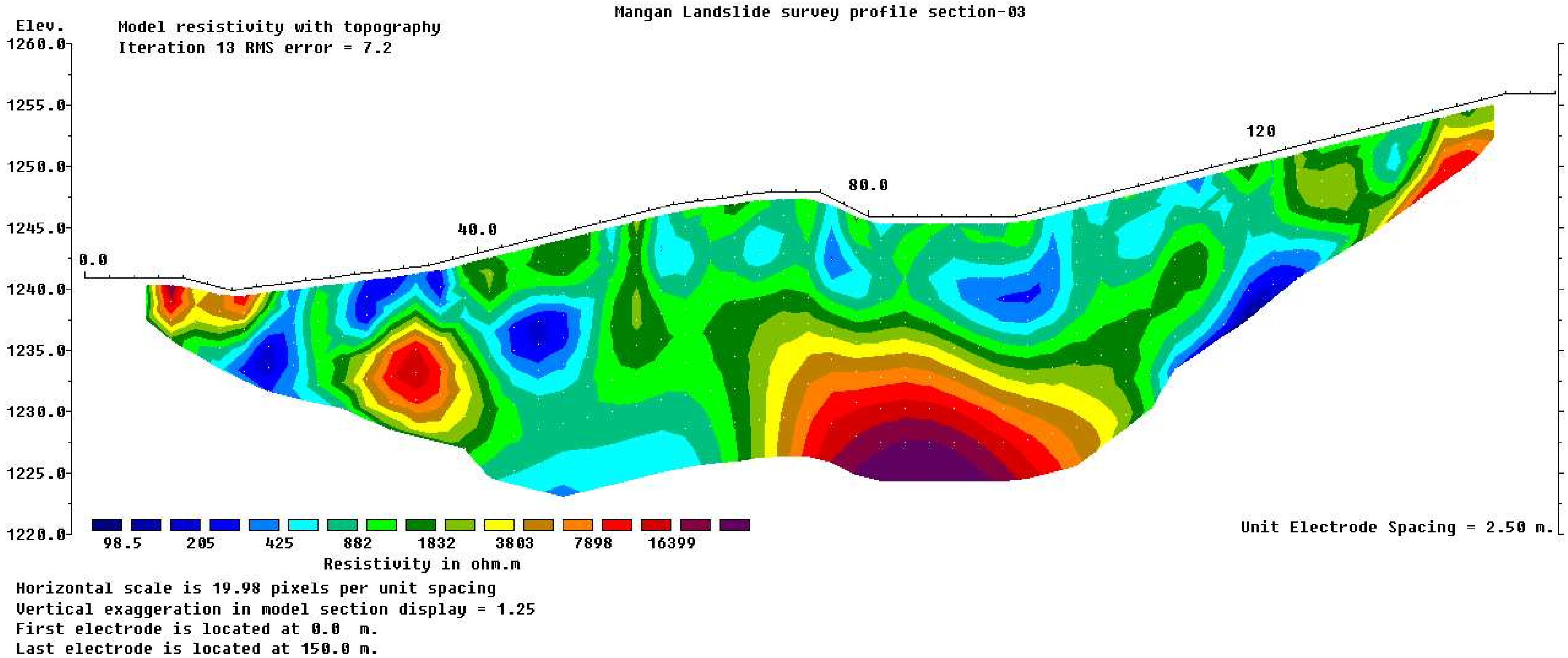


Fig: Electrical resistivity Tomography of Profile section–01 near Mangan Sr. Sec. School, North Sikkim

Table: 2 showing the inferred geology of sub–surface at profile–02.

Sl. No.	PS02–PS02' (0.0mts. – 150mts.)	Depth (m)	Resistivity(ohm–meter)	Inferred geology/type of materials Present
1	0m – 7.5m	–	–	*Field Gap (no information)*
2	7.5m – 15m	1334m – 1325m	1800 Ωm–4000 Ωm	*Slightly weathered mica schist*
3	15m – 17.5m	1334m – 1326m	1700 Ωm–1800 Ωm	*Semi- Weathered rock mica schist*
		1326m – 1322m	700 Ωm–1700 Ωm	*Fresh mica schist rock.*
4	17.5m – 20m	1335m – 1327m	1900 Ωm–2000 Ωm	*Semi- Weathered rock mica schist*
		1327m –1326m	1700 Ωm–1800 Ωm	*Semi- Weathered rock mica schist*
		1326m –1324m	700 Ωm–1700 Ωm	*Fresh mica schist rock.*
5	20m – 25m	1334m – 1332m	1700 Ωm–1800 Ωm	*Semi- Weathered rock mica schist*
		1332m – 1325m	1800 Ωm–10000 Ωm	*Fresh schistose rock slightly quartzic*
		1325m – 1324m	1700 Ωm–1800 Ωm	*Semi- Weathered rock mica schist*
		1324m – 1321m	700 Ωm–1700 Ωm	*Fresh mica schist rock.*
6	25m – 27.5m	1336m – 1325m	3000 Ωm–4000 Ωm	*Semi weathered mica schist overlain by soil cover*
		1325m – 1324m	1700 Ωm–1800 Ωm	*Semi- Weathered rock mica schist*
		1324m – 1319m	700 Ωm–1700 Ωm	*Fresh mica schist rock.*
7	27.5m – 30m	1332m – 1329m	700 Ωm–1700 Ωm	*Fresh mica schist rock.*
		1329m –1328m	1700 Ωm–1800 Ωm	*Semi- Weathered rock mica schist*
		1328m – 1326m	1800 Ωm–4000 Ωm	*Slightly weathered mica schist*
		1326m – 1324m	1700 Ωm–1800 Ωm	*Semi- Weathered rock mica schist*
		1324m – 1316m	800 Ωm–1700 Ωm	*Fresh mica schist rock.*
8	30m – 37.5m	1331m – 1325m	1800 Ωm–9200 Ωm	*Fresh schistose rock slightly quartzic*
		1325m – 1323m	1700 Ωm–1800 Ωm	*Semi- Weathered rock mica schist*
		1323m – 1321m	800 Ωm–1700 Ωm	*Fresh mica schist rock.*
		1321m – 1316m	1700 Ωm–1800 Ωm	*Semi- Weathered rock mica schist*

		1316m – 1313m	1800 Ωm – 5000 Ωm	*Fresh schistose rock*
9	37.5m – 40 m	1331m – 1320m	700 Ωm – 1800 Ωm	*Fresh mica schist rock.*
		1320m – 1318m	1700 Ωm – 1800 Ωm	*Semi- Weathered rock mica schist*
		1318m – 1313m	1800 Ωm – 9500 Ωm	*Fresh schistose rock slightly quartzic*
10	40m – 42.5m	1329m – 1309m	1800 Ωm – 4000 Ωm	*Slightly weathered mica schist*
11	42.5m – 45m	1329m – 1321	4000 Ωm – 9200 Ωm	*Relatively fresh schistose rock*
12	45m – 97.5m	1328m–1304m	1900 Ωm – 10000 Ωm	*Fresh schistose rock slightly quartzic*
		1304m–1300m	700 Ωm–1700 Ωm	*Fresh mica schist rock.*
		1300m–1329m	1700 Ωm–1800 Ωm	*Semi- Weathered rock mica schist*
		1329m–1289m	1900 Ωm–10000 Ωm	*Fresh schistose rock slightly quartzic*
13	97.5m–102.5m	1308m–1301m	700 Ωm–1700 Ωm	*Fresh mica schist rock.*
		1301m–1298m	1800 Ωm–1900 Ωm	*Semi- Weathered rock mica schist*
		1298m–1292m	1900 Ωm–10000 Ωm	*Fresh schistose rock slightly quartzic*
14	102.5m–110m	1308m–1303m	1700 Ωm–1900 Ωm	*Semi- Weathered rock mica schist*
		1303m–1301m	700 Ωm–1700 Ωm	*Fresh mica schist rock.*
		1301m–1299m	1700 Ωm–1800 Ωm	*Semi- Weathered rock mica schist*
		1299m–1296m	1800 Ωm–9500 Ωm	*Fresh schistose rock slightly quartzic*
15	110m–120m	1307m–1297m	700 Ωm–1700 Ωm	*Fresh mica schist rock.*
		1297m–1295m	700 Ωm–1800 Ωm	*Fresh mica schist rock.*
		1295m–1294m	20 Ωm–200 Ωm	*Ground water*
16	120m–122.5m	1304m–1297m	1700 Ωm–1800 Ωm	*Semi- Weathered rock mica schist*
		1297m–1296m	300 Ωm–800 Ωm	*Saturated weathered mica schist*
		1296m–1295m	20 Ωm–200 Ωm	*Ground water*
17	122.5m–132.5m	1306m–1301m	1800 Ωm–4000 Ωm	*Slightly weathered mica schist rock*
		1301m–1300m	1700 Ωm–1800 Ωm	*Semi- Weathered rock mica schist*
		1300m–1298m	20 Ωm–700 Ωm	*Saturated weathered mica schist*
18	132.5m–135m	1303m–1300m	700 Ωm–1700 Ωm	*Fresh mica schist rock*
		1300m–1297m	1700 Ωm–3900 Ωm	*Slightly weathered mica schist rock*


Mangan Landslide survey profile section-03
Elev.
Model resistivity with topography
Iteration 13 RMS error = 7.2
1260.0
1255.0
1250.0
1245.0
1240.0
1235.0
1230.0
1225.0
1220.0
0.0
40.0
80.0
120
98.5
205
425
882
1832
3803
7898
16399
Resistivity in ohm.m
Unit Electrode Spacing = 2.50 m.
Horizontal scale is 19.98 pixels per unit spacing
Vertical exaggeration in model section display = 1.25
First electrode is located at 0.0 m.
Last electrode is located at 150.0 m.

Profile section (PS03–PS03') near proposed administrative block:

Site Geology: Medium thick matured soil cover mixed with rock fragments underlain by low grade metamorphic rock sequence represented in the area by quartz chloritic sericitic phyllites. The depth wise inferred geology is formulated in the table 3.

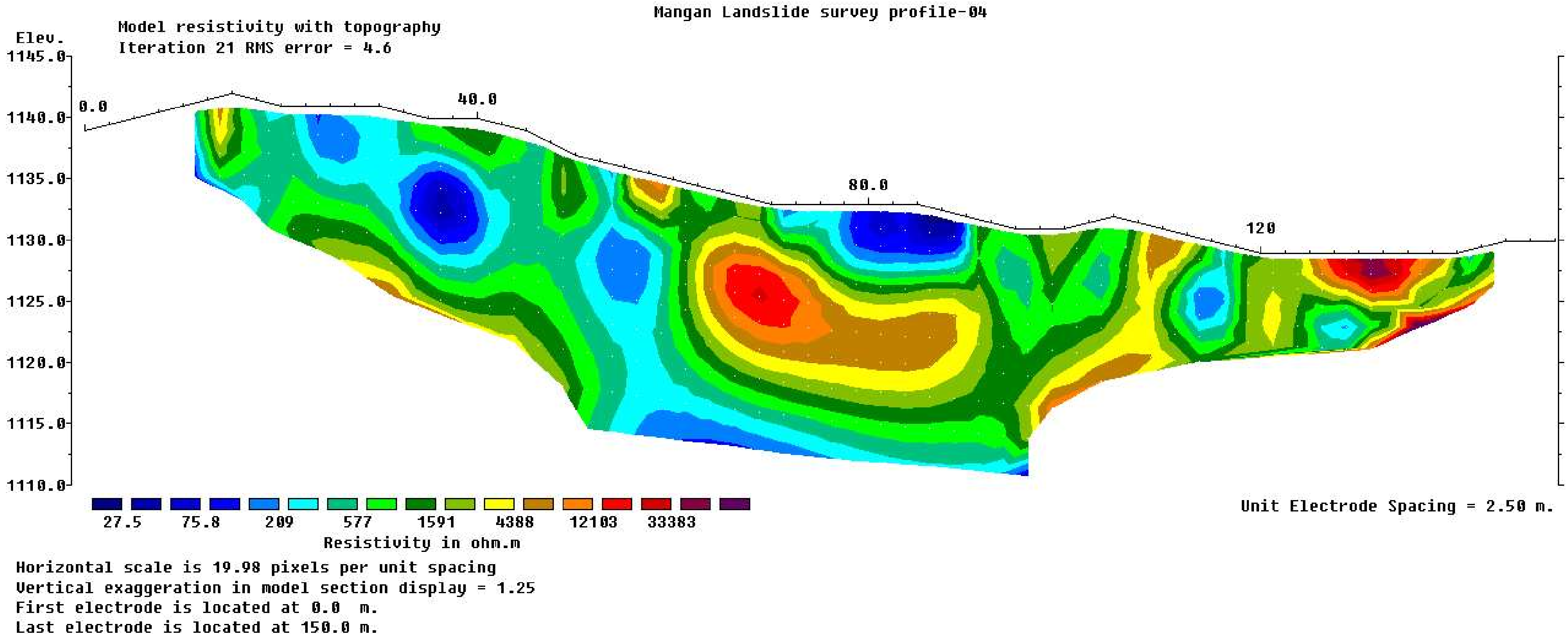
Table: 3 showing the inferred geology of sub–surface at PS–03 to PS03'

Sl. No.	PS03–PS03' (0.0mts. – 120mts.)	Depth (m)	Resistivity(ohm–meter)	Inferred geology/type of materials Present
1	0m – 5m	–	–	*Field Gap (no information)*
2	**5m – 7.5m**	**1240m – 1238m**	1800 Ωm–3800 Ωm	*Semi weathered mica schist overlain by soil cover*
3	**7.5m – 10m**	**1238m – 1237m**	4000 Ωm–9000 Ωm	*Relatively fresh schistose rock*
		1237m – 1236m	3000 Ωm–3900 Ωm	*Semi weathered mica schist rock*
		1236m – 1235m	1900 Ωm–3000 Ωm	*Slightly weathered mica schist*
4	**10m – 12.5m**	**1240m – 1237m**	3000 Ωm–3900 Ωm	*Semi weathered mica schist rock*
		1237m – 1234m	900 Ωm–2000 Ωm	*Highly weathered mica schist*
5	**12.5m – 17.5m**	**1239m – 1237m**	4000 Ωm–8000 Ωm	*Relatively fresh schistose rock*
		1237m – 1234m	**900 Ωm–2000 Ωm**	*Highly weathered mica schist*
		1234m – 1233m	500 Ωm–600 Ωm	*Water mixed with river bond material*
6	**17.5m – 20m**	**2139m – 1237m**	900 Ωm–3000 Ωm	*Highly weathered mica schist*
		1237m – 1233m	**90 Ωm–600 Ωm**	*Ground water*
7	**20m – 22.5m**	**1240m – 1231m**	**90 Ωm–600 Ωm**	*Raffong khola*
8	**22.5m – 25m**	**1240m – 1232m**	1700 Ωm–2000 Ωm	*Semi- Weathered rock mica schist*
		1232m –	500 Ωm–600 Ωm	*Water mixed with river bond*

		1231m		*material*
9	**25m – 37.5m**	**1241m – 1236m**	**100 Ωm–600 Ωm**	*Ground water*
		1236m – 1235m	3000 Ωm–6000 Ωm	*Relatively fresh schistose rock.*
		1235m – 1230m	7000 Ωm–16000 Ωm	*Fresh schistose rock slightly quartzic*
		1230m–1228m	3000 Ωm–6000	*Relatively fresh schistose rock..*
		1228m-1227m	1000 Ωm–2000 Ωm–	*Slightly weathered mica schist rock*
10	**37.5m – 52.5m**	**1241m – 1236m**	**1000** Ωm–2000 Ωm	*Slightly weathered mica schist rock*
		1236m-1231m	**90** Ωm–600 Ωm	*Ground water*
		1231m-1226m	**900** Ωm–2000 Ωm	*Highly weathered mica schist*
		1226m-1223m	**300** Ωm–600 Ωm	*Ground water*
11	**52.5m – 55m**	**1243m-1241m**	500 Ωm–600 Ωm	*Water mixed with river bond material*
		1241m-1227m	1000 Ωm–2000 Ωm	*Slightly weathered mica schist rock*
		1227m-1223m	500 Ωm-600 Ωm	*Highly weathered mica schist.*
12	**55m-57.5m**	**1244m-1227m**	1000 Ωm-2000 Ωm	*Slightly weathered mica schist rock*
		1227m-1224m	500 Ωm-600 Ωm	*Weathered mica schist with water saturation.*
13	**57.5m-60m**	**1246m-1241m**	500 Ωm-600 Ωm	*Water mixed with river bond material*
		1241m-1226m	1000 Ωm -2000 Ωm	*Slightly weathered mica schist rock*
14	**60m-70m**	**1247m-1245m**	1000 Ωm-2000 Ωm	*Slightly weathered mica schist rock*
		1245m-1241m	500 Ωm-600 Ωm	*Water mixed with river bond material.*
		1241m-1235m	1000 Ωm-2000 Ωm	*Slightly weathered mica schist rock*
		1235m-1234m	3000 Ωm-4000 Ωm	*Semi weathered mica schist rock*
		1234m-1226m	5000 Ωm-16000 Ωm	*Fresh schistose rock slightly quartzic*
15	**75m-77.5m**	**1245m-1239m**	300 Ωm-600 Ωm	*Water mixed with river bond material.*
		1239m-1235m	1000 Ωm-2000 Ωm	*Slightly weathered mica schist rock*
		1235m-1224m	5000 Ωm-16000 Ωm	*Fresh schistose rock slightly quartzic*
16	**77.5m-80m**	**1245m-1242m**	1500 Ωm-2000	*Semi- Weathered rock mica schist*

			Ωm	
		1242m-1239m	500 Ωm-600 Ωm	*Water mixed with river bond material.*
		1239m-1236m	1500 Ωm-3000 Ωm	*Slightly weathered mica schist rock*
		1236m-1235m	3000 Ωm-3900 Ωm	*Semi weathered mica schist rock*
		1235m-1230m	4000 Ωm-8000 Ωm	*Relatively fresh schistose rock*
		1230m-1224m	8000 Ωm-18000 Ωm	*Fresh schistose rock slightly quartzic*
17	**80m-82.5m**	**1244m-1243m**	500 Ωm-600 Ωm	*Water mixed with river bond material.*
		1243m-1234m	1500 Ωm-2000 Ωm	*Semi- weathered mica schist rock*
		1234m-1233m	3000 Ωm-3900 Ωm	*Semi weathered mica schist rock*
		1233m-1229m	4000 Ωm-8000 Ωm	*Relatively fresh schistose rock*
		1229m-1224m	8000 Ωm-18000 Ωm	*Fresh schistose rock slightly quartzic*
18	**82.5m-97.5m**	**1245m-1242m**	900 Ωm-1500 Ωm	*Slightly weathered mica schist rock*
		1242m-1236m	250 Ωm-600 Ωm	*Ground water*
		1236m-1235m	3000 Ωm-3900 Ωm	*Semi weathered mica schist rock*
		1235m-1227m	4000 Ωm-8000 Ωm	*Relatively fresh schistose rock*
		1227m-1223m	8000 Ωm-18000 Ωm	*Fresh schistose rock slightly quartzic*
19	**97.5m-100m**	**1224m-1236m**	250 Ωm-600 Ωm	*Ground water*
		1236m-1233m	800 Ωm-2000 Ωm	*Highly weathered mica schist*
		1233m-1231m	3000 Ωm-3900 Ωm	*Semi weathered mica schist rock*
		1331m-1326m	4000 Ωm-8000	*Relatively fresh schistose rock*
20	**100m-102.5m**	**1247m-1232m**	800 Ωm-2000 Ωm	*Highly weathered mica schist*
		1232m-1230m	3000 Ωm-3900 Ωm	*Semi weathered mica schist rock*
		1230m-1225m	3900 Ωm-4000 Ωm	*Semi weathered mica schist rock*
21	**102.5m-105m**	**1246m-1244m**	500 Ωm-600 Ωm	*Highly weathered mica schist.*
		1244m-1227m	800 Ωm-2000 Ωm	*Highly weathered mica schist*
22	**105m-110m**	**1247m-1245m**	1700 Ωm-1800 Ωm	*Semi-weathered mica schist rock.*

		1245m-1243m	500 Ωm-600 Ωm	*Highly weathered mica schist.*
		1243m-1229m	800 Ωm-2000 Ωm	*Highly weathered mica schist*
23	**110m-115m**	**1248m-1246m**	400 Ωm-600 Ωm	*Ground water*
		1246m-1235m	900 Ωm-2000 Ωm	*Highly weathered mica schist*
		1235m-1234m	300 Ωm-600 Ωm	*Ground water*
24	**115m-122.5m**	**1248m-1243m**	800 Ωm-2000 Ωm	*Highly weathered mica schist*
		1243m-1238m	90 Ωm-600 Ωm	*Ground water*
25	**122.5m-125m**	**1251m-1245m**	1900 Ωm-2000 Ωm	*Semi- Weathered rock mica schist*
		1245m-1242m	800 Ωm-1900 Ωm	*Highly weathered mica schist.*
26	**125m-145m**	**1253m-1251m**	1800 Ωm-2000 Ωm	*Semi- Weathered rock mica schist*
		1251m-1250m	3000 Ωm-3400 Ωm	*Semi weathered mica schist rock*
		1250m-1247m	4000 Ωm-8000 Ωm	*Relatively fresh schistose rock*



Mangan Landslide survey profile-04
Model resistivity with topography
Iteration 21 RMS error = 4.6
Elev.
1145.0
1140.0
1135.0
1130.0
1125.0
1120.0
1115.0
1110.0
0.0
40.0
80.0
120
27.5
75.8
209
577
1591
4388
12103
33383
Resistivity in ohm.m
Unit Electrode Spacing = 2.50 m.
Horizontal scale is 19.98 pixels per unit spacing
Vertical exaggeration in model section display = 1.25
First electrode is located at 0.0 m.
Last electrode is located at 150.0 m.

Profile section (PS04–PS04') below SNT Colony:

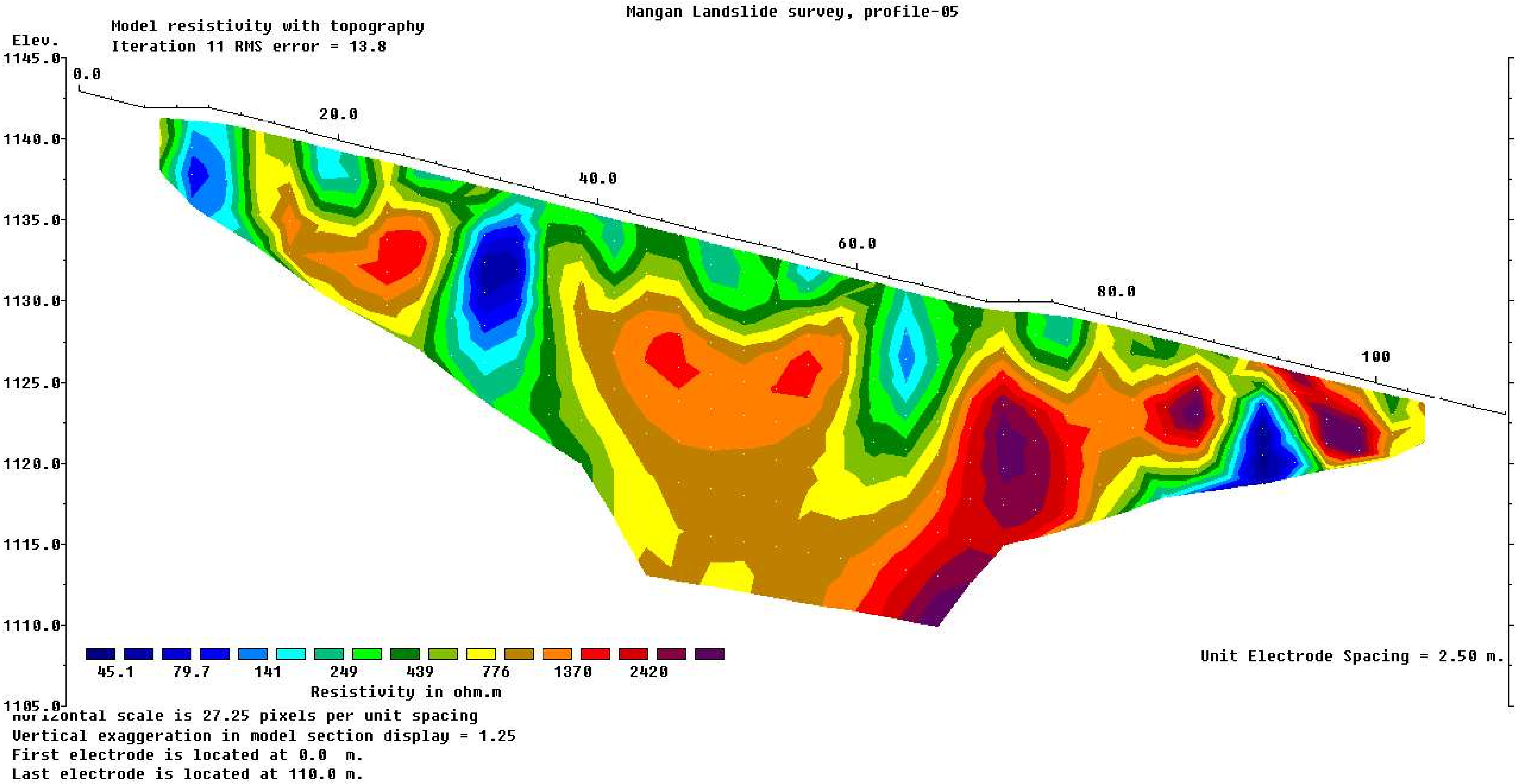
Site Geology: Medium thick matured soil cover mixed with rock fragments underlain by low grade metamorphic rock sequence represented in the area by quartz chloritic sericitic phyllites and mica shist.Further,there is high ground water movement in the area and Raffong khola is located north of the area.The area is a slow moving zone due to high ground water movement and toe erosion by Raffong khola. The depth wise inferred geology is formulated in the table below.

Section no.04

Sl. no	**Section PS 04-04' (0.0m-150m)**	**Depth (m)**	**Resistivity (Ohm-meter)**	**Inferred Geology (type of material present)**
1.	**Point X 0m-10m**	-	-	*Field Gap (no information)*
2.	**10m-12.5m**	0 m-2.5 m	400Ωm-600 Ωm	*Highly weathered mica schist.*
		2.5m-5 m	30Ωm-100 Ωm	*Ground water*
3.	**12.5m-15m**	0m-2.5m	1000Ωm-3000 Ωm	*Slightly weathered mica schist rock*
		2.5m-5m	200Ωm-500 Ωm	*Ground water mixed with sandy silty soil*
		5m-7.5m	30Ωm-100 Ωm	*Ground water*
4.	**15m-17.5m**	0.5m-5m	200Ωm-500Ωm	*Ground water mixed with sandy silty soil*
		5m-7.5m	30Ωm-100 Ωm	*Ground water*
5.	**17.5m-30m**	0m-5m	30Ωm-100 Ωm	*Ground water*

		5m-10m	200Ωm-500 Ωm	*Ground water mixed with sandy silty soil*
		10m-15m	1000Ωm-3000 Ωm	*Slightly weathered mica schist rock*
7.	**30m-42.5m**	0m-2.5m	200Ωm-500 Ωm	*Ground water mixed with sandy silty soil*
		2.5m-12.5m	30Ωm-100 Ωm	*Ground water*
		12.5m-15m	200Ωm-500 Ωm	*Ground water mixed with sandy silty soil*
		15m-20m	1000Ωm-3000 Ωm	*Slightly weathered mica schist rock*
8.	**42.5m-52.5m**	0 m-25 m	200Ωm-500Ωm	*Ground water mixed with sandy silty soil*
9.	**52.5m-55m**	0m-25m	30Ωm-100 Ωm	*Ground water.*
10.	**55m-60m**	0.5m-10m	1000Ωm-3000 Ωm	*Slightly weathered mica schist rock*
		10m-12.5m	200Ωm-500 Ωm	*Ground water mixed with sandy silty soil*
		12.5m-25m	30Ωm-100 Ωm	*Ground water*
11.	**60m-65m**	0.5m-5m	200Ωm-500Ωm	*Ground water mixed with sandy silty soil*
		5m-20m	2000Ωm-4000Ωm	*Slightly weathered mica schist*
		20m-22.5m	200Ωm-500Ωm	*Ground water mixed with sandy silty soil*
		22.5m-27.5m	30Ωm-100 Ωm	*Ground water*
12.	**65m-90m**	0.5m-7.5m	30Ωm-100 Ωm	*Ground water*
		7.5m-10m	200Ωm-500Ωm	*Ground water mixed with sandy silty soil*

		10m-20m	2000Ωm-4000Ωm	*Slightly weathered mica schist*
		20m-25m	200Ωm-500 Ωm	*Ground water mixed with sandy silty soil*
		25m-27.5m	30Ωm-100 Ωm	*Ground water*
13.	**90m-107.5m**	0m-27.5m	200Ωm-500Ωm	*Ground water mixed with sandy silty soil*
14.	**107.5m-112.5m**	0m-22.5m	2000Ωm-4000Ωm	*Slightly weathered mica schist*
15.	**112.5m-115m**	0m-20m	200Ωm-500 Ωm	*Ground water mixed with sandy silty soil*
16.	**115m-117.5m**	0m-17.5m	30Ωm-100 Ωm	*Ground water*
		17.5m-20m	200Ωm-500 Ωm	*Ground water mixed with sandy silty soil*
17.	**117.5m-120 m**	0m-17.5m	30Ωm-100 Ωm	*Ground water*
18.	**120m-125m**	0m-17.5	200Ωm-500 Ωm	*Ground water mixed with sandy silty soil*
19.	**125m-132.5m**	0m-7.5m	2000Ωm-4000Ωm	*Slightly weathered mica schist*
		7.5m-10m	200Ωm-500 Ωm	*Ground water mixed with sandy silty soil*
		10m-12m	30Ωm-100 Ωm	*Ground water*
		12m-12.5m	200Ωm-500 Ωm	*Ground water mixed with sandy silty soil*
20.	**132.5m-150m**	0m-10m	2000Ωm-4000Ωm	*Slightly weathered mica schist*
		10m-12.5m	200Ωm-100 Ωm	*Ground water*
		12.5m-17.5m	2000Ωm-4000Ωm	*Slightly weathered mica schist*



Mangan Landslide survey, profile-05
Model resistivity with topography
Iteration 11 RMS error = 13.8
Elev.
1145.0
1140.0
1135.0
1130.0
1125.0
1120.0
1115.0
1110.0
1105.0
0.0
20.0
40.0
60.0
80.0
100
45.1
79.7
141
249
439
776
1370
2420
Resistivity in ohm.m
Unit Electrode Spacing = 2.50 m.
Horizontal scale is 27.25 pixels per unit spacing
Vertical exaggeration in model section display = 1.25
First electrode is located at 0.0 m.
Last electrode is located at 110.0 m.

Profile section (PS05–PS05') below SNT Colony:

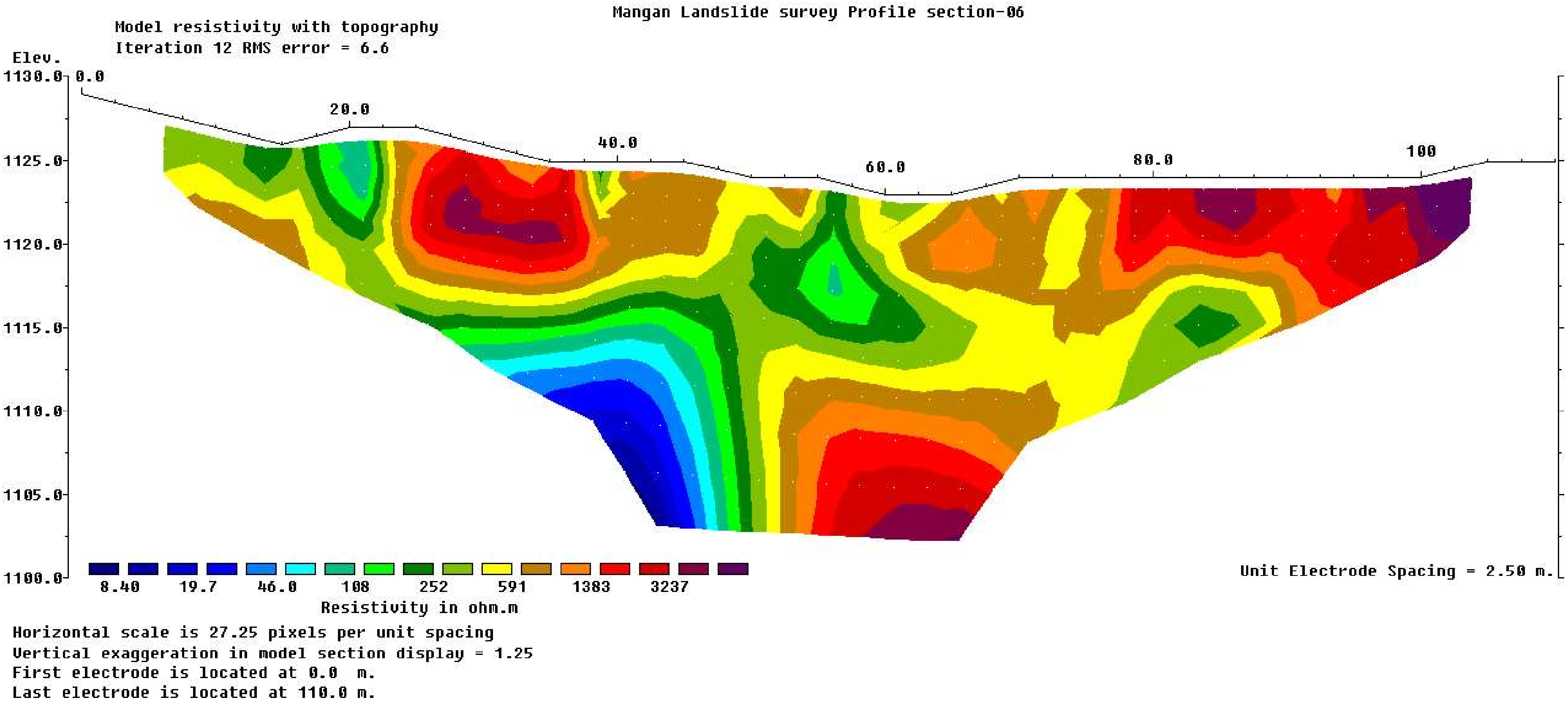
Site Geology: Medium thick matured soil cover mixed with rock fragments underlain by low grade metamorphic rock sequence represented in the area by quartz chloritic sericitic phyllites and mica schist.Further,there is high ground water movement in the area and Raffong khola is located north of the area.The area is a slow moving zone due to high ground water movement and toe erosion by Raffong khola. The depth wise inferred geology is formulated in the table below

Profile 5

Sl. No.	PS05–PS05' (0.0mts. – 120mts.)	Depth (m)	Resistivity(ohm–meter)	Inferred geology/type of materials Present
1	0m – 5m	–	–	*Field Gap (no information)*
2	5m – 7.5m	1142m – 1136m	200 Ωm–500 Ωm	*Ground water mixed with sandy silty soil*
3	7.5m – 10m	1142m – 1134m	40 Ωm–200 Ωm	*Ground water*
4	10m – 12.5m	1140m – 1133m	200 Ωm–500 Ωm	*Ground water mixed with sandy silty soil*
5	12.5m –15m	1140m – 1135m	600 Ωm–780 Ωm	*Saturated weathered mica schist*
		1135m – 1133m	400 Ωm–700 Ωm	*Slightly weathered mica schist.*
6	15m – 17.5m	1139m – 1137m	500 Ωm–600 Ωm	*Highly weathered mica schist.*
		1137m – 1136m	600 Ωm–780 Ωm	*Saturated weathered mica schist*
		1136m – 1132m	800 Ωm–1400 Ωm	*Slightly weathered mica schist*
7	17.5m – 20m	1139m – 1137m	150 Ωm–200 Ωm	*Ground water*
		1137m – 1134m	200 Ωm–500 Ωm	*Ground water mixed with sandy silty soil*
		1134m – 1133m	600 Ωm–780 Ωm	*Saturated weathered mica schist*
		1133m – 1131m	800 Ωm–1400 Ωm	*Slightly weathered mica schist*
		1131m–1130m	400 Ωm–700 Ωm	*Slightly weathered mica schist*
8	20m –22.5m	1139m–1134m	200 Ωm–600 Ωm	*Highly weathered mica schist*

		1134m – 1133m	600 Ωm–780 Ωm	*Saturated weathered mica schist*
		1133m–1129m	800 Ωm–1400 Ωm	*Slightly weathered mica schist*
		1129m–1128m	600 Ωm–700 Ωm	*Slightly weathered mica schist*
9	22.5m – 25m	1138m – 1136m	600 Ωm–780 Ωm	*Saturated weathered mica schist*
		1136m – 1129m	800 Ωm–2000 Ωm	*Slightly weathered mica schist*
		1129m–1127m	500 Ωm–780 Ωm	*Saturated weathered mica schist*
10	25m–30m	1138m–1136m	200 Ωm–500 Ωm	*Ground water mixed with sandy silty soil.*
		1136m–1135m	600 Ωm–780 Ωm	*Saturated weathered mica schist*
		1135m–1129m	800 Ωm–1400 Ωm	*Slightly weathered mica schist*
		1129m–1127m	500 Ωm–780 Ωm	*Saturated weathered mica schist*
11	30m–35m	1137m–1136m	250 Ωm–500 Ωm	*Ground water mixed with sandy silty soil.*
		1136m–1126m	40 Ωm–200 Ωm	*Ground water*
		1126m–1123m	300 Ωm–450 Ωm	*Highly weathered mica schist*
12	35m–37.5m	1137m–1121m	200 Ωm–600 Ωm	*Ground water mixed with sandy silty soil*
13	37.5m–40m	1136m–1133m	200 Ωm–600 Ωm	*Ground water mixed with sandy silty soil*
		1133m–1115m	600 Ωm–780 Ωm	*Saturated weathered mica schist*
14	40m–42.5m	1135m–1130m	200 Ωm –500 Ωm	*Ground water mixed with sandy silty soil*
		1130m–1129m	600 Ωm–780 Ωm	*Saturated weathered mica schist*
		1129m–1120m	780 Ωm–1000 Ωm	*Semi weathered mica schist*
		1120m–1116m	600 Ωm–780 Ωm	*Saturated weathered mica schist*
		1116m–1113m	780 Ωm–1000 Ωm	*Semi weathered mica schist*
15	4.25m–47.5m	1134m–1131m	400 Ωm–500 Ωm	*Highly weathered mica schist*
		1131m–1130m	600 Ωm–780 Ωm	*Saturated weathered mica schist*
		1130m–1113m	800 Ωm–1400 Ωm	*Slightly weathered mica schist*
16	47.5m–55m	1134m–1127m	200 Ωm–600 Ωm	*Ground water mixed with sandy silty soil*
		1127m–1126m	600 Ωm–780 Ωm	*Saturated weathered mica schist*
		1126m–1114m	800 Ωm–1400 Ωm	*Slightly weathered mica schist*
		1114m–1112m	600 Ωm–780 Ωm	*Saturated weathered mica schist*
17	55m–57.5m	1134m–1133m	140 Ωm–200 Ωm	*Ground water*
		1133m–1130m	200 Ωm–600 Ωm	*Ground water mixed with sandy silty soil*
		1130m–1129m	600 Ωm–780 Ωm	*Saturated weathered mica schist*
		1129m–1112m	800 Ωm–1400 Ωm	*Slightly weathered mica schist*
18	57.5m–60m	1133m–1131m	300 Ωm–500 Ωm	*Ground water mixed with sandy silty soil*
		1131m–1130m	600 Ωm–780 Ωm	*Saturated weathered mica schist*
		1130m–1118m	600 Ωm–1000 Ωm	*Semi weathered mica schist*

		1118m–1111m	780 Ωm–1000 Ωm	*Semi weathered mica schist*
19	60m–70m	1131m–1119m	100 Ωm–500 Ωm	*Ground water mixed with sandy silty soil*
		1119m–1113m	600 Ωm–780 Ωm	*Saturated weathered mica schist*
		1113m–1111m	800 Ωm–1500 Ωm	*Slightly weathered mica schist*
20	70m–72.5m	1131m–1129m	500 Ωm–600 Ωm	*Highly weathered mica schist*
		1129m–1128m	600 Ωm–780 Ωm	*Saturated weathered mica schist*
		1128m–1126m	800 Ωm–1000 Ωm	*Slightly weathered mica schist*
		1126m–1114m	1400 Ωm–3000 Ωm	*Slightly mica schist weathered rock*
21	72.5m–77.5m	1129m–1126m	200 Ωm–500 Ωm	*Ground water mixed with sandy silty soil*
		1126m–1125m	600 Ωm–780 Ωm	*Saturated weathered mica schist*
		1125m–1123m	800 Ωm–1000 Ωm	*Slightly weathered mica schist*
		1123m–1115m	1400 Ωm–3000 Ωm	*Slightly mica schist weathered rock*
22	77.5m–80m	1130m–1127m	600 Ωm–780 Ωm	*Saturated weathered mica schist*
		1127m–1116m	800 Ωm–1400 Ωm	*Slightly weathered mica schist*
23	80m–90m	1129m–1127m	400 Ωm–500 Ωm	*Highly weathered mica schist*
		1127m–1126m	600 Ωm–780 Ωm	*Saturated weathered mica schist*
		1126m–1125m	800 Ωm–1000 Ωm	*Slightly weathered mica schist*
		1125m–1123m	1500 Ωm–3000 Ωm	*Slightly mica schist weathered rock*
		1123m–1120m	800 Ωm–1000 Ωm	*Slightly weathered mica schist*
		1120m–1119m	600 Ωm–780 Ωm	*Saturated weathered mica schist*
		1119m–1118m	200 Ωm–600 Ωm	Ground water mixed with sandy silty soil
24	90m–92.5m	1129m–1128m	600 Ωm–800 Ωm	*Saturated weathered mica schist*
		1128m–1126m	400 Ωm–500 Ωm	*Highly weathered mica schist*
		1126m–1118m	40 Ωm–150 Ωm	*Ground water*
25	92.5m–97.5m	1128m–1119m	1000 Ωm–3500 Ωm	*Slightly mica schist weathered rock*
26	97.5m–100m	1127m–1121m	600 Ωm–800 Ωm	*Saturated weathered mica schist*
27	100m–102.5m	1128m–1126m	400 Ωm–600 Ωm	*Highly weathered mica schist*
		1126m–1122m	600 Ωm–800 Ωm	*Saturated weathered mica schist*
28	102.5m–105m	1126m–1121m	600 Ωm–780 Ωm	*Saturated weathered mica schist*


Mangan Landslide survey Profile section-06
Model resistivity with topography
Iteration 12 RMS error = 6.6
Elev.
1130.0
1125.0
1120.0
1115.0
1110.0
1105.0
1100.0
0.0
20.0
40.0
60.0
80.0
100
8.40
19.7
46.0
108
252
591
1383
3237
Resistivity in ohm.m
Unit Electrode Spacing = 2.50 m.
Horizontal scale is 27.25 pixels per unit spacing
Vertical exaggeration in model section display = 1.25
First electrode is located at 0.0 m.
Last electrode is located at 110.0 m.

Profile section (PS06–PS06') below Parking Stand,Mangan Bazaar:

Site Geology: Medium thick transported soil cover mixed with rock fragments underlain by low grade metamorphic rock sequence represented in the area by quartz chloritic sericitic phyllites and mica schist.Further,there is high ground water movement in the area indicated by number of streams and Jhoras.The area is a slow moving zone due to high ground water movement indicated by tilted trees and subsidence on the road section.. The depth wise inferred geology is formulated in the table below:-

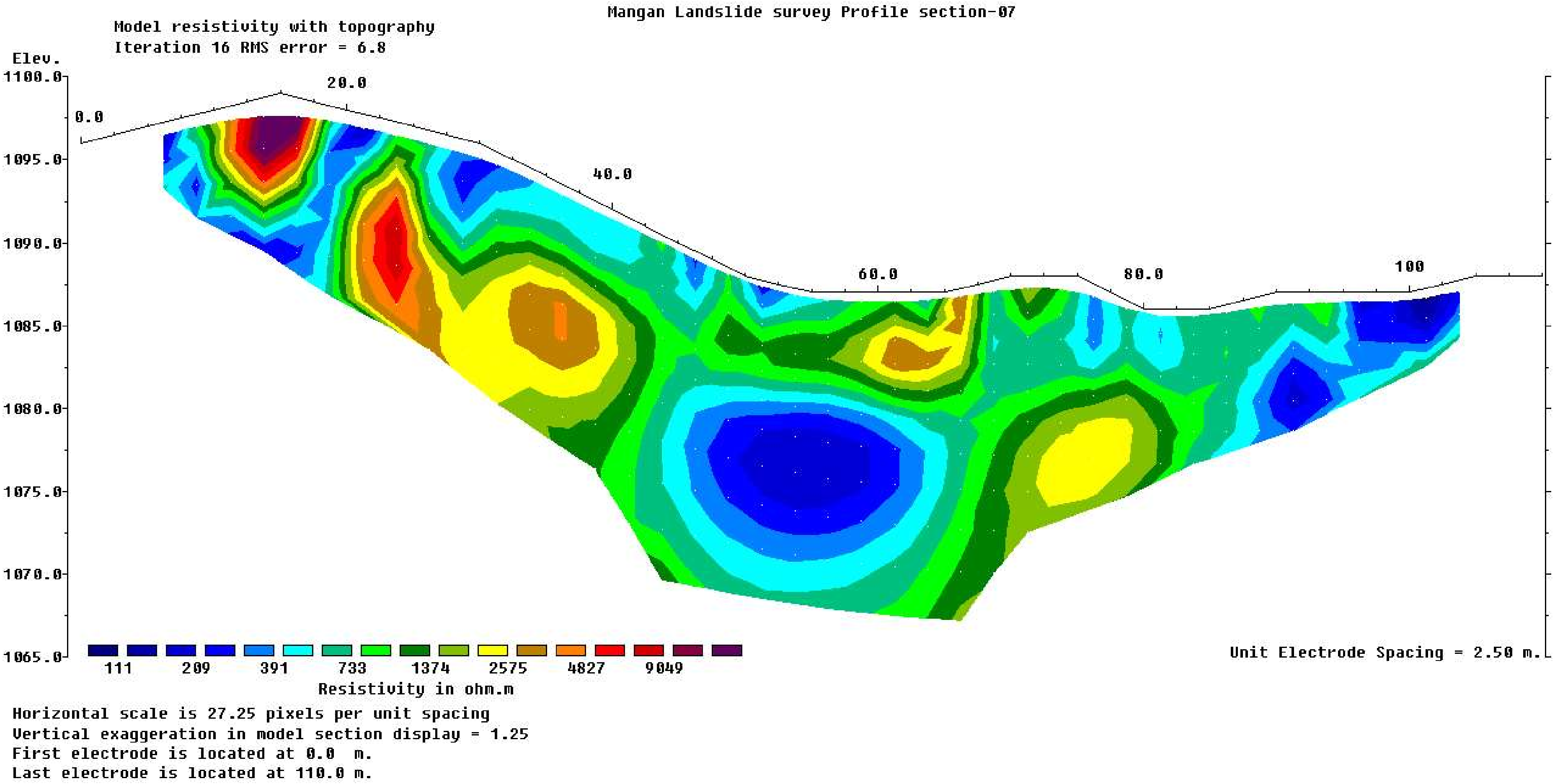
Profile no. 06

Sl. no	PS 06-06' (0.0m-110m)	Depth (m)	Resistivity (Ohm-meter)	Inferred Geology (type of material present)
1.	Point X 0m-7.5m	-	-	*Field Gap (no information)*
2.	7.5m-19.5m	2.5m-5m	108Ωm-252 Ωm	*Highly weathered mica schist*
		5-7.5m	400Ωm-591Ωm	*Saturated weathered mica schist*
		7.5m-10m	591Ωm-1000Ωm	*Weathered mica schist overlain by thick soil overburden*
3.	19.5m-22.5m	2.5m-12.5m	108Ωm-252 Ωm	*Highly weathered mica schist*
4.	22.5m-27.5m	0.5m-12.5m	400Ωm-591Ωm	*Saturated weathered mica schist overlain by saturated soil cover*
		12.5m-15m	108Ωm-252 Ωm	*Highly weathered mica schist*
5.	27.5m-37.5m	0.5m-12.5m	1383 Ωm-3237 Ωm	*Slightly mica schist weathered rock*

		12.5m-15m	108Ωm-252 Ωm	*Highly weathered mica schist*
		15m-17.5m	19Ωm-46 Ωm	*Ground water*
6.	**37.5m-47.5m**	0.5m-12.5m	400Ωm-591Ωm	*Saturated weathered mica schist overlain by saturated soil cover*
		12.5m-17.5m	108Ωm-252 Ωm	*Highly weathered mica schist*
		17.5m-27.5m	19Ωm-46 Ωm	*Ground water*
7.	**47.5m-55m**	0.5m-7.5m	400Ωm-591Ωm	*Saturated weathered mica schist overlain by saturated soil cover*
		7.5m-15m	108Ωm-252 Ωm	*Highly weathered mica schist*
		15m-17.5m	400Ωm-591Ωm	*Saturated weathered mica schist*
		17.5m-27.5m	1383Ωm-3237Ωm	*Slightly mica schist weathered rock*
8.	**55m-57.5m**	0.5m-15m	108Ωm-252 Ωm	*Highly weathered mica schist*
		15m-17.5m	400Ωm-591Ωm	*Saturated weathered mica schist*
		17.5m-20m	591Ωm-1000Ωm	*Weathered mica schist overlain by thick soil overburden*
		20m-27.5m	1383Ωm-3237Ωm	*Slightly mica schist weathered rock*
9.	**57.5m-60m**	0.5m-7.5m	400Ωm-591Ωm	*Saturated weathered mica schist overlain by saturated soil cover*
		7.5m-15m	108Ωm-252 Ωm	*Highly weathered mica schist*
		15m-17.5m	400Ωm-591Ωm	*Saturated weathered mica schist*
		17.5m-20m	591Ωm-1000Ωm	*Weathered mica schist overlain by thick soil overburden*

		20m-27.5m	1383Ωm-3237Ωm	*Slightly mica schist weathered rock*
10.	**60m-62.5m**	5m-7.5m	108Ωm-252 Ωm	*Highly weathered mica schist*
		7.5m-10m	400Ωm-591Ωm	*Saturated weathered mica schist*
		10m-17.5m	108Ωm-252 Ωm	*Highly weathered mica schist*
		17.5m-20m	400Ωm-591Ωm	*Saturated weathered mica schist*
		20m-22.5m	591Ωm-1000Ωm	*Weathered mica schist overlain by thick soil overburden*
		22.5m-27.5m	1383Ωm-3237Ωm	*Slightly mica schist weathered rock*
11.	**62.5m-65m**	5m-7.5m	400Ωm-591Ωm	*Saturated weathered mica schist overlain by saturated soil cover*
		7.5m-12.5m	591Ωm-1000Ωm	*Weathered mica schist overlain by thick soil overburden*
		12.5-15m	400Ωm-591Ωm	*Saturated weathered mica schist*
		15m-17.5m	108Ωm-252 Ωm	*Highly weathered mica schist*
		17.5-20m	400Ωm-591Ωm	*Saturated weathered mica schist*
		20m-22.5m	591Ωm-1000Ωm	*Weathered mica schist overlain by thick soil overburden*
		22.5m-27.5m	1383Ωm-3237Ωm	*Slightly mica schist weathered rock*
12.	**65m-75m**	5m-17.5m	591Ωm-1000Ωm	*Weathered mica schist overlain by thick soil overburden*
		17.5m-22.5m	400Ωm-591Ωm	*Saturated weathered mica schist*
		22.5m-27.5m	1383Ωm-3237Ωm	*Slightly mica schist weathered rock*
13.	**75m-77.5m**	5m-15m	591Ωm-1000Ωm	*Weathered mica schist overlain by thick soil overburden*
		15m-20m	400Ωm-591Ωm	*Saturated weathered mica schist*

14.	**77.5m-103m**	5m-15m	1383Ωm-3237Ωm	*Slightly mica schist weathered rock*
		15m-17.5m	591Ωm-1000Ωm	*Weathered mica schist overlain by thick soil overburden*
		17.5m-18m	400Ωm-591Ωm	*Saturated weathered mica schist*
		18m-20m	108Ωm-252 Ωm	*Highly weathered mica schist*



Mangan Landslide survey Profile section-07
Model resistivity with topography
Iteration 16 RMS error = 6.8
Elev.
1100.0
1095.0
1090.0
1085.0
1080.0
1075.0
1070.0
1065.0
0.0
20.0
40.0
60.0
80.0
100
111
209
391
733
1374
2575
4827
9049
Resistivity in ohm.m
Unit Electrode Spacing = 2.50 m.
Horizontal scale is 27.25 pixels per unit spacing
Vertical exaggeration in model section display = 1.25
First electrode is located at 0.0 m.
Last electrode is located at 110.0 m.

Profile section (PS07–PS07’) Adjacent to under construction Himgiri quarters at Adarsh Gaon.

Site Geology: Medium thick transported soil cover mixed with rock fragments underlain by low grade metamorphic rock sequence represented in the area by quartz chloritic sericitic phyllites and its variants.Further,there is high ground water movement in the area indicated by number of streams and Jhoras.The area is a slow moving zone due to high ground water movement indicated by tilted trees and subsidence on the road section.. The depth wise inferred geology is formulated in the table below:-

Profile 7

Sl. No.	PS07–PS07' (0.0mts. – 120mts.)	Depth (m)	Resistivity(ohm–meter)	Inferred geology/type of materials Present
1	0m – 5m	–	–	*Field Gap (no information)*
2	**5m – 7.5m**	**1096m – 1093m**	200 Ωm–500 Ωm	*Ground water mixed with sandy silty soil*
3	**7.5m – 10m**	**1095m – 1091m**	700 Ωm–1300 Ωm	*Highly weathered mica schist*
		1091m – 1090m	250 Ωm–500 Ωm	*Ground water*
4	**10m – 17.5m**	**1096m – 1093m**	5000 Ωm–10000 Ωm	*Fresh mica schist rock*
		1093m –1092m	2000 Ωm–2700Ωm	*Slightly mica schist weathered rock*
		1092m-1091	700 Ωm-1500 Ωm	*Highly weathered mica schist*
		1091m-1089	200 Ωm-500 Ωm	*Ground water*
5	**17.5m – 20m**	**1096m – 1091m**	700 Ωm–1300 Ωm	*Highly weathered mica schist*
		1091m – 1088m	**250 Ωm–500 Ωm**	*Ground water*
6	**20m – 22m**	**1096m – 1087m**	100 Ωm–500 Ωm	*Ground water mixed with sandy silty soil*
7	**22.5m –**	**1095m – 1094m**	**700 Ωm–1500**	*Highly weathered mica schist*

	27.5m		**Ωm**	
		1094m-1093m	**2000 Ωm-2700 Ωm**	*Slightly mica schist weathered rock*
		1093m-1085m	**3000 Ωm-6000 Ωm**	*Relatively fresh schistose rock*
8	**27.5m – 42.5m**	**1094m-1091m**	200 Ωm-500 Ωm	*Ground water*
		1091m-1088m	700 Ωm-1300 Ωm	*Highly weathered mica schist*
		1088m-1087m	2000 Ωm-2700 Ωm	*Slightly mica schist weathered rock*
		1087m-1083m	3000 Ωm-3500 Ωm	*Semi weathered mica schist overlain*
		1083m-1081m	2000 Ωm-2700 Ωm	*Slightly mica schist weathered rock*
		1081m-1078m	1400 Ωm-2000 Ωm	*Slightly mica schist weathered rock*
9	**42.5m – 45m**	**1091m – 1069m**	**700 Ωm–1300 Ωm**	*Highly weathered mica schist*
10	**45m – 47.5m**	**1089m – 1086m**	**300** Ωm–500 Ωm	*Ground water mixed with sandy silty soil*
		1086m-1082m	**1200** Ωm–1500 Ωm	*Fresh mica schist rock*
		1082m-1072m	**400** Ωm–500 Ωm	*Ground water*
		1072m-1069m	**1000** Ωm–1400 Ωm	*Fresh mica schist rock*
11	**47.5m – 50m**	**1088m-1083m**	1200 Ωm–1500 Ωm	*Fresh mica schist rock*
		1083m-1069m	200 Ωm–500 Ωm	*Ground water*
		1069m-1068m	600 Ωm-700 Ωm	*Saturated weathered mica schist on starting point & second point relatively fresh mica schist overlain soil cover*
12	**50m-55m**	**1088m-1083m**	200 Ωm-500 Ωm	*Ground water mixed with sandy silty soil*
		1083m-1081m	700 Ωm-1300 Ωm	*Highly weathered mica schist*
		1081m-1069m	200 Ωm-500 Ωm	*Ground water*
		1069m-1068m	600 Ωm -700 Ωm	*Saturated weathered mica schist on starting point & second point relatively fresh mica schist overlain soil cover*
13	**55m-57.5m**	**1087m-1081m**	700 Ωm-1500 Ωm	*Highly weathered mica schist*
		1081m-1069m	200 Ωm-500 Ωm	*Ground water*

		1069m-1067m	600 Ωm-700 Ωm	*Saturated weathered mica schist on starting point & second point relatively fresh mica schist overlain soil cover*
14	**57.5m-65m**	**1087m-1085m**	700 Ωm-1500 Ωm	*Highly weathered mica schist*
		1085m-1084m	2000 Ωm-2700 Ωm	*Slightly mica schist weathered rock*
		1084m-1082m	2700 Ωm-4500 Ωm	*Slightly weathered mica schist*
		1082m-1081m	2000 Ωm-2700 Ωm	*Slightly mica schist weathered rock*
		1081m-1078m	700 Ωm-1500 Ωm	*Highly weathered mica schist*
		1078m-1068m	200 Ωm-500 Ωm	*Ground water*
		1068m-1067m	600 Ωm-700 Ωm	*Saturated weathered mica schist on starting point & second point relatively fresh mica schist overlain soil cover*
15	**65m-67.5m**	**1087m-1082m**	2000 Ωm-3000 Ωm	*Slightly mica schist weathered rock*
		1082m-1079m	700 Ωm-1500 Ωm	*Highly weathered mica schist*
		1079m-1071m	400 Ωm-500 Ωm	*Ground water*
		1071m-1067m	1000 Ωm-1300 Ωm	*Fresh mica schist rock*
16	**67.5m-72.5m**	**1088m-1067m**	700 Ωm-1500 Ωm	*Highly weathered mica schist*
17	**72.5m-75m**	**1088m-1079m**	700 Ωm-1500 Ωm	*Highly weathered mica schist*
		1079m-1074m	2000 Ωm-2700 Ωm	*Slightly mica schist weathered rock*
		1074m-1073m	1300 Ωm-1500 Ωm	*Fresh mica schist rock*
18	**75m-77.5m**	**1087m-1083m**	300 Ωm-500 Ωm	*Ground water mixed with sandy silty soil*
		1083m-1077m	700 Ωm-1500 Ωm	*Highly weathered mica schist*
		1077m-1073m	2000 Ωm-2700 Ωm	*Slightly mica schist weathered rock*
		1073m-1072m	1300 Ωm-1500 Ωm	*Fresh mica schist rock*
19	**77.5m-80m**	**1085m-1079m**	700 Ωm-1500 Ωm	*Highly weathered mica schist*
		1079m-1074m	200 Ωm-2700 Ωm	*Semi weathered mica schist*
		1074m-1072m	1300 Ωm-1500	*Fresh mica schist rock*

			Ωm	
20	**80m-82.5m**	**1085m-1081m**	400 Ωm-500 Ωm	*Ground water mixed with sandy silty soil*
		1081m-1074m	700 Ωm-1400 Ωm	*Highly weathered mica schist*
21	**82.5m-87.5m**	**1085m-1075m**	1300 Ωm-1400 Ωm	*Fresh mica schist rock*
22	**87.5m-95m**	**1086m-1084m**	700 Ωm-1300 Ωm	*Highly weathered mica schist*
		1084m-1073m	250 Ωm-500 Ωm	*Ground water*
23	**95m-105m**	**1086m-1083m**	100 Ωm-500 Ωm	*Ground water mixed with sandy silty soil*
		1083m-1082m	1300 Ωm-1400 Ωm	*Fresh mica schist rock*

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A Report on Seismic Refraction Survey

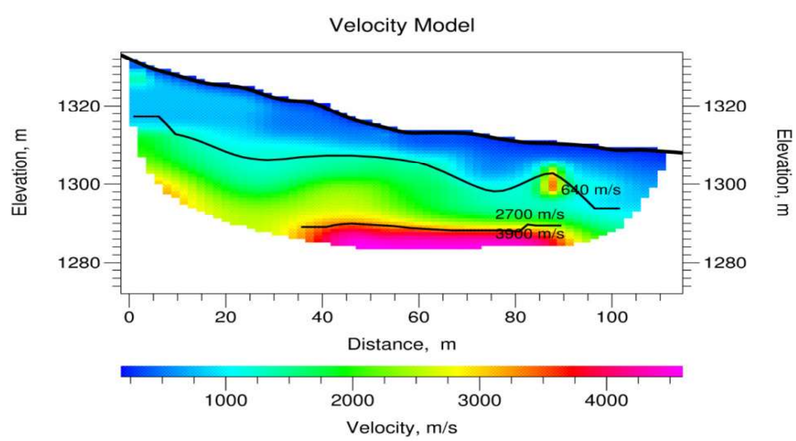
For

Seismic Refraction Survey of landslide area at Mangan North Sikkim

By

PARSAN Overseas (Pvt) Limited

(An ISO 9001-2015 Company)



October, 2017

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EXECUTIVE SUMMARY

In accordance with Work Order as per letter having Ref. No. 409/SSDMA/LRDMD/GoS/2017, dated 04.09.2017; Parsan Overseas Pvt Limited carried out Seismic Refraction Survey at the landslide area at Mangan, North Sikkim.

The field work was carried out from 25th to 26th October, 2017.

The report Includes Methodology, Field Operations as well as results.

TABLE OF CONTENTS

INTRODUCTION

Seismic Refraction Survey has been carried out by M/s Parsan Overseas Pvt. Ltd., New Delhi at the landslide area at Mangan, North Sikkim.

This report presents the findings of seismic refraction survey.

OBJECTIVE AND SCOPE OF WORK

The seismic refraction surveys were conducted at four locations provided by the client. The aim of the investigation was to provide information regarding subsurface soil-rock profiles along the surveyed lines.

SEISMIC REFRACTION SURVEY

Description of Seismic Profiles

Seismic survey has been carried out along three lines, viz. Profiles-1 to 4. Each profile was m long comprising 24 geophones located m apart. Cumulative length of all the profiles is 322 m (Table.1).

Table.1: Summary of seismic profiles

S. No.	Profile	Length (m)	Location
1	Profile-1	115	Mangan
2	Profile-2	69	"
3	Profile-3	92	"
4	Profile-4	46	"

Total Profile Length = 322 m

Equipments and Accessories

Following equipment and accessories were used

1.	Seismograph	:	Model Lakkolit Signal Enhancement type fully digital 24 channel Engineering Seismograph.
2.	Geophones	:	Moving-coil type digital grade Vertical & Horizontal Geophones, Natural Frequency 10 Hz
3.	Cable	:	Geophone spread cables, 5m spacing, water Proof joints, made in Germany
4.	Software	:	SeisOpt@2D V6.0

Energy Source

A Sledge Hammer was struck vertically on an iron plate to generate P-waves.

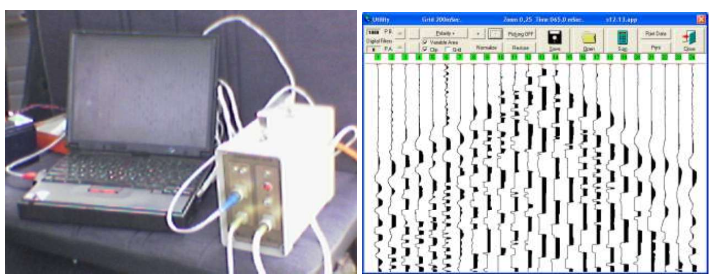
Sledgehammer as energy Source

Geophone and Geophone Spread

Low frequency (10Hz) spike Geophones were used to record seismic signals. The general layout of the seismic survey lines was supplied in accordance with the co-ordinate system provided by the client. Shooting progressed along the lines. For seismic lines 2/3/4/5m geophone spacing was used in a spread. Depending on the length available along seismic lines, 24 channels were used. The seismic spread consisted of five shots with a minimum of two end shots, two mid shots and one center shot.

Care was taken to ensure that the pointed ends (spikes) of the Geophones were fully embedded in the top soil.

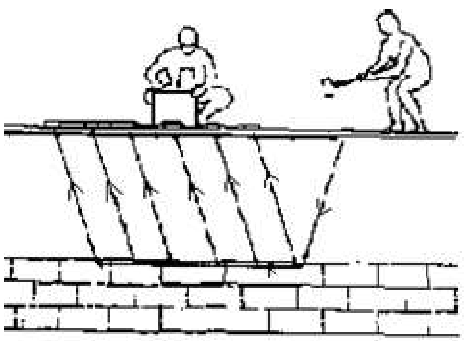
Seismograph

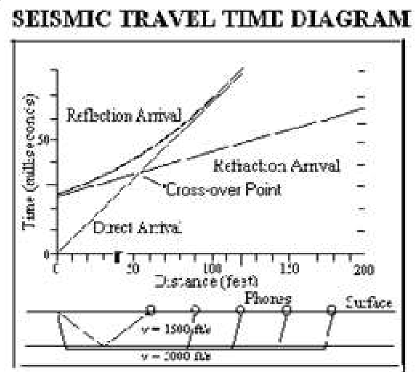


Lakkolit 24 channel Engineering Seismograph was used to record field data. The seismograph has the signal enhancement or stacking capability. The seismograph records the arrival of seismic waves through 24 channels. The seismic waves detected by each geophone are displayed simultaneously on the screen.

Seismic Refraction

With Seismic techniques, in general, a stress applied at the surface of an elastic media creates the conditions for the associated strains to propagate as elastic

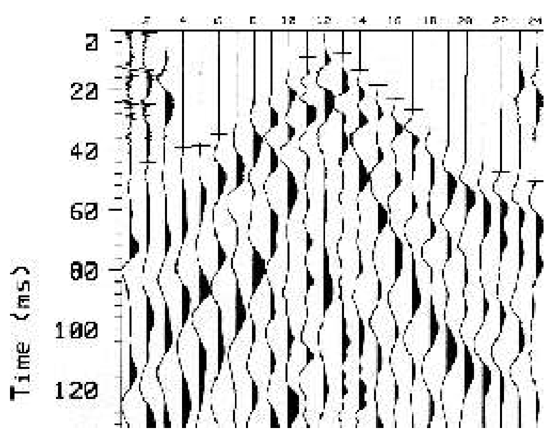




waves (P & S) in the subsurface material as pattern of particle deformation traveling with velocities that are dependent on the elastic properties and densities of the media through which they travel.

The basic principle behind seismic refraction surveys is to initiate elastic waves at a point at or near the ground surface and to determine at a number of other positions the arrival times of the seismic energy that has traveled along discontinuities or interfaces between surface layers and totally refracted back to the surface.

The seismic energy source creates the seismic elastic waves. The travel times of these elastic waves are detected by series of geophones, placed in line into the ground and connected to the seismograph, via the geophone cable. The seismograph will register these times and display them as traces of time for individual geophones.



By processing these arrival times the characteristic velocity and the thickness of the underlying layer can be calculated.

The detailed theory of the Seismic Refraction is provided in Appendix-C attached with this report.

Both normal and reverse profiles were considered during the field execution.

Data Interpretation

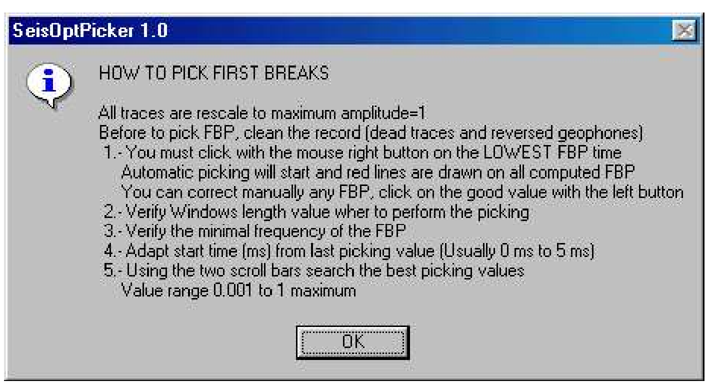
Data Processing

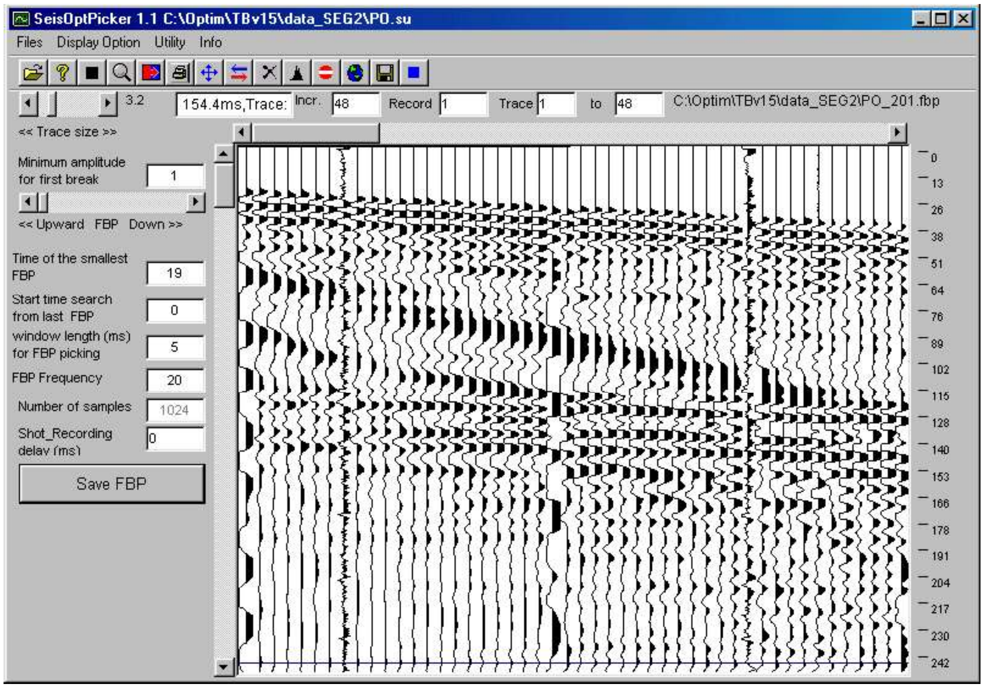
The data is stored in the hard disk of the seismograph at the time of data acquisition. The data is transferred to the computer for further processing.

The processing involves picking the first arrivals, input of data with geophone elevations and first arrivals, and final interpretation for velocity model. In case of noisy data there are intermediate steps of data processing using filtering, amplitude corrections etc.

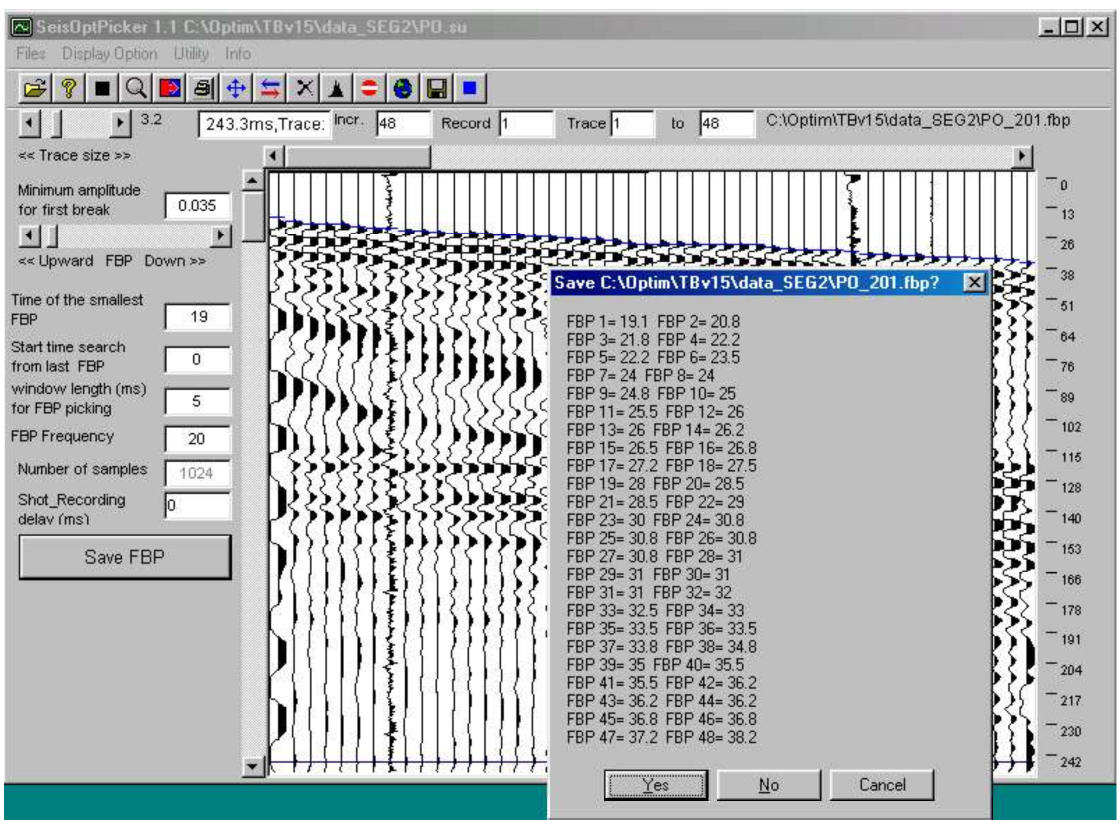
Picking of First Arrivals

Latest software SeisOptPicker was used for picking the first arrivals. SeisOptPicker is a first arrival, picking module that can read in raw shot gathers recorded in many different formats (for example, ABEM Terraloc, SEG-Y, SEG-2, and ES1225) and perform automatic and manual picking of first breaks. The picks and the survey geometry information can then be easily exported into files that can be used directly by SeisOpt @2D, Optim's Refraction interpretation software. In addition, the module also allows the user to interactively input and edit survey geometry, manipulate various display options, perform basic processing like Automatic Gain Control (AGC) and filtering, display and edit trace header values, compute frequency spectra and do a linear velocity analysis. It also has a printing module that enables the user to produce report-quality output.



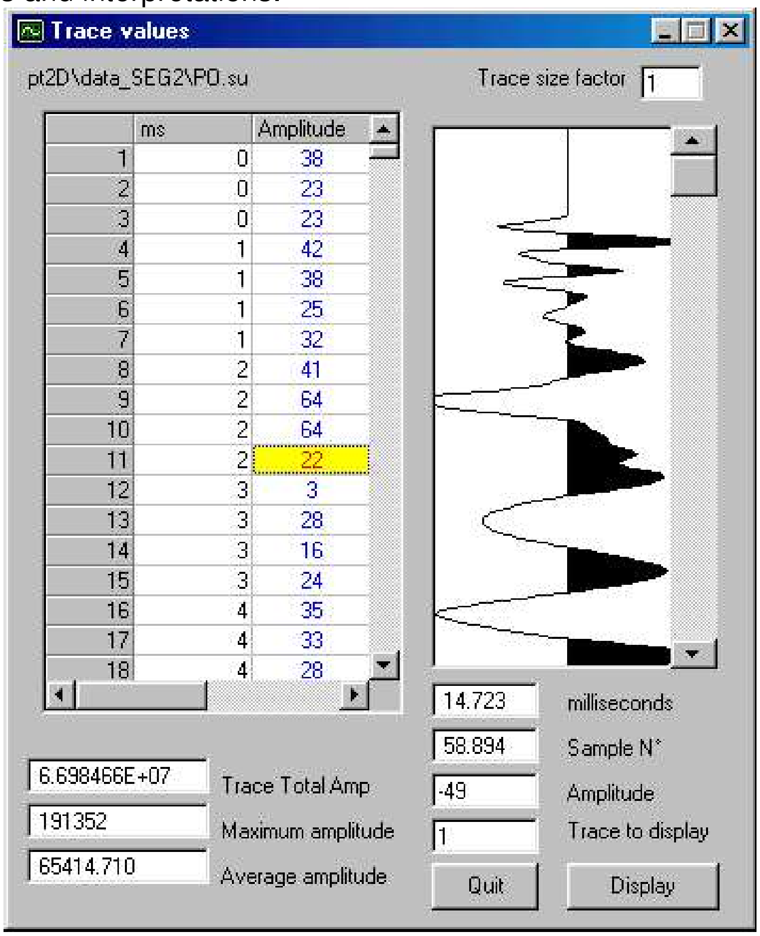


Display showing one shot gather



Automatic picking of first arrivals

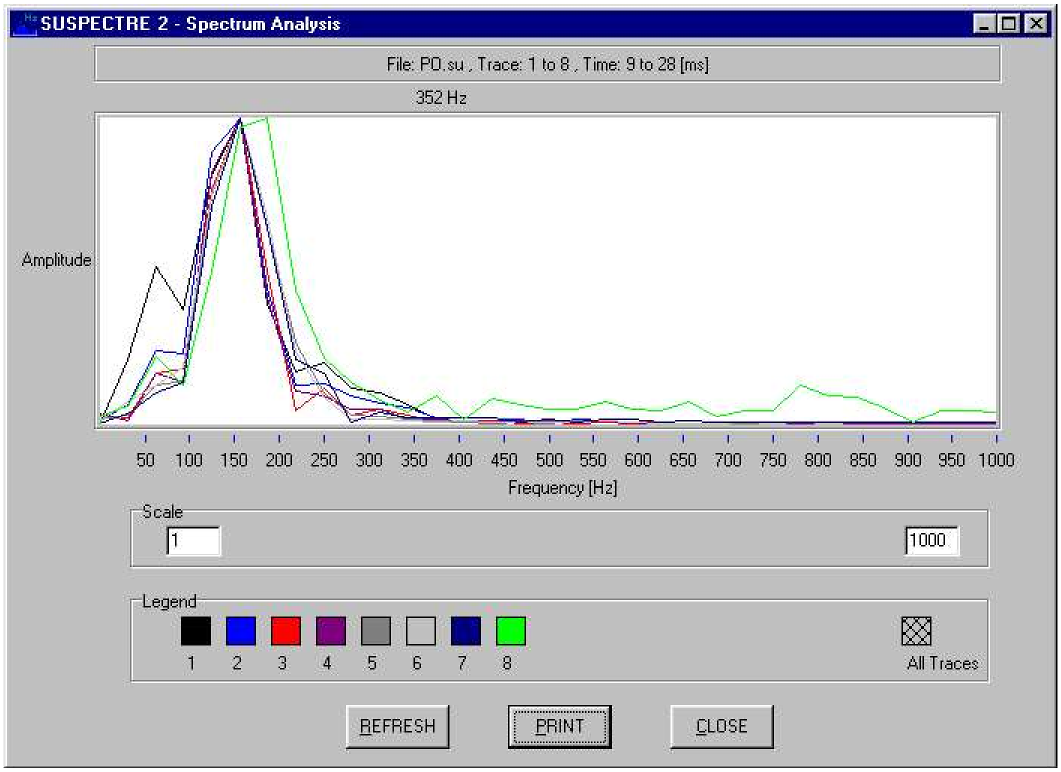
As discussed earlier, seismic refraction works with first arrival data only. The first arrivals can be direct arrivals or Refracted arrivals. The first arrival data is used to draw time-distance curves (also called T-X curves) which are used for computations and interpretations.



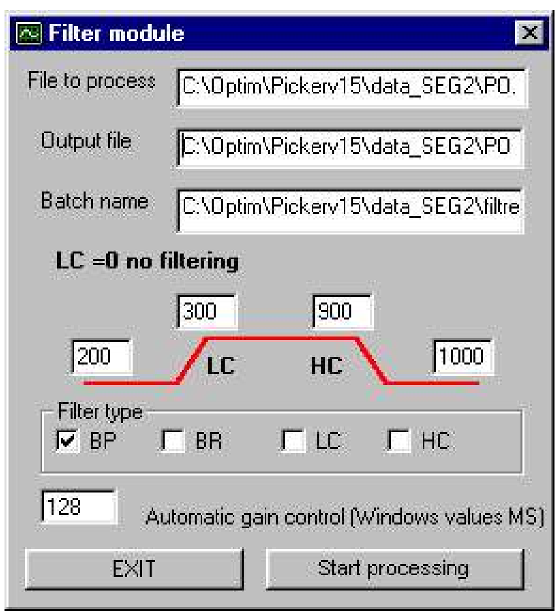
Trace Amplitude Corrections/ Adjustment

Seismic refraction survey is performed using geophones in a linear array, recording arrival times from shots at various places along the array. Geophones near the shot point receive strongest signals while those away from the shop point receive lesser amount of energy. Then will be able to pick first arrivals cleanly, it is therefore important to adjust amplitudes of traces for better visibility and judgment.

Noise from flowing rivers, traffic etc. also is recorded with signal. In such cases filtering is required to be performed on the signal, to suppress noise and enhance the signals. The software used allows for frequency spectrum analysis of the signal and subsequent filtering.



Frequency Spectra of Traces, for spectrum analysis & filtering



Velocity Model Development

One of the latest and most advanced software has been used for interpretation and velocity model computation of data obtained.
SeisOpt @2D is an automatic Refraction interpretation package that contains modules for performing velocity optimization and visualization, virtual survey design and output report quality images. SeisOpt@2D is the Graphical User Interface to the suite of modules for performing the velocity model optimization and visualization, interactive Seismic survey design, and outputting postscript images of the results for printing.

The main GUI display window is for viewing velocity models and other output from the optimization process. In addition, there are controls for setting parameters and launching the optimization module, as well as for making report quality output.

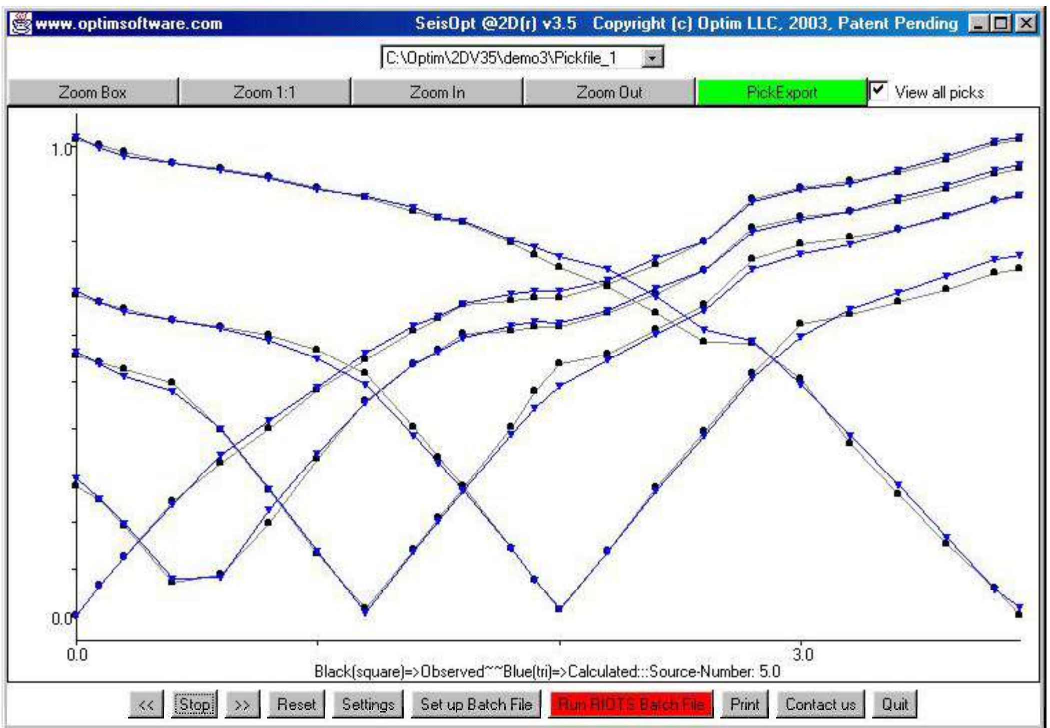
SeisOpt@2D uses only the first-arrival travel times and the survey geometry to derive subsurface velocity information. For this reason, accurate picks are important. It uses a nonlinear optimization technique called generalized simulated annealing and it involves forward modeling. Test velocity models are created, through which travel times are calculated. These calculated travel times are compared with the observed data. Testing every possible velocity model would take far too long, so SeisOpt@2D uses Optim's proprietary algorithm to search through only a small percentage of the many possible models, yet still find the best model. It is called an optimization because the discrepancy, or error, between the calculated and observed travel times is optimized. In this case the optimal solution is the velocity model with the minimum travel-time error.

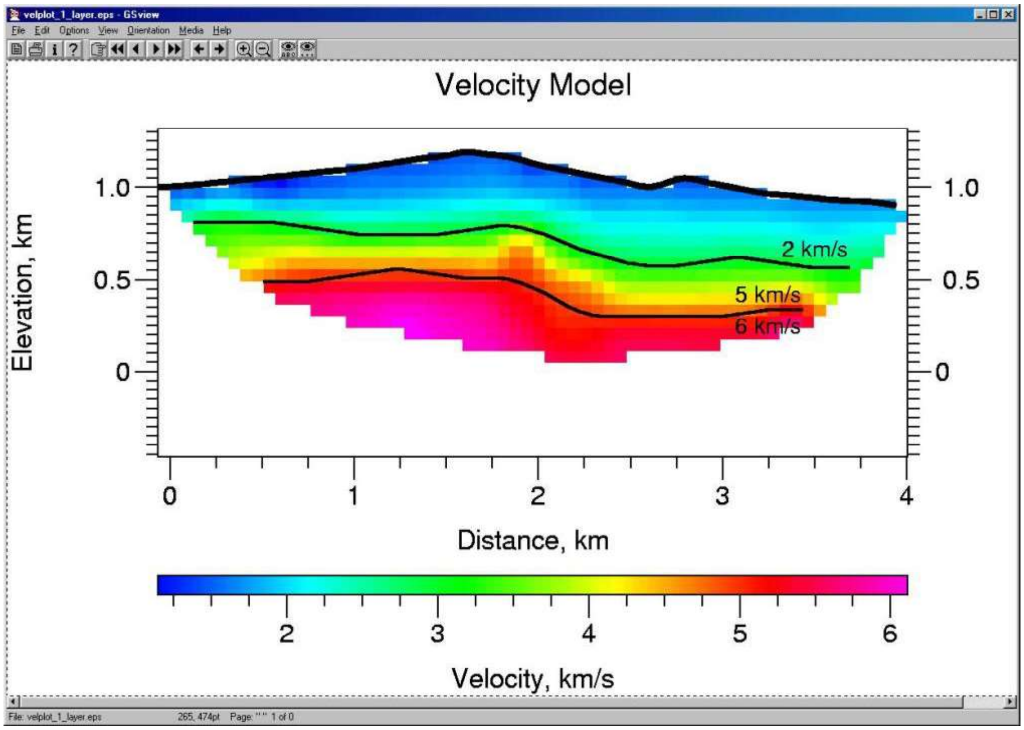
Within SeisOpt@2D, the velocity models are represented as discrete square cells. The term resolution is used to refer to the relative number of cells used to represent a given model. A low- resolution model would have a relatively low number of large cells, compared to a high-resolution model, which would be comprised of a large number of small cells. In SeisOpt@2D, the resolution can be adjusted. In general, the factors that determine the appropriate resolution are the receiver spacing and the size of the target subsurface features. SeisOpt@2D comes with several preset resolutions that are based on the receiver spacing of the current data set. Optionally, any resolution can be specified. However, increasing the resolution beyond the highest preset can cause artifacts, or false velocity features, in the final velocity model. Running the optimization on the same data with different resolutions and with different depth ranges at the same resolution of the velocity model can increase confidence in the results. Features that are present in models with different resolutions can be assumed to be real with much greater confidence.

For each velocity model optimization, SeisOpt@2D produces a file showing the number of times each cell in the model was sampled. This determines which parts of the velocity model are actually controlled by the data. Any gaps in the sampling at the end of the model correspond to unconstrained areas of the velocity model. Therefore, this sampling information should be considered before interpreting the optimized velocity model.

Why SeisOpt @2D?

SeisOpt @2D is Refraction velocity optimization software. The only input it requires is the first arrival picks and array geometry, making it an ideal tool to use in an area where very little information is available about the subsurface velocity structure. It can handle irregular topography and does not require any elevation correction of the data before analyses. SeisOpt @2D predicts subsurface morphology, maps strong lateral velocity variations, outputs a map of the subsurface ray coverage, contains tools to visualize and analyze the results, quantitatively compare the data (picks) and model, and interactively or automatically optimize the array geometry for sampling the desired subsurface target.





The interpretation accuracy increases tremendously by successive improvements in iterative manner.

The velocity gradually increases with depth, and layers are superimposed on the velocity model with information of site stratigraphy and correlation with existing data.

SEISMIC SURVEY RESULTS

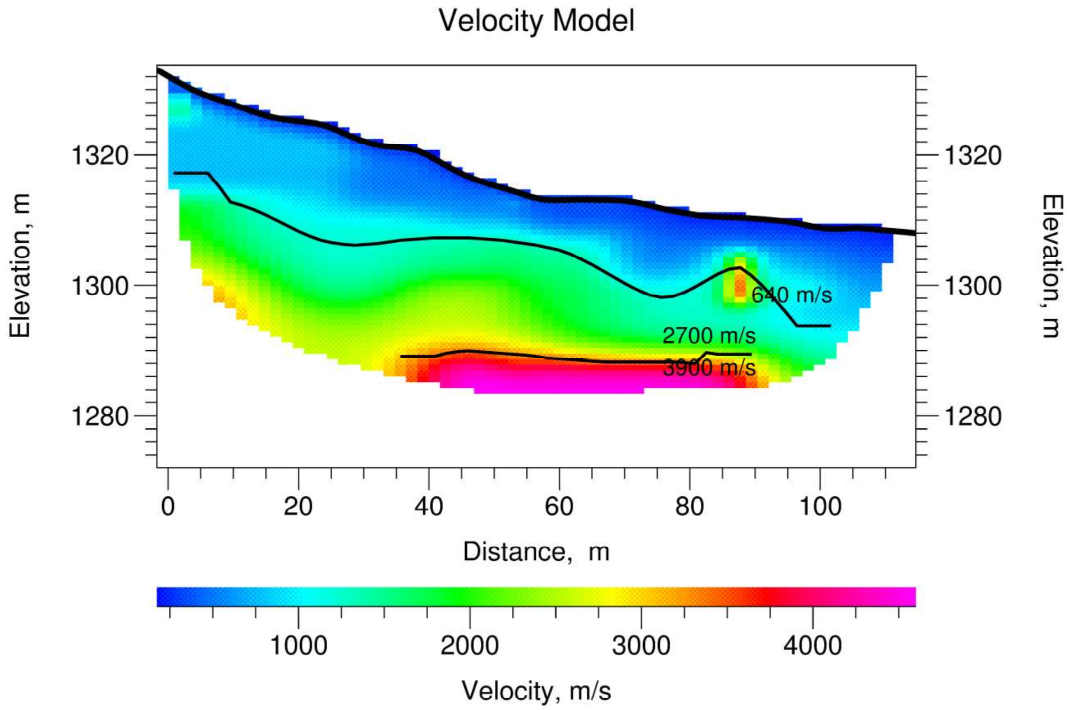
Seismic wave velocity in soil and rock is dependent on the soil type and its conditions. For rocks, degree of weathering, jointing, fracturing etc., are important. The velocity models obtained from the seismic refraction survey are enclosed. The results show variation in velocities up to the investigated depth associated with weathered/ compact rock.

The gradient type models assume an increasing velocity within layers also (more close to reality and geology) whereas traditional layered models assume distinct velocity changes and same velocity within a layer. Due to this inherent difference, there is always slight difference in depth to layer of a particular velocity.

Based on results of seismic survey, subsurface sections have been developed along all the survey lines.

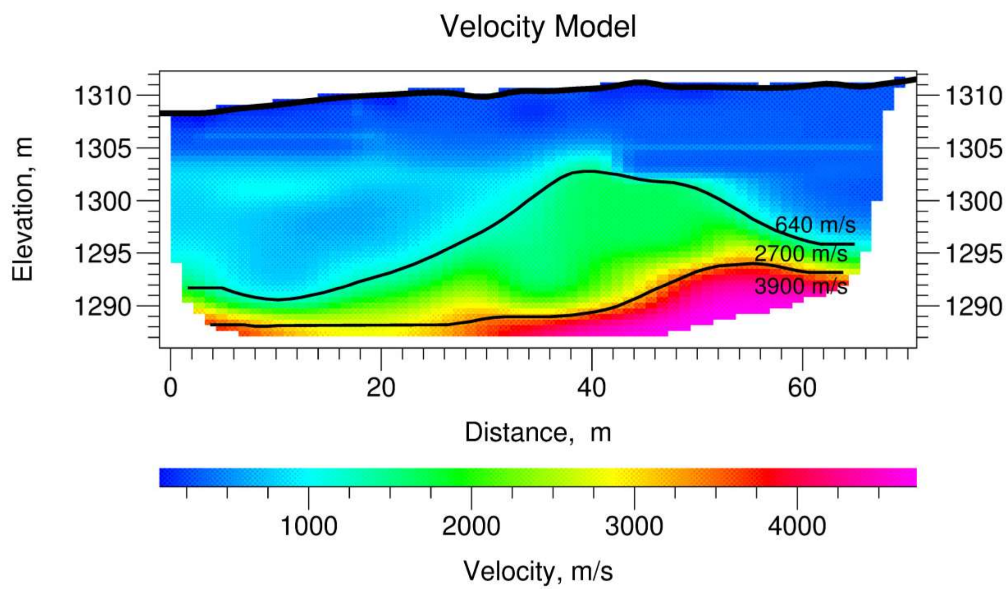
Results of all the four profiles are discussed below.

Profile 1



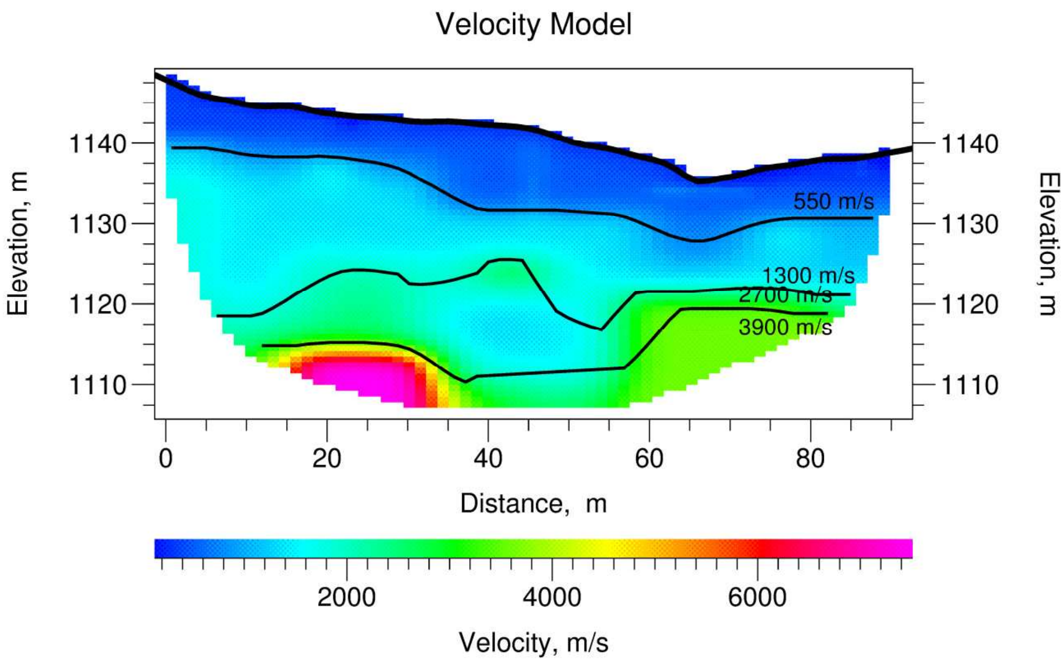
Total length of the profile-1 was 115m, with each geophone spacing of 05m. Here, three layer case have been observed. The top layer encountered an approx compressional wave velocity of 640 m/s, representing top soil. The second layer encountered compressional wave velocity of 2700 m/s, representing moderately weathered rock. The third and final layer encountered compressional wave velocity of 3900 m/s, representing competent rock.

Profile 2



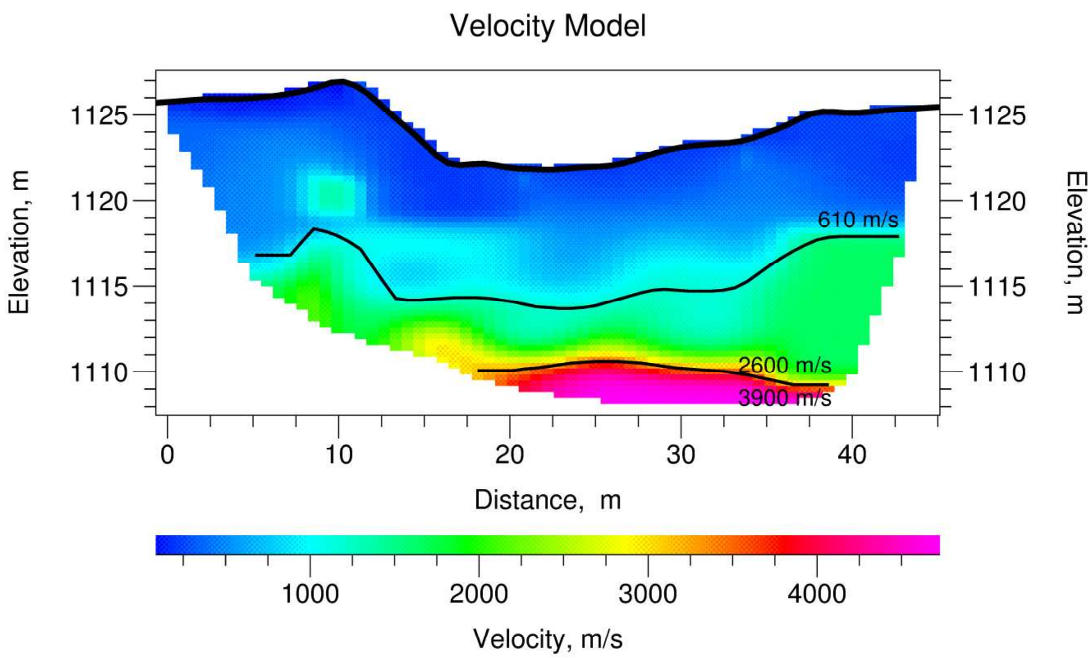
Total length of the profile-2 was 69m, with each geophone spacing of 03m. This profile was in continuation with profile-1. Here also, three layer case have been observed. The top layer encountered an approx compressional wave velocity of 640 m/s, representing top soil. The second layer encountered compressional wave velocity of 2700 m/s, representing moderately weathered rock. The third and final layer encountered compressional wave velocity of 3900 m/s representing competent rock.

Profile 3



Total length of the profile-3 was 92m, with each geophone spacing of 04m. Here, four layer case have been observed. The top layer encountered an approx compressional wave velocity of 550 m/s and the second layer encountered a velocity of 1300 m/sec. Both the layers representing top soil. The third layer encountered compressional wave velocity of 2700 m/s, representing moderately weathered rock. The fourth and final layer encountered compressional wave velocity of 3900 m/s, representing competent rock.

Profile 4



Total length of the profile-4 was also 46m, with each geophone spacing of 02m. Here, three layer case have been observed. The top layer encountered an approx compressional wave velocity of 610 m/s, representing top soil. The second layer encountered compressional wave velocity of 2600 m/s, representing moderately weathered rock. The third and final layer encountered compressional wave velocity of 3900 m/s, representing competent rock.

Annexure-1: Principle and Theory of Seismic Refraction

In Seismic Refraction technique, stress waves applied by impact of a hammer at the surface of an elastic media, creates associated strains to propagate as compressive elastic waves in the subsurface material in a pattern of particle deformation traveling with velocities dependent on the elastic properties and densities of the media through which they travel.

The basic principle behind Seismic Refraction Survey is to initiate elastic waves at a point on or near the ground surface, and to determine the arrival times of the Seismic energy that has traveled along discontinuities or interfaces between layers and refracted back to the surface at a number of points.

A Seismic energy by impact of a hammer on a steel plate creates the Seismic elastic waves. The travel times of the Refracted waves are detected by a series of Geophones placed in –line on the ground and connected to the Seismograph via Geophone cable. The Seismograph will register the ground response with time of arrival and display them as traces on the Seismograph; the data are stored internally for future retrieval. The characteristic velocities and thickness of the under laying layers can be calculated by processing the arrival times using computer.

Interpretation of the Seismic Refraction data was carried out using the Delay Time method to establish initial model for SIPT2 program from Rim-rock Geophysics Inc., which was refined by iteration process using ray tracing. In this method, the thickness of the subsurface layers and their velocities are calculated. The results were cross-checked by intercept time method. A brief outline of the intercept time method is given below.

In order to calculate the apparent P & S -wave velocities and the intercept times from various subsurface layers, the measured “first arrival times” are plotted versus distance. These ‘T-X’ curves are plotted for every shot point.

Intercept time method Seismic Refraction interpretation use a mathematical model of the subsurface in which each layer has a constant Seismic velocity and is bounded by horizontal or dipping interfaces. The Seismic velocities must increase with depth so that total Refraction can occur at each interface.

Considering a simple case of two layers on one interface, the total time “T” for Seismic waves to travel from the shot point A to Geophone D would be:

$T = t_{AB} + t_{BC} + t_{CD}$ ……………………. (1)

By simply representing the travel segments AB, BC and CD in the above equation in terms of the layers velocity (V_1 and V_2) thickness (h1) distance (X) and the incident angle (ϕ_{12}) total travel time T would be:

$$T = h_1/(\cos \phi_{12} V_{1)} + (X\text{-}2\, h_1 \tan \phi_{12)}/ V_2 + h_1 /(\cos \phi_{12} V_{1)} \qquad (2)$$

Applying Snell's Law, where Sin ($\phi_{12)}$ - V_1 / V_2 in case of total refraction and by rearranging equation 2, the total time "T" can be presented as:

$$T = (X / V_2) + (2\, h_1 (\cos \phi_{12} V_1) \qquad (3)$$

Where the second parameter of this equation equals to the intercept time "t1" (Sketch –1) i.e:

$$t1 = 2\, h_1 (\cos \phi_{12} V_1) \qquad (4)$$

To expand this equation to include an "n" number of layers

$$T = X / V_n + 2\, hi \cos \phi_{h\,n} / V_1 \qquad (5)$$

Where the intercept time for the "n" layer t_n will be:

$$t_n : \sum^{n-1} 2\, h_i \operatorname{Cos} \phi_{h\,n} / V_1 \qquad (6)$$

I = layer number

This Seismic Refraction method depends fundamentally on the propagation of Seismic waves in elastic or visco-elastic media. The Seismic waves travel through the Earth with a definite velocity depending upon the properties of material and along a definite path. The Seismic waves, like the light waves, follow the path which require the least time to travel from source to receiver. The velocity depends particularly upon the degree of consolidation of the subsoil material. A velocity but will be deflected if it passes through a discontinuity where there is distinct change in elastic properties. The amount of deflection follows Snell's Law of Refraction and may be expressed by the equation.

$$\frac{\text{Sin } I}{\text{Sin } r} = \frac{V_1}{V_2} \qquad (7)$$

I = angle of incidence

r = angle of refraction

V_1 = Velocity of propagation of the Seismic wave in the Incident medium, and

V_2 = Velocity of propagation of the Seismic wave in the Refracting medium

In Seismic Refraction Test, the rays which travel in a Critical angle, i.e. become Refracted parallel to the boundary (r=90°) and are Refracted back to the surface at the Critical angle are of interest. Accordingly for r=90°, equation (7) becomes

$$\text{Sin } i = \frac{V_1}{V_2} \qquad (8)$$

This phenomenon forms the basis of the Refraction Seismic surveying.

When the detector, commonly known as Geophone is located very close to the shot point in comparison to the depth of the horizontal in the upper medium at a velocity V_1 and will arrive at a time.

$$T1 = \frac{X}{V1} \qquad (9)$$

Where

X = horizontal distance between the Source and Receiver and

T1 = time of travel of the Seismic wave from Source to Receiver.

The Time-Distance curve is a straight line starting from the origin and having a slope of $1/V_1$

At certain distance X_c (Critical distance) a wave that has been refracted along the discontinuity will reach the surface at the same time as that traveled along the direct horizontal path with velocity V1. At all distances greater than the critical distance X_c, the wave refracted along the surface or horizontal discontinuity will reach the Earth's surface first and therefore, constitute the first arrival.

The time taken between the initiation of the Seismic wave at a shot point and its first arrival at the detector places at a measured distance is known as first arrival time. The first arrival times are plotted against the distances of the corresponding detectors from the source. These points are joined by straight lines. The slopes of different straight lines thus drawn are inversely proportional to the velocities of different layers with contrasting elastic properties. The resultant Time – Distance graphs are shown in plots.

From the slope of each straight line segment, velocities of the mediums with different elastic properties are found out and thicknesses of the layers are calculated.

Analyses of test results

Results of Seismic Test at each shot point have been analyzed using the following methodology.

1. First arrival Times from all Channels of the Seismic Unit are noted from the response charts and plotted against Geophone distance.

2. Best fit straight lines are drawn through these points

3. Slopes of each segment of straight lines are calculated. The slope is inversely proportional to the apparent velocity (v) of the elastic media.

4. Critical angle of each line segments are calculated as follows:

$$\theta_{12} = \sin^{-1} \frac{V_1}{V_2}$$

$$\theta_{23} = \sin^{-1} \frac{V_2}{V_3}$$

$$\theta_{13} = \sin^{-1} \frac{V_1}{V_3}$$

Where V_1, V_2 & V_3 are the velocities of P-wave in first, second and the third layers respectively

5. The straight line segments are extended to intercept the time axis of the Time –Distance plots, intercept times t1 and t2 are noted

6. Thickness of the first and second layers are calculated using the following equations:

$$h1 = \frac{t_1 V_1}{2 \cos \theta_{12}} \quad \ldots\ldots\ldots\ldots (10)$$

$$h2 = \left[t_2 - \frac{2\, h1 \cos \theta_{13}}{V_1} \right] \frac{V_2}{2 \cos \theta_{23}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$$

Where, h1 and h2 are the thickness of the first and the second layers.

7. Analysis of data and calculations has been carried out using standard software on computer. Summary of the results have been presented in Section – II

8. The existing ground levels recorded during ground survey and the reduced levels of interfaces have also been included.

Interpretation of Test Results

The general procedure for processing Refraction data included the following steps:

1. Review of all field report information to determine Refraction acquisition geometry.
2. Playback and analysis of raw data files from selected lines to determine the quality of Refraction arrivals, and if data requires pre-processing filtering or gain adjustments.
3. Perform data filtering, gain adjustments and trace edits to remove bad traces.
4. Load data into Refraction processing program to perform picking of first break Refraction arrivals, input elevation and geometry data.
5. Generate time distance curves for each Refraction line segment, and perform reciprocal time analysis.
6. Perform velocity inversion processing if low velocity layers or lateral velocity changes are high.
7. Interpret data and refine velocity plots.
8. Generate Final Refraction plots.

Annexure-2: Profile Co-ordinates

SRT-1

Geophone	E	N	Z
1	652132.331	3042749.119	1332.0517
2	652134.341	3042753.01	1329.6725
3	652137.014	3042757.336	1328.008
4	652139.687	3042761.662	1326.3435
5	652140.853	3042765.344	1325.2728
6	652144.284	3042770.361	1324.5997
7	652146.753	3042774.595	1322.7238
8	652149.413	3042778.034	1321.3514
9	652152.245	3042781.798	1320.7318
10	652154.281	3042786.186	1318.4261
11	652156.161	3042790.233	1316.2603
12	652159.058	3042794.155	1314.77545
13	652161.956	3042798.077	1313.2906
14	652165.146	3042803.218	1313.0854
15	652167.257	3042806.18	1313.0681
16	652170.577	3042810.185	1312.742
17	652172.668	3042814.361	1311.5946
18	652175.213	3042818.8	1310.7184
19	652178.046	3042822.066	1310.4302
20	652181.4	3042826.651	1310.1247
21	652182.711	3042830.053	1309.5395
22	652185.843	3042834.365	1308.6665
23	652188.844	3042838.112	1308.7556
24	652190.911	3042842.458	1308.3212

SRT-2

Geophone	N	E	Z
1	3042842.511	652190.5103	1308.2793
2	3042844.94	652192.2938	1308.2833
3	3042847.318	652194.0949	1308.657
4	3042850.296	652195.9244	1308.9469
5	3042853.765	652196.9319	1309.2809
6	3042854.956	652198.5314	1309.6383

7	3042857.586	652199.9958	1309.8993
8	3042860.035	652201.6455	1310.0576
9	3042862.865	652202.9368	1310.2221
10	3042865.775	652204.7254	1310.1631
11	3042868.405	652205.2826	1309.8258
12	3042871.593	652207.5514	1310.3501
13	3042874.474	652207.5152	1310.3741
14	3042876.438	652208.7621	1310.5584
15	3042879.034	652210.2501	1310.7983
16	3042882.308	652211.8387	1311.2309
17	3042885.558	652211.0626	1310.7633
18	3042888.634	652211.3353	1310.7754
19	3042891.515	652211.6067	1310.7177
20	3042893.772	652211.5981	1310.6887
21	3042897.675	652211.7982	1310.8158
22	3042900.954	652213.1943	1311.0854
23	3042903.608	652211.1463	1310.8091
24	3042907.507	652212.2725	1311.2046

SRT-3

Geophone	N	E	Z
1	3043020.872	651740.0836	1147.86
2	3043017.668	651740.8805	1146.1767
3	3043012.745	651741.7046	1145.2894
4	3043008.906	651742.534	1144.5439
5	3043005.249	651743.3547	1144.5515
6	3043001.889	651744.6221	1143.7644
7	3042996.534	651745.1065	1143.3145
8	3042993.719	651745.2971	1143.0584
9	3042990.137	651748.6213	1142.6403
10	3042987.173	651749.9949	1142.6763
11	3042983.531	651751.913	1142.3138
12	3042980.233	651752.9573	1142.0551
13	3042976.062	651754.8951	1141.258
14	3042971.892	651756.4654	1139.973
15	3042969.901	651759.2767	1139.3091
16	3042966.183	651761.4155	1138.3001
17	3042964.5	651764.9179	1137.1335
18	3042962.897	651768.5621	1135.2252
19	3042957.912	651769.8065	1135.8125

20	3042955.507	651772.7339	1136.81
21	3042953.009	651775.9616	1137.3535
22	3042949.542	651779.3326	1138.0128
23	3042948.348	651782.4717	1138.1272
24	3042945.061	651785.2256	1138.8057

SRT-4

Geophone	E	N	Z
1	651520.2356	3042919.004	1125.7568
2	651520.1946	3042917.075	1125.9059
3	651520.39	3042914.936	1125.9312
4	651520.3209	3042912.893	1126.0769
5	651520.4262	3042911.099	1126.3968
6	651520.6206	3042909.211	1126.9474
7	651520.735	3042907.28	1126.2015
8	651521.4584	3042905.144	1124.8719
9	651520.4408	3042903.595	1123.5618
10	651519.4231	3042902.046	1122.2517
11	651519.4808	3042900.513	1122.161
12	651518.613	3042898.289	1121.8877
13	651516.7916	3042896.277	1121.8103
14	651515.8355	3042893.529	1121.9451
15	651515.7839	3042891.384	1122.0922
16	651515.4406	3042889.209	1122.6532
17	651514.4235	3042887.389	1123.115
18	651514.7755	3042885.35	1123.3075
19	651514.0635	3042883.307	1123.5997
20	651513.074	3042881.352	1124.2891
21	651512.3646	3042879.555	1125.1073
22	651511.7675	3042877.97	1125.1137
23	651510.2704	3042875.716	1125.2447
24	651508.7733	3042873.461	1125.3757

Annexure: 3 Site Snaps


Seismic Refraction Survey at Mangan
October, 2017

Disclaimer: All projections and sections are subject to the inherent limitations of the technique employed and there could be variations as the underground conditions are not always amenable to physical interpretations.