GEOLOGICAL AND GEOTECHNICAL REPORT

DPR OF OCTOBER 2014

WANCHUCHU HYDRO ELECTRIC PROJECT

DETAILED PROJECT REPORT

CHAPTER: 5

SITE INVESTIGATION, GEOLOGY & CONSTRUCTION MATERIAL

APRIL 2014

5. GEOLOGICAL APPRAISAL

5.1. INTRODUCTION

Wangchu Hydro Electric Project has been conceived as Run of the River Scheme and is situated in Chukha District of South-Western Bhutan. The present chapter is abstract of Geological Studies and Construction Material Studies. For full understating of the geological aspects in details it is suggested that the concerned volumes **(Volume-IV, IVA & B)** must be referred.

5.2. SITE INVESTIGATIONS

5.2.1. Geological Mapping

Large scale geological mapping of the project area has been carried out on 1:10,000 / 1:5000 Scale from 500m U/s of dam axis upto the Piping - Wangchu River confluence. Detailed Geological Mapping on 1:1000 Scale has been carried out at the dam site, power house site and their appurtenant structures. The reservoir mapping has been carried out on 1:10000 Scale. Various litho-units and structural discontinuities present in the project area were mapped besides detailed discontinuity survey to know their behaviour / impact on the project components. The geological maps / plans and sections thus prepared are listed below:

Table-5.1: List of Geological Maps / Plans & Sections.

S. N.	Title of the Drawing	Drawing No.
1.	Location Map of the Project Area.	WHEP-DPR-GEO-001-00
2.	Layout Plan of the Project.	WHEP-DPR-GEO-002-00
3.	Regional Geological Map of Bhutan.	WHEP-DPR-GEO-003-00
4.	Structural Map of Bhutan, A fter Gansser, 1980.	WHEP-DPR-GEO-004-00
5.	Photo-geological and Photo-geomorphological Map of Part of Bhutan.	WHEP-DPR-GEO-005-00
6.	Geological Plan of Dam Area.	DAM-WHEP-DPR-GEO-006-02
7.	Geological Section along Dam Axis.	DAM-WHEP-DPR-GEO-007-03
8.	Geological Section along Bucket Area.	DAM-WHEP-DPR-GEO-008-01
9.	Geological Section along Plunge Pool Area.	DAM-WHEP-DPR-GEO-009-00
10.	Geological Section along U/S Coffer Dam.	DAM-WHEP-DPR-GEO-010-00
11.	Geological Section along Diversion Tunnel (DT-1).	DAM-WHEP-DPR-GEO-011-00
12.	Geological Section along Diversion Tunnel (DT-2).	DAM-WHEP-DPR-GEO-011A-00
14.	Geological Section along Power Intake.	DAM-WHEP-DPR-GEO-013-00
13.	Geological Plan along HRT Alignment.	HRT-WHEP-DPR-GEO-014-02

14.	Geological Section along HRT Alignment.	HRT-WHEP-DPR-GEO-015-03
15.	Geological Plan of Power House Area.	PH-WHEP-DPR-GEO-016-01
16.	Geol. Section from Surge Shaft to TR Channel.	PH-WHEP-DPR-GEO-017-01
17.	Geological Map of Reservoir Area.	WHEP-DPR-GEO-018-02
18.	3-D Geological Log of Drift DR-1 (0m to 70m).	DAM-WHEP-DPR-GEO-019-01
19.	3-D Geological Log of Drift DL-1 (0 to 70m).	DAM-WHEP-DPR-GEO-020-01
20.	3-D Geological Log of Drift DL-2 (0 to 70m).	DAM-WHEP-DPR-GEO-021-01
21.	3-D Geological Log of Drift PI -1, Power Tunnel Intake (0 to 50m).	DAM-WHEP-DPR-GEO-022-00
22.	Geological section along HRT Adit-1	HRT-WHEP-DPR-GEO-023-00
23.	Geological section along HRT Adit-2	HRT-WHEP-DPR-GEO-024-00
24.	Geological section along HRT Adit-4	HRT-WHEP-DPR-GEO-026-00
25.	Geological section along HRT Adit-5	HRT-WHEP-DPR-GEO-027-00
26.	Geological Plan at El 155.50m of Power House Area.	PH-WHEP-DPR-GEO-028-00
27.	Geological section along longer axis of Power House pit(Line A-B)	PH-WHEP-DPR-GEO-029-00
28.	3- D Geological Log of Drift DR-2 Right abutment (Ch 00.00 to 70.00m)	HRT-WHEP-DPR-GEO-030-00
29.	3- D Geological Log of Drift DR-2(Cross-Cuts) Right abutment (Ch 00.00 to 10.00m on each side of drift)	HRT-WHEP-DPR-GEO-030A-00
30.	3- D Geological Log of Drift DR-1(Cross-Cuts) Right abutment (Ch 00.00 to 10.00m on each side of drift)	HRT-WHEP-DPR-GEO-031-00
31.	3- D Geological Log of Drift DL-1(Cross-Cuts) Right abutment (Ch 00.00 to 10.00m on each side of drift)	HRT-WHEP-DPR-GEO-032-00
32.	3- D Geological Log of Drift DL-2(Cross-Cuts) Right abutment (Ch 00.00 to 10.00m on each side of drift)	HRT-WHEP-DPR-GEO-033-00

5.2.2. Exploratory Drilling

A total of 29 drill holes aggregating to 2048.50 m of exploratory drilling have been carried out in the project area. All the 29 drill holes done by SJVN Ltd. have been geologically logged on 1:100 scale on standard performa and are annexed with the report as **Appendix-1 to 34; Volume-IVA.**

The drilling done by SJVN Limited at various components is given below:-

Table-2.2: Details of drill holes at the project done by **SJVN Limited (2010-2013).**

Structure	No. of Holes	Drill Hole Numbers	Depth (m)
Dam Site	15	DH-1 to DH-15	1150.00
Head Race Tunnel	3	HRT-1 to HRT-3	220.00
Surge Shaft	1	SS-1	183.50

Penstock	3	PS-2 to PS-4	205.00
Power House	6	PH-5 to PH-10	260.00
Tail Race Tunnel	1	TRC-1	30.00
-	**29 Nos.**	**Total Drilling:**	**2048.50**

In addition, the power house area was earlier explored by 5 drill holes as reported in the report of M/s WAPCOS Limited in the year, 1995. One drill hole was drilled along the penstock slope (PS-1), and 4 drill holes at the power house site (PH-1, PH-2, PH-3 & PH-4) aggregating to 234.99 m. The details are given below:

Table-2.4: Details of drill holes at the PH Site done by **M/s WAPCOS Ltd. (Year-1995).**

Structure	No of Holes	Drill Hole Numbers	Depth (m)
Penstock	1	PS-1	50.25
Power House	4	PH-1 to PH-4	184.74
-	**5 Nos.**	**Total Drilling:**	**234.99**

Thus the project has been explored by 34 drill holes, aggregating to 2282.89 m of exploratory drilling.

Table-5.4: Details of the drill holes drilled at the Project Site.

Drill Hole No.	Location	Ground El. (m)	Coordinates	Total Depth (m)	Overburden / Rock Contact (m)	Bed Rock El/Depth (m)
DAM COMPLEX						
DH-1	Dam Axis - Right Bank.	407.794	**N:** 50060.510 **E:** 39916.111	50.0	15.0	392.794
DH-2	Dam Axis - Centre of River.	403.199	**N:** 50081.800 **E:** 39935.155	80.0	37.0	366.199
DH-3	Dam Axis - Left Bank.	404.483	**N:** 50111.841 **E:** 39957.256	80.0	27.0	377.483
DH-4	90m D/s of Dam axis in centre of river.	403.085	**N:** 50022.370 **E:** 40003.320	50.0	26.3	376.785
DH-5	150m D/s of Dam axis in centre of river.	401.210	**N:** 49958.110 **E:** 40033.920	50.0	27.0	374.210
DH-6	U/s Coffer Dam- centre of river.	-	-	50.0	19.5	-
DH-7	Dam Axis - Dam Top-Left abutment.	506.018	**N:** 50185.090 **E:** 40026.734	140.0	1.5	505.518
DH-8	Dam Axis - Dam Top Right Abutment.	486.0	-	130.0	2.0	484.0
DH-9	Diversion Tunnel Outlet.	455.0	-	50.0	21.0	434.0
DH-10a	Dam Axis - Right Bank (Angular).	In Progress				

Table Continue.....

Drill Hole No.	Location	Ground El. (m)	Coordinates	Total Depth (m)	Overburden / Rock Contact (m)	Bed Rock El./ Depth (m)
DH-1	Dam Axis Right Bank.	407.794	**N:**50060.510 **E:**39916.111	50.0	15.0	392.794
DH-2	Dam Axis Centre of River.	403.199	**N:**50081.800 **E:**39935.155	80.0	37.0	366.199
DH-3	Dam Axis Left Bank.	404.483	**N:**50111.841 **E:**39957.256	80.0	27.0	377.483
DH-4	90m D/s of Dam axis in the centre of the river.	403.085	**N:**50022.370 **E:**40003.320	50.0	26.3	376.785
DH-5	150m D/s of Dam Axis in the centre of the river.	401.210	**N:**49958.110 **E:**40033.920	50.0	27.0	374.210
DH-6	U/s Coffer Dam the centre of the river.	404.283	**N:**50150.353 **E:**39819.734	50.00	19.5	384.783
DH-7	Dam Axis Dam Top Left Abutment.	506.018	**N:**50185.090 **E:**40026.734	140.00	1.5	505.518
DH-8	Dam Axis Dam Top Right Abutment.	486.0	**N:**50000.989 **E:**39846.343	130.00	28.50	457.55
DH-9	Diversion Tunnel Outlet.	455.0	-	50.00	21.0	434.00
DH-10A	Dam Axis Right Bank (Angular).	404.438	**N:**50074.586 **E:**39938.709	75.00	43.50	364.00
DH-11A	Dam Axis - Right Abutment (Angular)	458.424	**N:**50019.783 **E:**39871.911	100.00	28.85	429.575
DH-12A	Dam Axis left bank (River bed)	404.083	**N:**50114.13 **E:**39958.27	75.00	42.00	365.00
DH-13	Right bank, 30 m d/s of dam axis	483.00	**N:**49955.027 **E:**39867.686	50.00	36.00	447.00
DH-14	Left bank, d/s of dam axis	404.00	-	135.00	0.00	404
DH-15	Dam axis right bank	463.00	-	35.00	12.00	451
HRT						
HRT-1	HRT Zilung nalla (u/s arm) crossing	550.00	**N:**51040 **E:**41580	75.00	13.90	536.10
HRT-2	HRT Zilung nalla (d/s arm) crossing	555.075	**N:**51650.051 **E:**42535.504	75.00	25.00	530.075
HRT-3	HRT Nunpani fault crossing	463.00		70.00	21.00	441.00
POWER HOUSE COMPLEX						
PH-1*	Along the long axis of Power House.	179.041	N:44715 E:49835	39.92	14.47	164.57
PH-2*	Along the long axis of Power House.	178.529	N:44772 E:49925	39.50	12.50	166.03
PH-3*	Along the short axis of Power House (Valley Side).	178.445	N:44761 E:50005	39.42	16.16	162.285
PH-4*	Along the short axis of power house (Hill Side).	187.83	N:44722 E:49935	65.90	21.65	166.18

PH-5	Centre of Power House.	± 179.0	N:44702.833 E:49926.654	50.0	12.0	167.0
PH-6	100m U/s of PH-5.	±179.82	N:44677.392 E:49829.944	50.0	19.5	160.32
PH-7	Longer Axis of Power House, d/s side	179	N:44699.5002 E:49949.2785	40.0	13.0	166.0
PH-8	Shorter axis of power house, valley side	179	N:44683.280 E:49904.858	40.0	16.75	162.25
PH-9	Shorter axis of power house, hill side	179	N:44715.28 E:49904.6999	40.0	15.50	163.50
PH-10	Longer axis of power house, u/s side	179	N:44699.0632 E:49860.9046	40.0	13.0	166.0
PS-1*	Penstock Slope.	±430.15	N: 45063 E: 49865	50.25	0 .0	430.15
PS-2	Penstock Slope.	±214.71	N:44804.353 E:49900.015	75.0	24.0	190.71
PS-3	Penstock Slope.	±372.41	N:45005.681 E:49847.121	50.0	2.0	370.41
PS-4	Penstock Slope.	480.0	N:45185.455 E: 49817.401	80.0	1.5	478.50
TRC-1	Along Tail Race Channel.	175.03	N: 49947 E: 44630	30.0	12.0	163.03
SS-1	Surge Shaft.	± 560.0	N:45339.176 E:49873.960	183.50	1.50	577.00

5.2.3. Permeability Tests

Water pressure tests for calculating permeability values in accordance with IS Codes were carried out simultaneously in the drill holes and the results are incorporated in the respective drill hole logs. The details relating to the permeability tests of every drill hole are appended with the report as **Annexure-II of Volume-IVA.** The detailed logs of the drill holes are given as **Appendix-1 to 34 of Volume-IVA.**

5.2.4. Exploratory Drifting

Five nos. exploratory drifts have been excavated at the dam site for an aggregate length of 440 m. The dam abutments have been explored by four drifts, with cross cuts, viz. DL-1, DL-2, DR-1 and DR-2 for a total length of 390 m to evaluate the nature of rock and the extent of stripping required. The fifth drift (PI-1) was excavated at one of the power

intakes on the left bank for 50 m length to assess the rock conditions likely to encounter in the intake. All these drifts have been geologically logged on 1:100 scale. The geological logs of the drifts are given as **(Drg. No.: DAM-WHEP-DPR-GEO-019-01 to GEO-022-00 & DAM-WHEP-DPR-GEO-030-00, DAM-WHEP-DPR-GEO-030A-00, DAM-WHEP-DPR-GEO-031-00 to GEO-033-00 ; Volume-IVB).**

Table-2.4: Drifting done at the Project.

Structure	No of Drifts	Drift Numbers	Total Length (m)
Dam Axis	4	DR-1 (with 2 cross-cuts of 10 m each) DR-2 (with 2 cross-cuts of 10 m each) DL-1 (with 2 cross-cuts of 10 m each) DL-2 (with 2 cross-cuts of 10 m each)	390
Power Tunnel Intake (Left Abutment)	1	PI-1	50
-	**5 Nos.**	**Total Drifting:**	**440**

5.2.5. Rock Mechanic Tests and Petrography

Detailed laboratory investigations were carried out on 55 No. core samples collected from the various rock types exposed in the project area to determine the engineering properties of rock. The tests were got conducted from Department of Earth Sciences, IIT, Bombay. The Laboratory Tests have been compiled in **Table-5.6 (Part-1 & 2)** for Dam, **Table-5.7 (Part1 & 2)** for HRT, **Table-5.8 (Part-1 & 2)** for Power House:

Table-5.6 (Part-1): Physical Properties of rock at Dam Site.

Sample No.	Location	Rock Type	Bulk Density (g/cc)	Grain Density (g/cc)	Porosity (%)	Ultrasonic Wave Velocity (m/sec) Dry		Ultrasonic Wave Velocity (m/sec) Wet	
						P-wave	S-wave	P-wave	S-wave
DH-1(1)	River bed, right bank	Quartzite	2.64	2.67	0.15	4157	2512	-	-
DH-1(2)	River bed, right bank	Quartzite	-	-	0.14	-	-	4011	2487
DH-1(3)	River bed, right bank	Quartzite	2.63	2.64	-	-	-	-	
DH-2(1)	River bed, centre of river	Quartzite	2.62	2.63	0.21	4434	2560	-	-
DH-2(2)	River bed centre of river	Quartzite	-	-	0.18	-	-	4079	2456
DH-2(3)	River bed centre of	Quartzite	-	-	-	-	-	-	-

	river								
DH-3(1)	River bed, left bank	Quartzite	-	-	4277	2419	3819	2389	-
DH-3(2)	River bed, left bank	Quartzite	2.64	2.68	0.18	-	-	-	-
DH-3(3)	River bed, left bank	Quartzite	-	-	-	-	3912	2367	
DH-4(1)	River bed, bucket area	Quartzite	2.67	2.69	0.20	4512	2711	-	-
DH-4(2)	River bed, bucket area	Quartzite	-	-	-	-	4012	2481	
DH-4(3)	River bed, bucket area	Quartzite	-	-	0.17	-	-	-	-
DH-5(1)	River bed, plunge pool	Quartzite	2.61	2.67	0.15	4534	2689	-	-
DH-5(2)	River bed, plunge pool	Quartzite	-	-	0.18	-	-	4121	2467
DH-6(1)	River bed, U/s coffer dam	Quartzite	-	-	4476	2617	-	-	-
DH-6(2)	River bed, U/s coffer dam	Quartzite	2.68	2.69	0.19	-	-	3817	2341
DH-6(3)	River bed, U/s coffer dam	Quartzite	-	-	-	-	-	-	-
DH-7(1)	Dam top, left bank	Quartzite	-	-	0.15	4226	2513	3978	2351
DH-7(2)	Dam top, left bank	Quartzite	2.65	2.67	-	-	-	-	-
DH-7(3)	River bed, Dam top, left bank	Quartzite	-	-	0.22	4234	2555	3998	2456
DH-7(4)	River bed, Dam top, left bank	Quartzite	-	-	-	-	-	-	-
DH-7(5)	River bed, Dam top, left bank	Quartzite	2.66	2.67	0.20	-	-	-	-

Table-5.6 (Part-2): Geo-mechanical Properties of rock at Dam Site.

Sample No.	Location	Rock Type	Poisson's Ratio	Elastic Modulus (E) (GPa)	Tensile Strength (MPa)	UCS (Mpa)		Triaxial Test	
						Dry	Wet	Cohesion (MPa)	Angle of Internal Friction (^{0})
DH-1(1)	River bed, right bank	Quartzite	0.24	21.5	21.35	166.27	-	34.12	39.5
DH-1(2)	River bed, right bank	Quartzite	-	-	-	157.76	-	-	-
DH-1(3)	River bed, right bank	Quartzite	0.24	21.98	20.84	169.38	-	-	-
DH-2(1)	River bed, centre of river	Quartzite	0.23	21.24	-	164.43	-	34.24	39.5
DH-2(2)	River bed centre of river	Quartzite	-	-	20.78	163.98	-	-	-
DH-2(3)	River bed centre of river	Quartzite	-	-	-	-	154.94	34.35	41
DH-3(1)	River bed, left bank	Quartzite	-	-	22.07	-	-	36.37	-
DH-3(2)	River bed, left bank	Quartzite	0.24	22.65	-	171.95	-	-	-
DH-3(3)	River bed, left bank	Quartzite	-	-	21.34	-	159.67	-	-
DH-4(1)	River bed, bucket area	Quartzite	-	2.69	21.94	171.84	-	-	-
DH-4(2)	River bed, bucket area	Quartzite	0.24	22.57	-	-	160.87	36.25	-
DH-4(3)	River bed, bucket area	Quartzite	-	-	22.03	-	-	-	-
DH-5(1)	River bed, plunge pool	Quartzite	-	-	20.85	-	158.07	35.97	-
DH-5(2)	River bed, plunge pool	Quartzite	0.23	22.68	-	170.37	-	-	-
DH-6(1)	River bed, U/s coffer dam	Quartzite	-	-	20.98	171.42	-	-	-
DH-6(2)	River bed, U/s coffer dam	Quartzite	0.23	22.75	-	-	-	35.36	-
DH-6(3)	River bed, U/s coffer dam	Quartzite	-	-	21.08	-	161.06	-	-

DH-7(1)	Dam top, left bank	Quartzite	0.24	21.35	-	165.35	-	-	-
DH-7(2)	Dam top, left bank	Quartzite	-	-	19.98	-	153.97	-	-
DH-7(3)	River bed, Dam top, left bank	Quartzite	-	-	164.67	-	34.86	41.5	-
DH-7(4)	River bed, Dam top, left bank	Quartzite	0.24	21.54	-	-	156.08		-
DH-7(5)	River bed, Dam top, left bank	Quartzite	-	2.67	20.05	166.08	-	35.27	42

Table-5.7 (Part-1): Physical and Geo-mechanical Properties of Rock at HRT.

Sample No.	Rock Type	Poisson's Ratio	Elastic Modulus (E) (GPa)	Tensile Strength (MPa)	UCS (Mpa)		Triaxial Test	
					Dry	Wet	Cohesion (Mpa)	Angle of Internal Friction(^{0})
HRT-1*	Slate	0.23	19.45	10.08	82.81	75.93	20.24	38
HRT-2 *	Slate	-	-	9.84	-	76.12	-	-
HRT-3*	Dolomite	-	6.76	65.12	-	15.12	39	-
HRT-4 *	Dolomite	0.23	16.67	-	-	55.35	-	-
HRT-5 *	Dolomite	-	7.93	66.03	-	-	-	-
HRT-6 *	Quartzite	0.24	22.13	15.67	-	-	35.65	41
HRT-7 *	Quartzite	-	-	-	167.92	153.95	-	-
HRT-8 *	Quartzite	-	-	168.09	159.47	35.47	41	-
HRT-9 *	Quartzite	0.24	22.43	19.86	166.98	-	-	-
HRT-10 *	Slate	0.23	19.47	13.54	64.87	-	15.37	37
HRT-11 *	Slate	-	65.19	47.96	-	-	-	
HRT-12 *	Quartzite	0.23	20.43	16.42	-	47.82	29.45	38
HRT-13 *	Quartzite	-	-	16.46	94.36	-	-	-

HRT-14 *	Quartzite	0.23	19.98	10.67	-	79.34	-	-
HRT-15 *	Quartzite	-	-	-	96.24	81.34	28.87	38
HRT-16	Quartzite	2.58	-	159.62	-	34.76	41	-
HRT-17	Quartzite	0.24	21.34	17.34	-	148.56	-	-
HRT-18	Micaceous Phyllite	0.22	11.56	6.23	39.18	14.69	7.46	38
HRT-19	Micaceous Phyllite	-	-	-	40.12	-	-	-
HRT-20	Micaceous Phyllite	11.68/0.22	2.83	5.97	-	13.95	-	-

* *Samples of drill holes done at the dam site of Reservoir Scheme (Year, 1993).*

Table-5.7 (Part-2): Physical and Geo-mechanical Properties of Rock of HRT.

Sample No.	Rock Type	Bulk Density (g/cc)	Grain Density (g/cc)	Porosity (%)	Wave Velocity (m/sec) Dry		Wave Velocity (m/sec) Wet	
					P-wave	S-wave	P-wave	S-wave
HRT-1*	Slate	2.62	2.71	1.86	-	-	5535	2816
HRT-2 *	Slate	2.63	2.74	1.93	6158	3395	-	-
HRT-3*	Dolomite	2.59	2.64	2.13	-	3125	1934	1934
HRT-4 *	Dolomite	-	-	-	3690	2341	3094	1925
HRT-5 *	Dolomite	-	2.61	2.03	3586	2258	-	-
HRT-6 *	Quartzite	2.58	2.61	0.16	4334	2721	3817	2489
HRT-7 *	Quartzite	2.63	2.67	-	-	-	-	-
HRT-8 *	Quartzite	2.59	2.65	0.20	-	-	3796	2376
HRT-9 *	Quartzite	-	-	4504	2819	-	-	-
HRT-10 *	Slate	2.68	2.78	0.11	6145	3356	5516	2713
HRT-11 *	Slate	-	-	0.17	-	-	-	-
HRT-12 *	Quartzite	2.66	2.63	-	-	-	-	-
HRT-13 *	Quartzite	2.67	2.62	0.21	4487	2413	-	-
HRT-14 *	Quartzite	2.63	2.59	-	-	3872	2367	2367

HRT-15 *	Quartzite	-	-	4158	2612	3765	2017	2017
HRT-16	Quartzite	2.62	2.58	0.18	-	-	-	-
HRT-17	Quartzite	2.5	2.61	0.13	4120	2448	3821	2314
HRT-18	Micaceous Phyllite	2.52	2.79	1.75	3678	2334	3214	1989
HRT-19	Micaceous Phyllite	-	-	-	3517	2219	3345	2112
HRT-20	Micaceous Phyllite	2.68	2.83	1.83	-	-	-	-

* *Samples of drill holes done at the dam site of Reservoir Scheme (Year, 1993).*

Table-5.8 (Part-1): Physical and Geo-mechanical Properties of Rock at PH.

Sample No.	Rock Type	Poisson's Ratio	Elastic Modulus (E) (GPa)	Tensile Strength (MPa)	UCS (Mpa)		Triaxial Test	
					Dry	Wet	Cohesion (Mpa)	Angle of Internal Friction(^{0})
PH-2	Quartzite	0.23	21.23	19.64	159.05	151.02	-	-
PH-3	Quartzite	2.65	17.58	157.98	148.56	33.99	39	-
PH-4	Phyllite	0.22	12.22	5.96	42.96	28.94	7.89	39
PH-5	Quartzite	0.23	22.46	18.78	158.96	149.96	-	-
PH-6	Quartzite	0.24	22.45	19.02	161.58	150.97	34.35	40
PH-7	Quartzite	-	-	-	-	34.67	40	-
PH-8	Dolomite	0.23	16.54	6.65	62.89	-	-	-
PH-9	Dolomite	-	-	-	26.67	16.25	39	-
PH-10	Dolomite	-	8.27	64.67	-	-	-	-
PH-11	Dolomite	0.23	17.12	12.4	80.78	67.15	18.45	40

Table-5.8 (Part 2): Physical and Geo-mechanical Properties of Rock at PH.

Sample No.	Rock Type	Bulk Density (g/cc)	Grain Density (g/cc)	Porosity (%)	Wave Velocity (m/sec) Dry		Wave Velocity (m/sec) Wet	
					P-wave	S-wave	P-wave	S-wave
PH-1	Phyllite	2.78	2.70	1.76	3346	2412	2596	1623
PH-2	Quartzite	2.64	2.69	0.16	-	-	-	-
PH-3	Quartzite	2.62	2.65	0.15	4782	2812	4245	2567

PH-4	Phyllite	2.79	2.69	1.98	3426	2317	2613	1734
PH-5	Quartzite	2.65	2.64	0.17	4723	2893	4213	2492
PH-6	Quartzite	2.66	2.63	0.21	-	-	4014	2315
PH-7	Quartzite	2.65	2.62	0.12	-	-	-	-
PH-8	Dolomite	2.72	2.78	-	3527	2245	-	-
PH-9	Dolomite	-	-	2.12	-	-	3012	-
PH-10	Dolomite	2.70	2.66	1.92	4241	2617	3412	-
PH-11	Dolomite	-	-	-	-	-	-	-

In addition 39 Rock Core Samples collected from the various drill holes drilled at the dam complex, HRT and power house complex were sent to Department of Earth Sciences, IIT, Bombay for Petrographic Studies. Thin sections of 0.03mm thickness were prepared and studied under Leica microscope in transmitted light. The details are given in **Table-5.9, Table-5.10 & Table-5.11:**

Table-5.9: Rock Types at Dam Site after Petrographic Studies.

Sample No.	Location	Rock Type	Remarks
DH-1	River Bed, Right Bank.	Quartzite	White in colour
DH-2	River Bed, Center of river.	Quartzite	White in colour
DH-3	River Bed, Left Bank.	Quartzite	White in colour
DH-4	River Bed, Bucket Area.	Quartzite	White in colour
DH-5	River Bed, Plunge Pool Area.	Quartzite	White in colour
DH-6	River Bed, U/s Coffer Dam.	Quartzite	White in colour
DH-7	Dam Top, Left Bank.	Quartzite	Last two samples show the light grey colour with minor amounts of pyrite minerals.

Table-5.10: Rock Types along HRT after Petrographic Studies.

Sample No.	Rock Type	Remarks
HRT-1 *	Slate	Blach coloured with Platy Texture.
HRT-2 *	Slate	Blach coloured with Platy texture.

HRT-3 *	Dolomite with Impurities.	Dark Grey Colour Rock with carbonate layers in between.
HRT-4 *	Dolomite with Impurities.	Dark Grey Colour Rock with carbonate layers in between.
HRT-5 *	Dolomite with Impurities.	Dark Grey Colour Rock with carbonate layers in between.
HRT-6 *	Quartzite	Light Green Quartzite.
HRT-7 *	Quartzite	Light Green Quartzite.
HRT-8 *	Quartzite	Light Green Quartzite.
HRT-9 *	Quartzite	Light Green Quartzite.
HRT-10 *	Slate	Black Colour with Slaty Cleavage.
HRT-11 *	Slate	Black Colour with Slaty Cleavage.
HRT-12 *	Quartzite	Light Green Quartzite.
HRT-13 *	Quartzite	Light Green Quartzite.
HRT-14 *	Quartzite	Light Green Quartzite.
HRT-15 *	Quartzite	Light Green Quartzite.
HRT-16	Quartzite	Light Green Quartzite.
HRT-17	Quartzite	Grey Quartzite with Pyrite Minerals.
HRT-18	Micaceous-phyllite	Dark Green Coloured Phyllite with Foliation.
HRT-19	Micaceous	Dark Green Coloured Phyllite with Foliation.
HRT-20	Micaceous	Dark Green Coloured Phyllite with Foliation.

*****_Samples of drill holes done at the dam site of Reservoir Scheme (Year, 1993)._

Table-5.11: Interpreted Rock Type at the Power House Site after Petrography.

Sample No.	Rock Type	Remarks
PH-1	Phyllite	Greenish, foliated
PH-2	Quartzite	Light grey in colour
PH-3	Quartzite	Light grey in colour

PH-4	Phyllite	Greenish, foliated
PH-5	Quartzite	-
PH-6	Quartzite	-
PH-7	Quartzite	-
PH-8	Dolomite with impurities.	Dark Grey Colour Rock with carbonate layers in between
PH-9	Dolomite with impurities.	Dark Grey Colour Rock with carbonate layers in between
PH-10	Dolomite with impurities.	Dark Grey Colour Rock with carbonate layers in between
PH-11	Dolomite with impurities.	Dark Grey Colour Rock with carbonate layers in between

The detailed report of the above studies is enclosed as "Geo-mechanical Properties of Drill Core Samples" as **Annexure-III of Volume-IVA.**

5.2.7. Geophysical Studies

Geophysical survey at the dam site and power house site was carried out by AIMIL, New Delhi by refraction survey using hammer technique. A total of six numbers of profiles were surveyed aggregating to 887 running meters. The report is enclosed as **Annexure-IV of Volume-IVA.**

5.2.8. Photo-geological Studies

The photo geological study earlier carried out under the Wangchu Reservoir Scheme by GSI in the Year, 1993 has been referred for Run of the River Scheme also. The detailed report is enclosed as **Annexure-VA & VB of Volume-IVA.**

5.2.9. Seismic Studies

A preliminary seismic study was done by Central Water and Power Research Station, Pune in July, 1993 for Reservoir Scheme using past data on earthquake occurrences and knowledge of various tectonic and geological features of the region from which design seismic forces were evaluated in terms of acceleration response spectra. The report on the study is enclosed as **Annexure-VI of Volume-IVA.**

Additionally, CWPRS, Pune has been assigned the work of Seismic Studies. The details are dealt in Civil Design Volume.

5.2.10. Other Studies

The Director, Geological Survey of India has visited the project on 26 October, 2010 and on 06 December, 2011 as a representative of Govt. of India (MoE).

5.3. GEOLOGY OF THE PROJECT AREA

The main components of the project, i.e. dam, diversion tunnel, 60% of HRT and the reservoir area will be located in the Shumar Formation, remaining 40% of HRT, Surge Shaft, Penstocks, Power House and Tail Race Channel will be located in the Buxa Group of Rocks.

The Litho-Stratigraphy of the project area as established from North to South is as under **(Table-5.12)**:

Table: 5.12: Litho-Stratigraphy of Wangchu Project Area.

----------**M.C.T**----------	
Shumar Formation	Quartzite, Phyllite, chlorite mica schist, with occasional Carbonaceous Phyllite Bands.
----------**Shumar Thrust**----------	
Buxa Group	Thungsing Formation: Gritty Feldspathic Quartzite with Pebbly and Conglomerate Bands with thin intercalation of Slate, Phyllite and Metabasics.
	----------**Conformable Contact**----------
	Manas Formation: Dolomite, Quartzite, Carbonaceous Phyllite.
	Phuntsholing Formation: Green to greenish grey Phyllite, Purple Phyllite, and Carbonaceous Phyllite with thin interbands of green, purple quartzite.

Detailed Geological Mapping on 1:10000 Scale for over 3 Sq. Km. was carried out for the Reservoir 0.75 Sq. Km of the Dam site area on 1:1000 Scale**,** 16 Sq. Km of HRT on 1:5000 Scale and 0.85 Sq. Km of Power House, Surge Shaft, Penstock & TRT Area on 1:1000 Scale**.** Based on the geological mapping it is assessed that bed rock and both the abutments over which the concrete gravity dam will be founded consists of quartzite with occasional phyllite interbands of Shumar Formation. The U/s 60% length of the HRT (Adits 1 and 2) will be excavated in Shumar Formation consisting of quartzite, phyllitic quartz with thin interbands of chlorite mica schist and occasional carbonaceous phyllite, whereas D/s 40% of the HRT (Adit-3 & Adit-4) will be excavated in the Buxa Group of rocks comprising of feldspathic quartzite, dolomite, phyllites and carbonaceous phyllites. The surge shaft, power house and tail race channel will lie in the dolomite, quartzitic phyllite and quartzite rocks of the Manas and Phuentsholing Formations of the Buxa Group.

5.3.1. Tectonic Structures

Major Thrusts / Faults of the Bhutan Himalaya, from south to north, are:

a) The Main Boundary Fault / Thrust (MBF);
b) The thrust between Damuda Group and Buxa Group;
c) The Shumar Thrust between the rocks of Shumar Formation and the Buxa Group;
d) The Main Central Thrust (MCT) between the Frontal Belt and the Central Crystalline Belt.

A number of major fold structures have been recognised in Bhutan Himalayas. Folds within the Buxa Group have a general axial trace in E-W direction. Overturned regional anticline and syncline are seen in Mangde Chu and the Sankosh river sections, where various formations of the Buxa Group are repeated due to the folding. The dolomites of the Manas Formation occupy the core of the syncline where as the quartzite belonging to Thungsing Formation occupy the core of the anticlinal structure.

5.4. GEOTECHNICAL EVALUATION OF CIVIL STRUCTURES

5.4.1. Concrete Dam

5.4.1.a. Foundation Condition

Detailed geotechnical investigations were carried out at the foundation level at the dam axis by three drill holes in the riverbed along dam axis indicate that the depth of riverine deposits range between 15 to 37m. Below the riverbed the rock encountered is white to light grey coloured, hard and compact quartzite which is mostly moderately to closely jointed.

The presence of hard compact and strong quartzite with high compressive strength (164 to 172 Mpa), weathering limited to some reaches only, suggests good foundation condition in the riverbed. Stripping depth at bed level is confined to the stained and fractured / jointed reach which is observed to lie within 1.5 to 6 m as recorded from the core data with around 2m stripping at the deepest level. The deepest foundation level arrived at will be at El. 364m. However, the permeability values ranging from 8 to 17 lugeons in general with one or two values below 3 indicating that the foundation will not be very tight and will require effective grouting.

5.4.1.b. Abutment Condition

The left bank consists of well exposed quartzite rock upto the dam height with thin debris cover. Based on the exploratory drift data of DL-1 (El. 420m) & DL-2 (El. 460m) and one no. drill hole data on the left bank; the stripping limit shall be of the order of around 17 m

on the left bank at El. 420 m and 5 -10m around El. ±460m. The slope profile upto El. 450m appears to be controlled by valley dipping prominent joints. The abutment rises steeply above El. 450 m which can be attributed to the slope failure along the valley dipping steep shear. The presence of valley dipping joints on bank makes it vulnerable to failures and will require concurrent support during excavation.

On the right bank the quartzite rock is exposed between El. 412m (Bed Level) to El. 450m and above El. 550m as picked up during geological mapping. The reach between the El. 450 to 550m is covered with loose slope wash material consisting mainly of quartzitic - phyllite / quartzite boulders. A maximum of 30 -35 m thick overburden has been established on the abutment slopes between El. 445 – 480m by subsurface investigation. The drift DR-1 at El. 420m has indicated the stripping limit to be of the order of 10 to 12m approximately upto 420m. The drift DR-2 at El. 460m has encountered 3om overburden so the stripping limit around El. 460m will be 31m. The encountering of few valley dipping shears in the drift DR-1 & DR-2 indicates that the right bank slopes are likely to become unstable during excavation and will need concurrent support during excavation.

5.4.1.c.Bucket Area:

Geological mapping in the bucket area has revealed a narrow ledge of quartzite rock extending from the dam to upto 15m D/s at the bed level on the right bank. The area beyond 15m has overburden of slope wash deposits on a gentle hill slope (22° to 25°). The left bank however, has quartzite exposures throughout the bucket area. The bucket area has been explored by one drill hole DH-4 done 90m D/s of the dam axis in the river towards the right bank. The hole has indicated an overburden of 27m with rock at El. 376m. A geological section has been prepared at the bucket area along the drill hole DH-4 **(Drg. No.: DAM-WHEP-DPR-GEO-008-00; Volume-IV.B).**

Based on the drill hole it is assessed that the foundation rock will be white to light grey, hard and compact, stained and slightly weathered quartzite under riverine deposit of 26.30m toward right bank which may increase in the middle of the river. The high in-situ permeability values of 12.45 to 15.10 lugeons indicate open nature of joints. However, due to the presence of occasional closely jointed and fractured zones in the foundation rock, effective consolidation at depths would be required. The left bank slopes are 45° to 50° with a hump of shattered rock between the El. 420m to 450m. Rock is exposed on the left bank slopes and needs support during excavation. The right bank slopes are

gentle and with an overburden cover of 10 to 12m. No problem of slope failure is foreseen during the excavation of the right bank slope.

5.4.1.d.Plunge Pool

Quartzite rock is exposed at the U/s end of the plunge pool area on the right bank. On the D/s portion a seasonal nallah (chhu) is seen with a gentle slope (22° to 25°). The left bank however, has quartzite exposures throughout the plunge pool area, a part of which intrude into the river channel which needs to be removed. The area has been investigated by a drill hole DH-5, located 150m D/s of the dam axis in the river channel towards the right bank, has indicated an overburden of 24m with rock levels at 377m.

Foundation rock in the plunge pool area will be white to light grey coloured, hard and compact, stained quartzite under river deposit of 24m towards the right bank which will increase towards middle of the river. The high in-situ permeability values of 11.62 to 14.95 lugeons indicate presence of open joints. In addition, due to the presence of occasional closely jointed and fractured zones in the foundation rock, effective consolidation in the foundation will be required. A geological section has been prepared at the plunge pool area along the drill hole DH-5 located at the U/s edge **(Drg. No.: DAM-WHEP-DPR-GEO-008-00; Volume-IV.B).** During excavation, concurrent support will be required in the left bank. As a long term stability measure, the rock slopes above the plunge pool will require strengthening. The right bank slopes overlooking the plunge pool area are covered by seasonal nallah (chhu) deposits and slope debris with very few rock exposures. Although the right bank slope is quite gentle, still a lot of drainages and slope protection work will be required.

5.4.2. Diversion Tunnel

Geological mapping in the area has revealed that the inlet portal has a steep rock face formed of slightly weathered, blocky quartzite rock from the river bed level for 50 m (upto El. 450m) above which the river profile becomes very gentle. Outlet portals area is covered with overburden of around 21m depth.

The bedding / foliation planes will have a favourable orientation from the inlet end upto RD 100-130m as the angle between the strike direction of the bedding / foliations and the tunnel alignment will be almost 70 º to 90 º. But as there is overburden above tunnel, weathering of rock and flow of water is expected in this reach. In the intermediate reach (for a length of ± 250m) bedding / foliations will make 30 º to 60 º angle with the tunnel alignment. The profile above tunnel has steep hills with rock exposed invariably. This

part of the tunnel will offer better tunnelling media except in and around a nallah (chhu) which can be structurally controlled feature and can be a potential source of seepage. The remaining reach of the diversion tunnels will be unfavourable for excavation as the strike direction of the bedding / foliations will be almost parallel to the tunnel alignment but the rock exposure at the surface along the tunnel alignment in this reach points to still better tunnelling conditions. Around the outlet portals, due to the presence of thick overburden along the tunnel alignment difficult tunnelling conditions are expected.

The overall rock mass classification is as under **(Table-5.13)**:

Table-5.13: Rock Mass Classification along Diversion Tunnel-1 & 2.

Class	**Length**	**Percentage**
DIVERSION TUNNEL-1		
II	165	39.2% ±20%
III	195	46.31%±20%
IV	35.5	8.43% ±20%
V	25.5	6.05% ±20%
Total	421	
DIVERSION TUNNEL-2		
II	175	32.64% ± 20%
III	220	41.04% ± 20%
IV	83	15.5%±20%
V	58	10.82% ± 20%
Total	536	

From the drill hole data of drill hole DH-9, it is evident that the first 22 to 30m of excavation from the outlet portal will be through cut and cover due to the presence of thick overburden almost upto tunnel level, after which the portal can be established.

5.4.2.a.Upstream Coffer Dam

The U/s Coffer Dam has been located 130 m upstream of the proposed dam axis in a narrow gorge with steep abutments. Massive, bedded quartzite though highly jointed with

minor thin bands of quartzitic-phyllite is exposed on both the abutments. The general foliation trend is N80^{0}W - S80^{0}E with 50^0 northerly dip i.e. dipping in upstream direction. The important set of joints recorded in quartzite outcrop trends in **i)** E - W with 70^0 N dip, **ii)** N 20^{0}W - S20^{0}E with 80^0 Southerly dips, and **iii)** N40^{0}E - S40^{0}W with 20^0 dip towards SE. Competent, jointed quartzite rock is available on either banks almost at surface or at a very shallow depth. However in the river bed which will accommodate the maximum length of the dam, 19.5m thick riverine material has been found above the bed rock based on bore hole (DH-6) data. The bedrock consists of white colour quartzite. The bed rock have open joints as such high permeability values range between 12.44 to 17.36 lugeon for which special deep grouting is required to control seepage for safety of coffer dam.

5.4.3. Power Intake

The intake area has been geological mapped on 1:1000 Scale and explored by a drift of 50 m length at an El. of 472.0 m to access the rock conditions likely to be encountered. The intake portals have rock exposures of quartzite from El. 420m to above 550 m. The intake area slopes has been traversed by 3-4 sets of joints. Intersection of joint sets will give rise to wedge failures during excavation of the intake structure. In view of the same, excavation for the power intake portal structure is apprehended to result in planar failure along the steep, valley dipping joints which will need to be contained by suitable length of rock bolts for maintaining stability of the portal. The loosely lying shallow slope wash material above 450 m El. can also pose problem during excavation.

5.4.4. Head Race Tunnel

8.5m dia circular, 12.38 Km long HRT will be located on the left bank of the river. One drill hole HRT-1 for 75m depth has been done at the U/s arm of Zuling Nallah (chhu) at its intersection with HRT. The geological mapping has revealed the following lithological units likely to be encountered during the excavation of the HRT **(Table-5.14):**

Table-5.14: Percentage and Length of Litho-units along HRT.

Rock type	Length (m)	Percentage of HRT Length
Quartzite	6350	51.62 %
Phyllitic Quartzite	4600	37.40 %
Dolomites, Phyllite, Slate, Carbonaceous Phyllite etc.	1357	10.98%

Total Length	12357m	100%

The rocks along the HRT alignment can broadly be divided into two different types based on the stratigraphically sequence in the project area, i.e. Shumar Formation and Buxa Group of rocks. The Shumar thrust divides the two rock types. Within these two formations there are different rock types encountered. The surface data collected is depicted in the geological plan of HRT **(Drg. No.: HRT-WHEP-DPR-GEO-014-02; Volume-IV.B)** and projected data at the tunnel grade in the geological section **(Drg. No.: HRT-WHEP-DPR-GEO-015-03; Volume-IV.B).**

5.4.4.a.Tunneling Conditions

The geological mapping along the HRT alignment on the left bank of the Wangchu river has brought out the following facts:

From intake to Zuling nallah (chhu) u/s branch (± 1600m) HRT will pass through rocks of Shumar formation comprising of bedded quartzites jointed and fractured at places. The alignment of the tunnel is N62E and rock in general strike in N70˚W-S70°e to E-Wwith 40°to 55°dips in north direction. The strike orientation seems to be favorable but few prominent joints will be unfavorable during the excavation. Last 300m reach of this stretch will be in the vicinity of Zilung Nallah (chhu) which is a perennial stream. A drill hole HRT-1 has proved more than 3D rock cover above the HRT in the Nallah (chhu) section comprising of quartzite / Phyllitic quartzite with shears. The 200m reach below the Nallah (chhu) can have very poor tunneling conditions (with high seepage) with 100m on either side of fair to poor rock conditions

Between Zuling Nallah (chhu) **to Tallung Nallah** (chhu) **(RD. ±4700m), the HRT will essentially passes through phyllitic quartzite and schistose quartzite with thin Interbands of carbonaceous phyllite. The quartzite in this reach has developed schistosity which may deteriorate its quality.** The first 100m reach will be affected by the Zilung Nallah (chhu) upstream arm and will have fair to poor rock tunneling conditions. 200m zone below Zuling Nallah (chhu) will offer mostly very poor tunneling conditions, whereas 200m length U/s of nallah (chhu) & 500m length D/s of nallah (chhu) will have Fair to Poor conditions owing to unfavorable orientation of foliation.

The 200m zone below Tallung Nallah (chhu) is a low cover zone and may pose difficult tunneling conditions with considerable seepage due to the presence of possible shear zone along filiation.

From Tallang Nallah (chhu) to 200 m short of Shumar Thrust (RD. ± 8000m), bedded and well jointed quartzite with fractures and minor shears have been picked up during the mapping. This reach is likely to offer Fair to Good tunneling media with very few problems during the excavation.

From Shumar Thrust (RD. ± 8000m) to end of HRT, in the first 1800m mostly quartzite will be of Good to Fair, whereas in the remaining reach quartzite, dolomite, slates & carbonaceous Phyllite will be encountered and are expected to be Fair to Very Poor. The HRT in this reach intersect Shumar Thrust which separates the rocks of Shumar formation from Buxa Group. The Shumar thrust is reported to have a very low hade, thereby expected to affect quite a long reach of HRT. The tunnel expected to cross the thrust zone consisting of highly sheared and fractured quartzite. Very poor rock conditions with limited standup time requiring immediate support is anticipated. Ground water and squeezing/flowing conditions cannot be ruled out. Further the D/s and u/s reaches of this Thrust (200 & 400m respectively) may be affected by the thrust and may offer mostly poor tunneling conditions. Further the HRT will encounter a lineament called Nunpani Fault (±13 Km) with vertical hade will be an affected zone with unfavorable foliation, may pose mostly poor tunneling conditions.

Ground water and squeezing / flowing condition are not ruled out in a cumulative length of 1900 m. The relatively softer bands of phyllite, carbonaceous phyllite and slate are expected to have poor arch action leading to roof collapses. In weathered and saturated conditions, these bands will tend to flow in. The tunneling will be still more hazardous where carbonaceous phyllite trend along tunnel alignment or occur at its crown. Difficult tunneling conditions are anticipated in this reach with limited stand up time, which will be requiring immediate support. Tunneling in Shumar Thrust zone & Nunpani tear fault may pose challenges.

There are 7 to 8 main cross drainages cutting across the HRT alignment. The fractured nature of the rock mass and deep weathering condition may facilitate deep permeation of annual rainfall experienced by the area, thereby, creating pockets of ground water. During tunneling, many such ground water pockets are expected particularly along major structural weak zones of long continuity, comparatively more in harder rocks like quartzite.

The anticipated rock mass classification along the HRT is as under: -

The anticipated rock mass classification along the HRT is as under **(Table-5.15):**

Table-5.15: Rock Mass Classification along Head Race Tunnel.

Class	Length	Percentage
II	1654.64	13.38 ± 20%
III	5979.99	48.62% ± 20%
IV	2827.17	22.98 % ± 20%
V	1846.37	15.01 % ± 20%
Total:	**12299.17**	**99.99 %**

The above prediction of rocks encountering the HRT is a tentative estimate worked out on the basis of surface geological studies and very limited sub-surface information. It gives only a general idea of the overall rock condition but may be different during actual tunnelling.

5.4.5. Surge Shaft

5.4.5.a. Geology

Geological Mapping of 148.50m deep (including 2.0 m restricted orifice), 20 m diameter surge shaft has been carried out on 1:1000 scale. The site for the surge shaft is located at an El. 580 m where the slopes are 35° to 45°. Surface geological mapping have revealed that the area around surge shaft is covered with overburden comprising blocks of dolomite underlain by jointed dolomite striking N12°W-S12°E and dipping at 42° towards N78°E. In general, the dolomites at the surface are highly jointed and fractured and appear like stacked blocky mass liable to easy crumbing. The bedding planes strike swings between N60°W- S60°E to N50°E-S50°W and dip at 45°/N 30°E to 25°/N 70°W indicating that the rocks are intricately folded close to surge shaft location.

One drill hole (SS-1) located in the centre of the surge shaft at El. 580 m has been drilled for a length of 183.50 m, to evaluate the rock conditions to be encountered in the surge shaft (Drg. No.: PH-WHEP-DPR-GEO-016-01; Volume-VB). Drill hole has encountered overburden of 1.5 m of pit material followed by grey colored shattered / fractured, sheared and jointed dolomite with calcite along the entire length of the hole. Geological log of drill hole SS-1 is enclosed in Volume-VA.

The surge shaft hill will have to be cut down from El. 616.38 m to the surge shaft top level El. 559 m. This 57.38 m of hill slope will lie in jointed and fractured dolomites and will require concurrent support during excavation. The surge shaft from its top 559 m will have 2-D cover and beyond El. 547 m more than 3-D cover. The entire surge shaft would lie in highly jointed and fractured dolomite bands with occasional bedding shears of 1.5 to 16.5 m thickness. The intersections of various joint sets will results in wedge formation which will have a tendency to fall during the excavation of the surge shaft. In addition failure along few joints cannot be ruled out. Therefore, regular support is required during the excavation. A geological section from Surge Shaft to Tail Race Channel is enclosed as Drg. No.: PH-WHEP-DPR-GEO-017-01; Volume-VB.

Based on the drill hole data the surge shaft is expected to be excavated 10 to 20% in good rock mass, 35 to 45% in fair rock mass and 35 to 55% in poor to very poor rock mass.

5.4.6. Pressure Shaft

2 No., 4.8m dia, 852m long circular pressure shaft have been explored by 4 No. drill holes (3 by SJVN Limited and 1 by M/s WAPCOS Limited in the Year, 1995). The pressure shaft slope has been geologically mapped on 1:1000 Scale **(Drg. No.: DAM-WHEP-DPR-GEO-016-00; Volume-IVB).** The pressure shaft slopes are 35° to 45° and are covered with loose slope wash materials consisting mainly of quartzitic phyllite / quartzite boulders in the lower reaches and quartzite and dolomite boulders in the middle reaches up to an El. 305m. Between the El. 305 and 400m the slopes expose purple and white, highly fractured, jointed and blocky quartzite.

The surface geological mapping and drill hole data have indicated that the upper horizontal reach (185m length) of the pressure shaft starting from the bottom of the surge shaft (El. 402m) will encounter fractured and jointed dolomites with a thick shear zone (45 - 50m depth). The top ±100m of vertical pressure shaft will essentially lie in jointed dolomite with foliation shears. The lower ±100m length of the vertical pressure shaft will pass through jointed quartzites with bedding shears with a shear zone (20 to 25m) at the lower portion. In-between these two reaches a 32 - 35m thick highly sheared and crushed zone of dolomite, slate, and carbonaceous phyllite will be encountered separating the upper dolomite reach and lower quartzite reach. The D/s horizontal reach (472m) will pass through quartzite with dolomite bands having foliation shears with 100m of carbonaceous phyllite reach. Last few meter of the pressure shaft will lie essentially in

overburden. In addition the horizontal portion of the pressure shaft in the vicinity of the power house will have low vertical and side cover adequate slope stability measure have to be taken during the construction of this reach. The Rock Mass Quality Index 'Q' generally ranges from 1.8 to 5.5 in closely jointed dolomite, 2.5 to 8.6 in thinly bedded quartzite and quartzitic phyllite and 0.2 to 0.72 in sheared and shattered rock. The pressure shaft after excavation may immediately be supported by steel rib - cast concrete - fibre crete to avoid chances of collapses in the sheared and shattered rock zone. The quartzite phyllite and quartzite may be taken care of by rock bolting and shotcreting.

The presence of open joints (few mm upto 10cm) with yellowish brown infiltrated clayey material fillings in the exposed rock on the penstock slope, can pose slope stability problems, especially movements along these planes are anticipated under adverse hydrostatic and / or seismic vibrations of magnitude upto 7.5. An elaborate treatment for the stabilization of the pressure shaft has to be formulated.

5.4.7. Surface Power House

124m (L) x 21.5m (W) x 44.5m (D) surface power house located over middle terrace namely (T2) with average El. 179m, will be excavated mostly in overburden and partly in rock consisting of highly jointed and fractured sequence of dolomite, phyllite and quartzite belonging to Manas Formation of Buxa Group. The power house bench has been explored by 6 No. drill holes (4 by M/s WAPCOS Limited in the Year, 1995 and 2 by SJVN Limited in the Year, 2010) as detailed below **(Table-5.16)**:

Table-5.16: Bed Rock Level at power house site inferred from the drill holes

Drill Hole No.	Ground El. (m)	Bed Rock El. (m)	Rock Type
PH-1*	179.041	164.57	Interbands of thinly bedded quartzite and dolomite.
PH-2*	178.529	166.03	Purple phyllite and thin greenish grey quartzite.
PH-3*	178.445	162.285	Grey and purple/ green quartzite and purple phyllite bands.
PH-4*	187.83	166.18	Thinly bedded greenish grey quartzite.
PH-5	± 179.0	167.0	Light to dark grey coloured quartzite.
PH-6	179.82	160.32	Purplish, greenish grey and grey to light grey coloured quartzite.
PH-7	179	166.0	Purplish, greenish grey and grey to light grey coloured quartzite.
PH-8	179	162.25	Purplish, greenish grey and grey to light grey coloured quartzite.
PH-9	179	163.50	Purplish, greenish grey and grey to light grey coloured quartzite.
PH-10	179	166.0	Purplish, greenish grey and grey to light grey coloured quartzite.

* *Drill Holes drilled by M/s WAPCOS Limited in the Year, 1993.*

At the central part of the power house, the acceptable foundation grade would be at R.L. 159m (approximately) requiring excavation of 16 to 21m. (NSL El. 179m).The water percolation tests conducted in the drill holes have given high permeability values indicating open nature of joints. This may require elaborate foundation treatment in the power house pit and adjoining area including the provision of drainage holes. The presence of fractured, shattered and shear zones will call for in-situ consolidation by means of effective grouting to attain a water tight foundation.

The power house site is located in the foot of the hill. The excavations of the power house pit make rate and imbalance in the stability in the hill mass. Several protective measures have to be carried out to safe guard to power house during and after construction and are given below:

a) Diversion of the major streamlets on the hill slopes far away from the power house area and thus preventing deposited material eroded material coming into the power house.

b) Construction of deeply anchored dwarf wall across the hill slope separating the power house bench and slope above.

c) Construction of concrete pedestals all around deeply seated rock boulders so that they should not roll down in due course of time. Loose big boulder may be manually rolled down and removed at the start of the construction activity.

d) Anchoring of large rock boulders.

e) Construction of deflector walls in the upper reaches of slopes to hold back / arrest the motion of rolling boulders.

In addition, protection wall along the Piping and Wangchu River may be required to protect the power house from flash floods and river erosion.

5.4.8. Tail Race Channel

The Tail Race Pool and Channel (90m) lies on the left bank of Wangchu river which is primarily formed of four level of river terraces, viz. T0, T1, T2 and T3 consisting mainly of boulders and cobble size material with less of gravel. The sandy layer is confined to the top 1m to 1.5m gravelly layer. The tail race channel will be excavated through terraces T2 and T1. The maximum and minimum tail water will be 175m and 170.30m respectively.

T0 terrace is confined within the channel section and present day flood level and occur at approximately river level. Wangchu River as a linear strip sand witched between the T1 terrace and present day river borne material. T1 terrace occurs at about 1.5m to 2m above T0 terrace level and has extensive deposit. T1 is quite long, wide and flat and mapped all along the left bank of Wangchu River. T2 terrace occur at about 3m above T1 terrace level and is the next extensively developed terrace close to the foot hill base in the area. The power house is located partially on this terrace. The tail race channel will be excavated in terrace deposit material. The one drill hole drilled along the tail race channel alignment has proved bed rock at an El. of 163m comprising of dark grey quartzite rock with some light grey quartzite bands. The rock mass is jointed and shattered which will require effective treatment for a tight foundation for laying the tail race channel.

5.4.9. Seismicity

The project areas lie in the known Himalayan Seismic belt. Bhutan had experienced a number of shocks in the historical past and their epicentral locations lie within a radius of 1-150 Km from the project. Dhurbi earthquake of 1930 (M 7.1) and an earthquake of 21 January, 1941 (M 8.1, which was experienced at 27° 30'E) had seriously affected areas in India and adjoining Bhutan. Between 1929 and 1986 more than 50 shocks of magnitude 4.6 to 6.8 originated in the area bounded by 27° and 28°N latitudes and 89° and 92° longitudes.

Major dislocation features of significance in the project are: Main Boundary Fault (MBF), Main Central Thrust (MCT) and Piping river fault, which are regarded as moderate to steep angle thrust/faults. The MCT and MBF, two closest dislocation features to the project are located about 3 Kms north and 11 Kms south of dam site, respectively. Piping tear fault, as mapped by Geological Survey of India, Bhutan Unit, is considered to be a transverse tectonic plane trending nearly at the foothill near Bhutanghat - Piping Section of Wangchu River which displaces the main Boundary Fault.

In Bhutan Himalaya there are centres of earthquake activity and some of the epicentres are located within a distance of 100 - 150 Km from the project sites. This is corroborated by the fact that more than 50 earthquake events of magnitude ranging between 4.6 and 6.8 have originated at 27°0':90°0' in Bhutan. On the basis of seismic records, events of M-6 to 7.5 are significant and shocks of M-6 to 6.5 may be expected within a radius of about 100 Km from the project sites.

Earthquake may be concentrated in those parts of the faults that either branch out or where two or more fault systems intersect. Hence the location of intersection of N-S and

E-W tendering tectonic systems would be area of future seismicity. The project areas fall within the Seismic Zone-IV to V as per Seismic Zoning Map of India (IS: 1893-2002) where shocks of the intensity M-6 to 7 are expected which correspond to the basic horizontal seismic co-efficient of 0.05 to 0.08g.

Moderately high Seismic activities of north-eastern part of India Sub-continent bordering Assam - Bhutan, doubtdly indicate extension of high ambient tectonic stresses in the lithospheric crust in this region.

An important and very significant observation in this premises is that such phenomena is most probable in geologically recent normal or strike-slip faulting environment and least likely in thrust faulting environment prevalent in Himalaya region.

Thus, in spite of high stressed nature of the crust in this region, the tectonic probability of impoundment induced seismicity seems to be low. However, in order to monitor any changes in the seismicity levels of this region a suitable array of (5 to 6) independently working seismograph stations, capable of detecting events of M-4 should be set up around the dam site.

5.4.10. Reservoir

The catchment area of Wangchhu river system is of the order of 4147 Sq. Km upto dam site at Akum Village. The Wangchhu reservoir at the proposed FRL of 494 m would impound 53.58 x 10^6 cum of water spreading over an area of 159.58 hectare area, upto the tail race Tunnel outfall level of the Tala Hydro Electric Project. The reservoir area mapped extend as linear bay in NWW direction from the proposed dam axis to near TRT outfall of the Tala Hydro Electric Project for a length of about 8 Km with width falling in between 520m contour levels **(Drawing No.: WHEP-DPR-GEO-018-00; Volume-VIB).** However geological mapping at places upto 700m contour levels have been carried out to accommodate rock slides escarpment faces and shear zones features of geological interest. The linear bay widens near east of Aiga Village and near intersection of Baisakhola, Samachina, Khamjelung nalas (chhus) of the right bank beside unnamed nallahs (chhu) on the left bank of the Wangchhu Reservoir which is now occupied by talus, slope wash, drift material and riverine deposits. A rock slide on left bank of Baisi Khola Nallah (chhu) is exposed before its joining with the Wangchu river. In most of the reaches the reservoir will remain contained within steep valley gorge, excepting immediately 6 Km upstream of the dam site where valley slightly opens up with a prominent declivity and the reservoir has a maximum width of the order of 560m; minor valley widening is also exhibited near 750m, 1600m and 4500m upstream of the dam site due to cross valley drainages containing drift material showing signature of creep, at

places river borne material and terrace deposits later concealed by drift material. This material at times with poor shear characteristics have resulted in slope failure / debris avalanches on imposition of partial submerged conditions, in the rocky slope section, the reservoir rim is beset with longitudinal and diagonal joints with steep values. At places, these sets dip into the Reservoir forming potential planes for rock slide, the rock glide. The rocks on left bank near 4750m, 3100m, 2400m and upto 750m upstream from dam site are traversed by these sets of joints.

The geological map of the reservoir area is completely devoid of any karstic formation. As such, the formation of solution cavities in arenaceous rock assemblage to act as underground conduit out of reservoir water is not possible. No major fault, shear or other mega fractures have been noticed. The minor open fractures / shear recorded in the drifts and right and left abutments of the dam site needs due care by consolidation and curtain grouting. The left bank of the reservoir shows sign of instability along valley ward dipping shears and joints. This process may be further abetted by drawdown. It is imperative therefore to contemplate effective remedial measures to arrest these slopes, particularly in the dam abutment and adjacent areas. The mapping has also located a wide seepage zone near west of Samachina village possibly along the lithological contact of quartzites and phyllitic quartzite (Photo No.-5) with its overlying quartzite with slivers of Thimphu Crystalline (Photo No.-6) marked by highly sheared and pulverized seepage zone forming part of the Shumar Formation. The rock mass on both the banks of the reservoir are identical, comprising mainly of quartzite, highly jointed and fractured with occasional bands of phyllitic quartzite, schistose quartzite (Photo No.-1 and 4) and carbonaceous phyllitic quartzite. The foliation of rocks trend from N70W - S70E to E-W with moderate dips of 40° to 55° in northerly direction. Few minor shears recorded are trending in N50W -S50E to N65W - S65E with shallow to steep dips of 35° to 75° in north easterly direction. The Shumar quartzite at places are exhibiting tight synformal fold as exposed along road section of Silli Village.

Reservoir Treatment Plan

The reservoir treatment plan is formulated to mitigate the geo-environmental hazards in the project areas especially reservoir area. Geo-environment hazards may be defined as those extreme events induced by geological setup of the region, which exceed the tolerable magnitude within or beyond certain time limits, make adjustment difficult, result in catastrophic losses of property, income and lives. In any development project, planning of geo-environment hazard is as important as the construction of the project structures. Therefore, importance should be given to the geo-environmental aspects.

The main objectives behind the Reservoir Treatment action plan is to check the sedimentation in the reservoir caused by the loose debris on critical slopes, landslides etc

In Wangchu HE project considering the magnitude of landslide near the reservoir, the following measures are suggested to control it; however expertise may be taken if required.

i) The water to be captured and drainage of surface water flowing into the slide area

The following are the actions suggested for controlling the land slides in the project area.

i). the impact of landslide on the project could be managed by arresting the potential landslides zones through suitable engineering treatments, aforestation etc.

ii). Landslide Control with Coir-Geo-textiles.

iii) Biological measures

5.5. CONSTRUCTION MATERIAL SURVEY

5.5.1. Introduction

The Wangchu Hydro Electric Project envisages construction of a 134m high concrete gravity dam, 296m length at crest, 12.38 Km long HRT of 8.5m finished diameter, a surface power house and around 90m of length of TRT Pool and Channel. The estimated quantity of concrete will be around 18.87m^3.

5.5.2. Earlier Studies for Reservoir Scheme

The construction material survey for the Wangchu Hydro Electric Project (Reservoir Scheme) was carried out in detail (Year, 1993) and the report titled “Construction Material Survey and Geo-technical Studies” is attached as **(Annexure-VII of Volume-IVA).**

Five nos. of quarry sites were identified: during the above study, the location and rock type of which are given below:

i) Left bank of Wangchu river, 2.5 Km U/s of dam site (Reservoir Scheme), 7.5 m D/s of present dam axis - Quartzite rock.

ii) Right bank of Wangchu river, 1 Km U/s of dam site, (Reservoir Scheme), 9 Km D/s of present dam axis -Quartzite rock.

iii) Right bank of Wangchu river, 2 Km D/s of dam site (Reservoir Scheme), 12 Km D/s of present dam axis- Dolomite & Quartzite rock.

iv) Right bank of Wangchu river, 2 Km D/s of power house site (Piping) Quartzite rock.

v) Right bank of piping river, 2 Km from power house - Quartzite rock

In addition River bed material on right bank of Wangchu River, D/s of dam site (Reservoir Scheme), 10 Km D/s of the present dam axis

Samples were collected from the five query site sites detailed above by blasting and, form river bed and sent for laboratory testing. The test results of these were incorporated in volume VII DPR (January 1995) of the Wangchu Reservoir Scheme. As this volume of the DPR is not available, the test results cannot be looked into in detail, but a brief summary of the results were incorporated in the Volume-1 (Pg.-8.5) of DPR (January 1995) of Wangchu Reservoir Scheme which are summarized below:

a) The rocks from the quarries were found suitable for use as coarse and cursed sand in concrete for wearing and non wearing surfaces.

b) Petrographic testes were done on the coarse and fine aggregates.

c) Suitable concrete mixes can be designed using the available aggregate.

d) Samples were found safe from the view point of alkali – silica reaction.

5.5.3. Present Studies for ROR Scheme

5.5.3.a.Estimated_Requirement_of_Construction_Material

The estimated quantity of coarse and fine aggregate required for the construction of the dam, diversion tunnel, surge shaft, penstocks, power house and other appurtenant structures of the project is 23,84,853 lac m^3 is given below **(Table-5.17)**:

Table-5.17: Details of Coarse and Fine Aggregate required for the project

Structure	Coarse Aggregate Quantity	Fine Aggregate Quantity
Dam, DT, Coffer Dam, Intake	1262871	631436
HRT	199327	99663
PH Complex	99053	49527
Dam Wearing Surface	28651	14325
	1589902	**794951**
Total Quantity Required (Coarse & Fine):		**23,84,853**

5.5.3.b.Source_of_Construction_Material

Table-5.18: Source and Quantity of Construction Material.

Location	Quarry - Shoal Identification	Quantity Expected (Lac m^3)	Remarks
Excavated Muck of Dam, DT,	Excavated	2.00	Assuming

and HRT (U/s of Adit-3, 30% of HRT length).	Muck		70% wastage.
Rock Quarry on the left bank of river Wangchu 700m (U/s of Dam).	Dam Site Quarry.	9.00	-
Shoal Deposite on the Right bank of Wangchu River D/s of Wangchu Piping Confluence.	PH Site Shoal	15.00 (3.00 Lac m^3 every Year x 5 Years).	-
Total Quantity Available:		**26: Lac m^3**	-

Against a total requirement of 23.48 Lac m^3 (coarse & fine), a quantity of 26.00 Lac m^3 is available.

5.6. DESCRIPTION OF BORROW / ROCK QUARRIES

5.6.1. Excavated Muck from DAM, DT & HRT

The muck from dam, DT, HRT will be generated during their excavation. As this muck will essentially be the of quartzite rock this can be utilized as aggregate. The quantity of muck generated from dam will be around 4.80 lac cub m3, from DT 1.10 lac cub m^3 and from HRT (U/s portion - 30% of HRT length) 1.13 lac cub m^3, totalling to around 7.03 lac cub m3. Assuming 30% utilization (70% wastage), about 2.00 lac cubic m^3 material will be available.

5.6.2. Rock Quarry on the Left Bank (700m U/s of the Dam)

During reconnaissance of the dam site, a rock quarry site was identified on the left bank of the Wangchu River, 700m U/s of the dam site. Hard and compact quartzite rock is exposed at this location which can be utilized as construction material for the dam complex and initial part of HRT. Survey of this area has already been completed on 1:5000 Scale. An area of 250m length, by 45m width can be mined at an El. 420m to El. 500m. Thus a total of about 9 lac m^3 of aggregate will be available from this quarry.

5.6.3. Power House Quarry:

A river shoal deposit immediately downstream of the confluence of Piping and Wangchu rivers has been identified as a potential aggregate site extending for around 2 Km downstream.

This shoal is located on the right bank of river Wangchu just D/s of confluence of Wangchu River with the Piping Nallah (chhu) and extend for 2 Kms. towards D/s. Although average width of this shoal has been taken as 75 m at many places it's width is more than 100m. Considering an average of 2m depth of material extraction each season, the quantity available will be around 3 Lacs m^3 every season (2000m x 75m x

2m). Total quantities come out to be 15.00 Lacs m^3 in five years considering the river deposits get replenished every year after the monsoon. Further many areas are above the flood plains and can be mined throughout the year to deeper depths.

5.6.4 Additional Rock Quarry

As the dam site quarry located 700m u/s of dam on the left bank could not be tested for want of approach, CWC insisted for locating another quarry. Samples from Quarry no.4, selected by WAPCOS in the year 1995 for the Reservoir scheme, were sent to CSMRS for studying the suitability of the quartzite rock present in this quarry. The test report has indicated that the aggregate from this quarry is suitable for wearing and non-wearing surfaces.

Coarse aggregate quantity required is approx. 21 Lac m^3 inclusive of 38% rejection loss.

Required quantity of Aggregates shall be made available from following:

• Shoal deposite on the Right bank of Wangchu River D/s of Wangchu Piping Confluence.	9.3 Lac Cum (After deducting 38% loss/rejection)
• Rock quarry site (Quarry no. 4) on left bank of Wangchu river , 2 km from Power House site	13.5 Lac Cum
• Excavated Muck of Dam, DT, and HRT (U/s of Adit-3, 30% of HRT length).	2.81 Lac Cum

5.6.5 Fine Aggregate

Fine Aggregate will be obtained from RBM by sieving and from Rock Quarry while manufacturing the aggregates. No separate quarry have been earmarked / identified for fine aggregates.

5.6.6 Testing of Borrow Areas:

The laboratory testing for coarse and fine aggregate have been carried out by the Central Soil and Material Research Station (CSMRS) as per BIS / ISO Codes. The rock samples from the Dam area and Quarry no. 4 (location 1&3) have been found suitable for use in both wearing and non-wearing surfaces, whereas samples from power house area (RBM-1, 2 &3) and Quarry no. 4 (location 2) have been found suitable for use in non-wearing surfaces only. The report on the test results have been appended as **Annex- 5.1**

GEOLOGICAL AND GEOTECHNICAL REPORT

DPR OF MAY 2014

1. INTRODUCTION

1.1. General

The Kingdom of Bhutan lies in the eastern Himalayas which is located North of Bengal - Assam plains and is bounded by Arunachal Pradesh in the East, Tibet in the North and Sikkim in the West. It lies between latitudes 26.7°- 28.4^{o} N and longitudes 88.7°- 92.2°E. The area of the country is 46.620 Sq. Kms. The average rainfall in the country from North to South varies from 500 to 2000mm and 2000 to 5000mm, respectively. The terrain descends from 7,554m in the North to less than 100m in the Southern foothills. The country is drained by numerous snows fed rivers and streams and is endowed with large hydro-power potential. It was thus that The Royal Government of Bhutan proposed to develop a 20 year Power System Master Plan to investigate the possibilities for export of the country's vast hydropower potential. The main rivers draining Bhutan from East to West are the Manas, Sankosh, Wangchu or Raidak & Torsa. The Manas and its tributaries constitute the largest river system in Bhutan with a total length of about 3200 km. The main Manas or Gong River originates from the West Kameng, District of Arunachal Pradesh, India and enters into Bhutan.

The total hydroelectric potential of Bhutan is estimated to be 30,000 MW of which a small percentage has been tapped so far. Many hydroelectric projects have been initiated by India in collaboration with the Bhutan Government. These are mostly run of the river projects involving lesser submergence and minimum environmental impacts.

The development of Wangchu Hydro Electric Project located in Western Bhutan has been entrusted to SJVN Limited, A Joint Venture of of Govt. of India & Govt. of Himachal Pradesh.

The Wangchu River originates from snowy ranges located along the Northern Bhutan frontiers from North to South direction. Paro Chu and Hoa Chu are the main tributaries that join it on the right bank while Piping Chu joins it on the left bank. The overall river profile of Wangchu from source to the dam site is about 60.76 Kms. The average slope of the river up to the project site is about 46m / Kms.

The Wangchu Hydro Electric Project has been contemplated as a Run-of-River scheme and is situated in the Chukha district of Western Bhutan. The proposed dam site is located on Wangchu River, at about 17 Kms U/s of its confluence with the Piping Chu & about 7 Kms D/s of TRT of Tala Hydro Electric Project. The project will

utilize a net head of 301m and design discharge of 210.0 cumecs for generation of 570 MW (4 x 142.5 MW).

1.2. Accessibility

The project is located in the Lesser Himalayan Belt of Bhutan Himalaya. The only approach to the dam site is through the Indo-Bhutan Highway which, at around 44 Kms links with Tala Hydro Electric Project road, from where a 26 Kms long, partially metalled / kuchha road leads to Deorali. Thereafter, the dam site is approachable on foot through 7 Kms long track, descending downslope from El. 1560 m to El. 400 m (River Bed of Wangchu Dam Site) via Gamana.

Phunetsholing to Hashimara - Mahakaal Chowk.	30 Kms	State Highway.
Mahakaal Chowk - Tamukhtala Chowk.	40 Kms.	NH-31.
Tamukhtala Chowk - Bhutanghat (SSB Camp).	25 Kms.	Fair Weathered Road.
Bhutanghat - Sako Nallah.	08 Kms.	Temporary Road.

From Sako Nallah, the power house site is approachable by trekking around 5 Kms along the right bank of Wangchu River and after crossing the Wangchu River near Piping Village. The distance between Phuntsholing and Bhutanghat ($26^0$46': $89^0$51': 78 F/9) is 100 Kms **(Drg. No.: WHEP-DPR-GEO-001-00; Volume-IVB)**.

1.3. Project Proposal

The Wangchu Hydro Electric Project envisages construction of a 134m high concrete gravity dam across river Wangchu in Bhutan near Silli Village (26^0 48' 45" N, 89^0 38' 57" E, Toposheet No.: F/9). The water is proposed to be conducted through a 12.3 Kms long, circular, Head Race Tunnel of 8.5 m diameter to a surface power house located on the left bank just upstream of Wangchu - Piping River confluence (26^0 46'06" N, 89^0 44' 08" E Toposheet No.: F/9). The scheme would utilize a rated net design head of 301m available after the Tala Hydro Electric Project upto Wangchu - Piping Confluence generating 570 MW (Installed Capacity) of power **(Drg. No.: WEHP-DPR-GEO-002-00; Volume-IV.A)**.

1.4 Salient Features

1.	**INSTALLED CAPACITY**	570 MW (4 x 142.5 MW)
2.	**LOCATION**	
	Country / State	Bhutan
	District	Chukha
	River	Wangchu
	Nearest Village (Dam Site)	Akum
	Nearest Village (Power House site)	Piping
	Access:	
	Airport	Paro(Bhutan) to Phuentsholing- 165 Kms.
		Bagdogra to Phuentsholing - 162 Kms.
	Rail Head	Alipurduar to Phuentsholing - 70 Kms.
	Geographical Co-ordinate	Dam Site
	Latitude (N)	26° 48' 45''N
	Longitude (E)	89° 38' 57'' E
	Geographical Co-ordinate	Power House Site
	Latitude (N)	26° 46' 06''N
	Longitude (E)	89° 44' 08'' E
3.	**METEOROLOGY IN CATCHMENT**	
	Average Rainfall	1737 mm
	Atmospheric Temperature	
	Maximum Temp.	32°C
	Minimum Temp.	4°C
4.	**HYDROLOGY**	
	Catchment Area at Diversion Site	4184.16 Sq. Km
	Snow catchment (Out of Total)	946.79 Sq. Km
	Max observed Discharge at Dam Site	1207 Cumec
	Min observed Discharge at Dam ite	41.48 Cumec
	Probable Maximum Flood (PMF)	10300 Cumec
5.	**RESERVOIR**	
	Full Reservoir Level (FRL)	EL. 494 m
	Minimum Drawdown Level	EL. 484 m
	Water Spread at FRL	159.58 Ha
	Gross Storage at FRL	53.60 MCM
	Dead Storage at MDDL	39.09 MCM
	Live Storage	14.50 MCM
	Length of Reservoir	7.5 km
6.	**DAM**	
	Type of Dam	Concrete Gravity
	Top Elevation of Dam	EL. 498 m
	River Bed Level at Dam Site	EL. 403 m
	Dam Height above River Bed	95 m
	Deepest Foundation Level	EL. 364 m
	Max. Height above Foundation	134 m

Length of Dam at Top	295 m
Top Width of Dam	8 m
No of Bays	7
Overflow Blocks	110.6 m
Non-overflow Blocks	184.4 m

7. SPILLWAY

Type	Ogee with Sluice Type (Lower Tier) Ogee with Open Crest (Upper Tier)
Design Flood	10300 Cum (PMF)
Regulation gates (Clean Opening)	7 Bays each of size 7.80 m (W) x 9.40m (H) in lower tier & 1 Bay of size 6.0 m (W) x 4 m (H) in upper tier
Crest Level	EL. 436m (Lower Tier) EL. 490m (Upper Tier)
Energy Dissipation System	Trajectory Bucket

8. DIVERSION TUNNEL

Location of Diversion Tunnel	Right Bank
Nos., Size & Shape	2 No, 10.00 m dia. Horse Shoe Shaped
Length Between Portals	585m & 485m
Diversion Discharge (25 Years)	2284 Cum
Invert Level at Tunnel Inlet	EL. 407m
Invert level at Tunnel Outlet	EL. 403m
Diversion Tunnel Gates. No. & Size	2 No, 10m (Width) x 10m (Height)

9. POWER INTAKE

Type	Two Nos. Straight Type With Bell Mouth
Invert Level	EL. 470m
Center Level	EL. 473m
Top Level	EL. 480.35m
Intake/ Feeder Tunnel	2 Nos, 6m Φ Circular Shaped
Length	232.95m & 219.38m
Stop log Gate	4.75m (W) x 6m (H)
Design Discharge	116.60 Cum Each

10. HEAD RACE TUNNEL

Shape and Size	8.5m Φ Circular Shaped
Design Discharge	212 Cum
Length	12.357 Kms
Adit	5 Nos. 7.0 m Φ D Shaped
Adit to Penstock	1 No. 7.0m Φ D Shaped

11. SURGE SHAFT

No. & Type	One No. Restricted-Orifice
Shape and Size	Circular, 20m Dia
Height	148.50m
Top Level	EL 559m
Surge shaft Gates. Nos & Size	2 Nos, 3.80m (W) x 8.5m (H)
Max Upsurge Level	EL 532m
Min Upsurge Level	EL 527m

12. VALVE HOUSE

Type	Butterfly Valve
Nos.	2 Nos.
Dia of valve	4.8 m Φ
Size	60.65 (L) x 14 (W) x 18.85 (H)

13. PRESSURE SHAFT

Nos, Size & Shape	Two Nos, 4.8m dia,852.5m long circular pressure shafts each bifurcated to two nos, 3.3m dia, 44.80m long, to feed four units
Design Discharge	106 Cumec Each

14 POWER HOUSE

Type& Location	Surface Power House on left bank of Wangchu River
Installed capacity	4 x 142.5 MW (570MW)
Size of power house	120m x 50 m x 47.5m
Elevation of M/C	179.00m
Elevation of generator floor	173.50m
Elevation of turbine floor	168.00m
Elevation of MIV floor	160.00m
Drainage/Dewatering gallery	155.50m
EOT Crane	
Rating	250T / 25T
Numbers	2

15. TAIL RACE CHANNEL / OUTFALL

Maximum tail water level (with 10% overload)	175.00m
Minimum tail water level (No Load)	170.30m
Normal tail water level	174.50m
Width	15.50m
No. of gates	2 No.
Size of the gate	4.17(W) x 4(H)

16. CONSTRUCTION PERIOD

6 Years after 2 Years of Pre-Construction Period.

* * * * * *

2. FIELD INVESTIGATIONS

2.1. Scope of Work

The scope of work covers Surface and Sub-surface Geological Investigations, Rock Mechanic Tests, Identification of Borrow Area and Assessment of Quality and Quantity of Construction Material (Coarse and Fine Aggregates) for the project construction. The basic aim was to fulfill the following objectives:

a) To collect sufficient geological and geotechnical data in terms of quality and quantity for the techno-economic design of the civil structures.

b) To study various project alternatives and optimise the project layout.

c) To collect adequate geotechnical data for adopting suitable construction methodology and to arrive at realistic cost estimate.

d) To highlight the geological problems likely to be encountered during the construction of the project.

2.2. Previous Work

On the request of Royal Govt. of Bhutan, the Feasibility Studies of the Wangchu Reservoir Scheme were carried out by M/s WAPCOS Limited and a report was submitted in January, 1995 to the Royal Govt. of Bhutan. The Wangchu Reservoir Scheme envisaged construction of a 258m high rock fill dam on the Wangchu river in a narrow gorge just U/s of the loop near village Baikinza (10 Km D/s of the present dam site) creating a reservoir capacity of 710 million cubic meter at FRL of 490m. The water was proposed to be conducted through a 4.48 Km long Head Race Tunnel from the left bank of the Wangchu river to a surface power house located just U/s of the Wangchu-Piping river confluence on the left bank. The scheme would have utilised a net head of 323m and would have generated 900 MW (6 x 150 MW) of power. This scheme was shelved in favour of the present Run of the River Scheme with the dam site located 7 Km D/s of Tail Race Tunnel of Tala Hydro Electric Project (10 Kms U/s of the dam site of the Reservoir Scheme), whereas the power house site remains more or less at the same location.

2.3. Project Alternatives Considered For DPR Study

For locating the dam site for the Run of the River Scheme, three reconnaitory traverses along the Wangchu River from Tala Tail Race Tunnel D/s upto the dam site of Wangchu Reservoir Scheme near Baikinza was taken by a team of officials of SJVN Limited comprising of Geologists and Designers. A location, 7 Kms D/s of the Tala Hydroelectric Project Tail Race Tunnel appeared suitable as it was located

along a straight stretch of the river. There is no suitable location for the dam site U/s of the bank of river because of the lack of straight stretches, the river valley being open combined with the fact that the U/s sites will be more closer to the Main Central Thrust (MCT) which is located 7 Km U/s of the present dam axis along the river. There is no favorable location in the D/s also as the Wangchu valley widens out in this reach and also there is no straight stretch to accommodate the dam. In addition, due to the abrupt change in gradient of the Wangchu river in the D/s, the river bed levels drops considerably resulting in appreciable increase in the height of the dam.

The Director, Geological Survey of India during his first visit to the project site on 26.10.2010 proposed five alternatives for the dam site in the area. Out of these five alternatives, four alternatives were located in & around the present dam site in a straight stretch of 1.4 Km and the fifth alternative (E-E') was located at the D/s bend of Wangchu river **(Figure-2.1).**

A brief description of the five alternative dam sites is as under:

Dam Axis A-A':

The Dam Axis A-A' is the U/s most and is unapproachable most of the time. This dam axis is characterized by the following facts:

a) Immediately U/s of this axis, a nallah on the left bank channelises the water from a massive old slide from an elevation of about 1160m. This nallah can bring in debris from the slide and pose a threat to the dam structure.

b) The left abutment has slope debris/overburden at the base up to the elevation 430m (river level ±420) and thereafter rock at shallow depth will be available above upto the full dam height and above.

c) Rock is available on the right bank also.

d) The width of the river bed is 130m at the dam axis.

e) There is no suitable location for the intake structure on the left bank.

This location is rejected as it lies in close vicinity of a massive old slide on the left bank which can be dangerous to the dam structure and, also due to the non-availability of a suitable location of intake structure. Further the site is in-accessible for most part of the year.

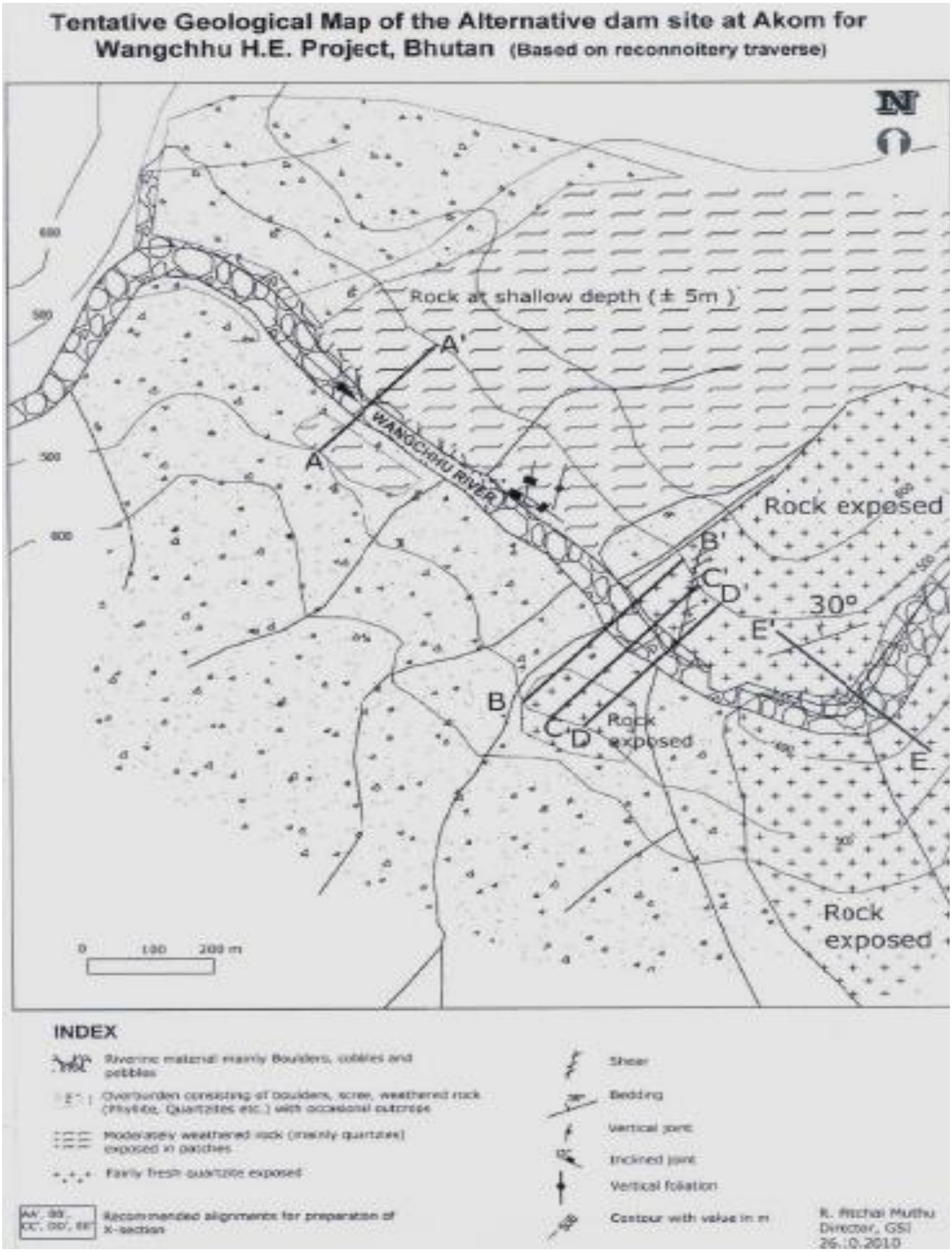

Figure-2.1: Location of Five Alternatives of dam sites as suggested by Director (GSI).

Dam Axis B-B':

This dam axis is located 350m D/s of Dam Axis A-A' and 50m U/s of the present dam axis.

a) A gully was observed just U/s of this axis on the left abutment with rock exposed, originating from an elevation of around 550m.

b) Similarly, a deep incised nalla was observed just U/s of this axis on the left abutment originating from an elevation of around 650m.

c) A deeply incised perennial nallah is located, on the right bank.

d) No portal site for Power Tunnel Intake could be located.

This site was not favored because of the presence of nallah / gully on either bank.

Dam Axis C-C':

The dam axis C-C' is located 50m D/s of Dam Axis B-B' and is the present dam axis which is characterised by the following facts:

a) The left abutment in general has outcrops of closely jointed quartzite from river bed to a height of over 300m with a thin cover of slide debris.

b) On the right abutment, quartzite rock (ledge) extending along the river is exposed from the river bed level upto 40 to 50m height (riverbed ± 400m), extending 50m in the D/s direction and some 200m in the U/s direction. Thereafter, the slopes are dominated by overburden up to the dam top elevation of 500m and above upto El. 550m. The rock is expected below an overburden depth of 2 to 10m on the hill slope.

c) Rock outcrop is available for the Power Tunnel Intake Structure on the left bank.

d) For construction of diversion tunnel, rock is available at the Inlet portal, whereas at the outlet portal rock is not exposed.

This is the present dam axis where exploration has been done.

Dam Axis D-D':

This dam axis is located 100m D/s of the Dam Axis B-B' or 50m D/s of Dam Axis C-C' and passes through a very large boulder on the right bank having a bench mark of El. 406.49m.

a) The left abutment has similar rock conditions as seen at Dam Axis C-C' but there is one perennial nallah on the right abutment. A conical structure is present on the left abutment with thick vegetation. The hill slope at the end of the cone structure is

broken; otherwise the hill has a steep slope above and below. This could be a sign of slumping. The area is unapproachable.

b) The right abutment has a gentle slope of around 23° as compared to the other four axis with scanty rock outcrops in its vicinity.

c) A rock ledge of around 28m length and 18m height protrudes across the river on the left bank, just 70 m D/s of this axis which breaks the river flow.

d) The width of the dam at the dam top (El. 500m) will be around 380m.

The site was not considered suitable because of its close proximity to one perennial nallah on the right bank. In addition the right abutment is quite gentle and has scanty rock exposures.

Dam Axis E-E':

The Dam Axis E-E' is inaccessible because of the almost vertical rocky abutments. This axis was also the least preferred by Director, GSI on the fact that kinks / bends of the river are considered the intersecting points of cross faults and moreover, a dam located within a range of 250m from the D/s bend would not be suitable for energy dissipation and can cause bank erosion and may trigger slides.

From the above it can be concluded that the Dam Axis (C-C') was considered the most suitable of the five dam axis on the facts given below. Perhaps, Director, Geological Survey of India during his visit on 26/10/2010 also wanted to refer the Dam Axis C-C' as the most preferred dam axis in his report but for the misprinting.

a) It has rock exposures extending both in the U/s and D/s of the axis on the right abutment at river bed level for a length of approximately 250m.

b) Rock outcrops were also observed on the right abutment at higher elevations extending approximately for around 150m along the river in the U/s and D/s directions.

c) No major depression/gully formation was observed in the near vicinity of the dam axis on both the banks.

d) The left bank has massive outcrops of jointed quartzite from river bed to a height of over 300m.

e) The Power Tunnel Intake location on the left bank and Diversion Tunnel Intake on the right bank are located on rocky outcrops.

The location of the power house has been kept the same as that of the Reservoir Scheme. It is located at the Piping - Wangchu river confluence on the left bank of Wangchu River. No alternate study for the power house location was done.

The HRT likewise will remain on the left bank but will be of a longer length and smaller diameter as compared to the Reservoir Scheme. The right bank which is comparatively gentle in nature is dominated by overburden, mainly in the form of slope debris with scanty rock exposures and lots of cultivation and habitat. Soft, phyllite rock which is susceptible to weathering dominates the right bank, which would not be favorable for the construction of HRT. The right bank slopes are dissected by around 23 nallahs. In contrast the left bank slopes are rocky and are invariably formed of quartzite and phyllitic - quartzite rock which is hard and compact and less susceptible to weathering and with less nallahs which influenced the decision to keep the HRT on the left bank. Refer Note of Director, GSI enclosed as **Annexure-I of Volume-IVA.**

With the above alternative studies, the present Run of the River Scheme would thus envisage construction of a 134m high concrete gravity dam with top of the dam at El. 498m, a 8.5m diameter, Circular shaped, 12.30 Km long HRT on the left bank of Wangchu river, a surface power house of 124m (L) x 41.50m (W) x 44.5m (H) utilizing a net design head of 301m for generating 570 MW (4 x 142.5 MW) of power.

2.4. Methodology and Extent of Studies

Geological investigations were carried out at the project site at Dam Axis C-C', the surface power house located at the Piping - Wangchu River confluence and HRT on the left bank of the Wangchu River.

2.4.1. Topographic Survey

The investigations were first started by carrying out the project survey on 1:5000 / 10000 Scale and subsequently the main project components were surveyed on 1:500 / 1000 Scale. These survey sheets were taken as the base maps for doing the geological mapping/studies. The structure wise survey maps are as follows:

Project Area (HRT and Reservoir Area)	=	1:5000 / 10,000 Scale.
Dam Site Complex, Power House Complex	=	1:500 / 1000 Scale.

2.4.2. Geological Mapping

Large scale geological mapping of the project area has been carried out on 1:10000 / 1:5000 Scale from 500m U/s of dam axis upto the Piping - Wangchu River confluence. Detailed Geological Mapping on 1:1000 Scale has been carried out at

the dam site and power house and their appurtenant structures. The reservoir mapping has been carried out on 1:10000 Scale. Various litho-units and structural discontinuities present in the project area were mapped besides detailed discontinuity survey to know their behavior / impact on the project components. The geological maps / plans and sections thus prepared are appended with the report as **Drg. No.: DAM-WHEP-DPR-GEO-001-00 to 32; Volume-IVB** and are tabulated below in **Table-2.1:**

Table-2.1: Details of Geological Plans and Cross / Longitudinal Sections.

S. N.	Title of the Drawing	Drawing No.
1.	Location Map of the Project Area.	WHEP-DPR-GEO-001-00
2.	Layout Plan of the Project.	WHEP-DPR-GEO-002-00
3.	Regional Geological Map of Bhutan.	WHEP-DPR-GEO-003-00
4.	Structural Map of Bhutan, A fter Gansser, 1980.	WHEP-DPR-GEO-004-00
5.	Photo-geological and Photo-geomorphological Map of Part of Bhutan.	WHEP-DPR-GEO-005-00
6.	Geological Plan of Dam Area.	DAM-WHEP-DPR-GEO-006-02
7.	Geological Section along Dam Axis.	DAM-WHEP-DPR-GEO-007-03
8.	Geological Section along Bucket Area.	DAM-WHEP-DPR-GEO-008-01
9.	Geological Section along Plunge Pool Area.	DAM-WHEP-DPR-GEO-009-00
10.	Geological Section along U/S Coffer Dam.	DAM-WHEP-DPR-GEO-010-00
11.	Geological Section along Diversion Tunnel (DT-1).	DAM-WHEP-DPR-GEO-011-00
12.	Geological Section along Diversion Tunnel (DT-2).	DAM-WHEP-DPR-GEO-011A-00
14.	Geological Section along Power Intake.	DAM-WHEP-DPR-GEO-013-00
13.	Geological Plan along HRT Alignment.	HRT-WHEP-DPR-GEO-014-02
14.	Geological Section along HRT Alignment.	HRT-WHEP-DPR-GEO-015-03
15.	Geological Plan of Power House Area.	PH-WHEP-DPR-GEO-016-01
16.	Geol. Section from Surge Shaft to TR Channel.	PH-WHEP-DPR-GEO-017-01
17.	Geological Map of Reservoir Area.	WHEP-DPR-GEO-018-02
18.	3-D Geological Log of Drift DR-1 (0m to 70m).	DAM-WHEP-DPR-GEO-019-01
19.	3-D Geological Log of Drift DL-1 (0 to 70m).	DAM-WHEP-DPR-GEO-020-01
20.	3-D Geological Log of Drift DL-2 (0 to 70m).	DAM-WHEP-DPR-GEO-021-01
21.	3-D Geological Log of Drift PI -1, Power Tunnel Intake (0 to 50m).	DAM-WHEP-DPR-GEO-022-00
22.	Geological section along HRT Adit-1	HRT-WHEP-DPR-GEO-023-00
23.	Geological section along HRT Adit-2	HRT-WHEP-DPR-GEO-024-00
24.	Geological section along HRT Adit-4	HRT-WHEP-DPR-GEO-026-00

25.	Geological section along HRT Adit-5	HRT-WHEP-DPR-GEO-027-00
26.	Geological Plan at El 155.50m of Power House Area.	PH-WHEP-DPR-GEO-028-00
27.	Geological section along longer axis of Power House pit(Line A-B)	PH-WHEP-DPR-GEO-029-00
28.	3- D Geological Log of Drift DR-2 Right abutment (Ch 00.00 to 70.00m)	HRT-WHEP-DPR-GEO-030-00
29.	3- D Geological Log of Drift DR-2(Cross-Cuts) Right abutment (Ch 00.00 to 10.00m on each side of drift)	HRT-WHEP-DPR-GEO-030A-00
30.	3- D Geological Log of Drift DR-1(Cross-Cuts) Right abutment (Ch 00.00 to 10.00m on each side of drift)	HRT-WHEP-DPR-GEO-031-00
31.	3- D Geological Log of Drift DL-1(Cross-Cuts) Left abutment (Ch 00.00 to 10.00m on each side of drift)	HRT-WHEP-DPR-GEO-032-00
32.	3- D Geological Log of Drift DL-2(Cross-Cuts) Left abutment (Ch 00.00 to 10.00m on each side of drift)	HRT-WHEP-DPR-GEO-033-00

2.4.3 Exploratory Drilling:

The dam site has been explored by 15 no's of exploratory drill holes aggregating to 1150 m of drilling, of which 8 were drilled at the dam axis (DH-1, DH-2, DH-3, DH-7, and DH-8, DH-10A, DH-11A and DH-12A), 5 drill holes in the dam body (DH-4, DH-5, DH-13, DH-14 and DH-15), one at the upstream coffer dam (DH-6) and one at the diversion tunnel outlet area (DH-9).

The HRT alignment has been explored by 3 no's of drill holes, one at the HRT-Zilung nallah upstream branch crossing (HRT-1), another hole at the d/s arm of the HRT-Zilung nallah crossing (HRT-2) and the third drill hole (HRT-3) towards the d/s end of HRT (near Nunpani fault).

The Power House Complex has been explored by 11 nos. of drill holes; including 1 hole along the surge shaft (SS-1), 3 drill holes along the penstock; 6 drill holes at the power house site and one in the Tail Race Channel (TRC-1); totaling to 678.50 m.

Thus a total of 29 drill holes aggregating to 2048.50 m of exploratory drilling have been carried out in the project area. All the 29 drill holes done by SJVN Ltd. have been geologically logged on 1:100 scale on standard performa and are annexed with the report as **Appendix-1 to 29; Volume-IVA.**

The drilling done by SJVN Limited at various components is given below:-

Table-2.2: Details of drill holes at the project done by **SJVN Limited (2010-2013).**

Structure	No. of Holes	Drill Hole Numbers	Depth (m)
Dam Site	15	DH-1 to DH-15	1150.00
Head Race Tunnel	3	HRT-1 to HRT-3	220.00
Surge Shaft	1	SS-1	183.50
Penstock	3	PS-2 to PS-4	205.00
Power House	6	PH-5 to PH-10	260.00
Tail Race Tunnel	1	TRC-1	30.00
-	**29 Nos.**	**Total Drilling:**	**2048.50**

In addition, the power house area was earlier explored by 5 drill holes as reported in the report of M/s WAPCOS Limited in the year, 1995. One drill hole was drilled along the penstock slope (PS-1), and 4 drill holes at the power house site (PH-1, PH-2, PH-3 & PH-4) aggregating to 234.99 m. The details are given below:

Table-2.4: Details of drill holes at the PH Site done by **M/s WAPCOS Ltd. (Year-1995).**

Structure	No of Holes	Drill Hole Numbers	Depth (m)
Penstock	1	PS-1	50.25
Power House	4	PH-1 to PH-4	184.74
-	**5 Nos.**	**Total Drilling:**	**234.99**

Thus the project has been explored by 34 drill holes, aggregating to 2282.89 m of exploratory drilling.

2.4.4 Permeability Tests

Water pressure tests for calculating permeability values in accordance with IS Codes were carried out in the drill holes and the results are incorporated in the respective drill hole logs. The details relating to the permeability tests of every drill hole is appended with the report as **Annexure-II of Volume-IVA.**

2.4.5 Exploratory Drifting

Five nos. exploratory drifts have been excavated at the dam site for an aggregate length of 440 m. The dam abutments have been explored by four drifts, with cross cuts, viz. DL-1, DL-2, DR-1 and DR-2 for a total length of 390 m to evaluate the nature of rock and the extent of stripping required. The fifth drift (PI-1) was excavated at one of the power intakes on the left bank for 50 m length to assess the rock conditions likely to encounter in the intake. All these drifts have been geologically

logged on 1:100 scale. The geological logs of the drifts are given as **(Drg. No.: DAM-WHEP-DPR-GEO-019-01 to GEO-022-00 & DAM-WHEP-DPR-GEO-030-00, DAM-WHEP-DPR-GEO-030A-00, DAM-WHEP-DPR-GEO-031-00 to GEO-033-00 ; Volume-IVB).**

Table-2.4: Drifting done at the Project.

Structure	No of Drifts	Drift Numbers	Total Length (m)
Dam Axis	4	DR-1 (with 2 cross-cuts of 10 m each) DR-2 (with 2 cross-cuts of 10 m each) DL-1 (with 2 cross-cuts of 10 m each) DL-2 (with 2 cross-cuts of 10 m each)	390
Power Tunnel Intake (Left Abutment)	1	PI-1	50
-	**5 Nos.**	**Total Drifting:**	**440**

2.4.6. Rock Mechanic Tests and Petrography

Detailed laboratory investigations were carried out on 55 no. of core samples collected from the various rock types exposed in the project area to determine the engineering properties of rock. The tests were got conducted from Department of Earth Sciences, IIT, Bombay. The following laboratory tests have been performed on the core samples:

i) <u>Physical Properties of Rock</u>:

a) Bulk Density.
b) Porosity.
c) Grain Density.

ii) <u>Geo-mechanical Properties of Rock</u>:

a) Uniaxial Compressive Strength (UCS) under dry and saturated conditions.
b) Tensile Strength (Brazilian Test).
c) Shear Strength of Triaxial C.
d) Deformability Characteristics.
e) Slake Durability.
f) P-Wave and S-Wave Velocity under dry and saturated conditions.

In addition 39 Rock Core Samples collected from the various drill holes drilled at the dam complex, HRT and power house complex were sent to Department of Earth Sciences, IIT, Bombay for Petrographic studies. Thin sections of 0.03mm thickness were prepared and studied under Leica microscope in transmitted light. The detailed study is enclosed as “Geo-mechanical Properties of Bore Hole Samples; By IIT, Bombay (in the Year, 2011)” **Annexure-III of Volume-IVA.**

2.4.8 Geophysical Studies

Geophysical Survey at the dam site and power house site was carried out by AIMIL, New Delhi by refraction survey using hammer technique. A total of six numbers of profiles were taken aggregating to 887 running meters. The report titled "Report on Seismic Refraction Survey for WHEP, By AIMIL, New Delhi (Year, 2011)" is enclosed as **Annexure-IV of Volume-IVA.**

2.4.9. Photo Geological Studies

This study is aimed to understand the regional setup, lineaments, joint and fracture patterns and to map the broad geomorphological land forms. The objective is to provide the field geologist with a map which will elaborate the regional set up and the structural framework of the region and the project area.

The photo geological study of the project area was earlier carried out under the Wangchu Reservoir Scheme by Photo-geology and Remote Sensing Division (Year, 1992), GSI, Eastern Region, Lucknow. 2 No. reports on the study alongwith the map titled as "Note on Photo-geological Studies of the area around Tala Hydro Electric Project (Chukha Stage-II) & Wangchu Reservoir Scheme (Chukha Stage-III)" and "Final Note on Photo-geological Studies of the area around Tala Hydro Electric Project (Chukha Stage-II) and Wangchu Reservoir Scheme (Chukha Stage-III)" are enclosed as **Annexure-V.A and V.B of Volume-IVA** respectively**.**

2.4.10. Seismic Studies

A preliminary seismic study was done by Central Water and Power Research Station (CWPRS), Pune in July, 1993 using past data on earthquake occurrences and knowledge of various tectonic and geological features of the region from which design seismic forces were evaluated in terms of acceleration response spectra. The report titled "A Preliminary Evaluation of Design, Earth Quake Spectra to Tala Hydro Electric Project and Wangchu Hydro Electric Project" is enclosed as **Annexure-VI of Volume-IVA.**

Additionally, CWPRS, Pune has been assigned the work of Seismic Studies. The details are dealt in Civil Design Volume.

2.4.11. Other Studies

Director, Geological Survey of India has visited, the project on 26-10-2010 and 06-12-2011 as Nodal officer of Ministry of Energy, GOI to evaluate the geological aspects of the project. The report of the first visit is appended as **Annexure-1, Vol-IVA.** The report of the second visit is awaited.

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3. REGIONAL GEOLOGY

3.1. Introduction

Bhutan is predominantly a land locked mountainous country, bounded by Arunachal Pradesh in the east, Sikkim in the west and Assam and West Bengal in the south. In the north it is bounded by Tibet. Thimpu is the capital of Bhutan and is centrally located.

3.2. Physiography

Physiographically, the Bhutan Himalaya can be divided roughly in to three zones from south to north; **(i)** Sub-Himalaya or Foothill zone; **(ii)** Lesser Himalaya and **(iii)** Great Himalaya.

3.2.1. Sub-Himalaya or Foothill Zone

The Sub-Himalayan zone consists of the Siwalik sediments of Tertiary period, lying to the south of the Main Boundary Fault (MBF) and is characterised by low lying hills generally below an altitude of 1500m. Because of a gap in the Siwalik exposures between the Teesta and Torsa rivers in this part of Himalaya, the Sub-Himalayan zone is missing and Lesser Himalaya starts immediately after the alluvial plains of North Bengal, as seen near Phuentsholing.

3.2.2. Lesser Himalaya

The Lesser Himalaya consists of chains of ranges of hills, rising to 1500m to 4925m in altitude, which radiate southward from the Great Himalayan Range, forming the watersheds between the main rivers. The terrain is rouged, characterized by deep valleys with precipitous slopes and thick cover of vegetation. This zone includes rocks of all three belts, i.e. the Frontal belt (excluding the Siwalik Sediments), Central Crystalline Belt and the Tethyan Sedimentary Belt of the Black Mountain Region. The highest peak in this zone in Central Bhutan is the Black Mountain (4925m above the mean sea level). The Wangchu Hydro Electric Project lies in frontal feet.

3.2.3. Great Himalaya

The Great Himalayan Zone lying to the north of the Lesser Himalaya is characterized by a chain of snow-covered, high peaks along the Tibetan border. The main peaks along the Great Himalayan Range in Bhutan from west to east are Chomolhari (7314m), Kungphu (6797m), Takaphu (6532m) and Kula Kangri (7516m), among many others. The Great Himalayan Zone in Bhutan comprises rocks of the Central Crystalline Belt, Tethyan Sedimentary Belt and younger ‘Chomolhari Granites’.

3.3. Geomorphology of Bhutan

Bhutan has predominantly a mountainous terrain and is located in the north of the Indian plains. The abrupt rise in altitude from the Indian plains is conspicuously reflected. The highest peak in the High Himalayas is the Kamker Phunsum (7561m). Trema Wagye and Monlaka are important passes between Bhutan and Tibet.

The main rivers flowing in Bhutan are Amo Chu, Wang Chu, Sankosh Chu, Mangde Chu, Bumthang Chu, Kuru Chu, and Gamri Chu flowing towards south. These rivers originate from High Himalayan region contributing large perennial discharges. The main river flowing in the project area is Wangchu river flowing towards south direction.

All the rivers generally flow towards southerly direction except Dragma Chu which flows in south-westerly direction with local variations of minor streams. These rivers enter the Indian plains abruptly, dropping their gradients and depositing large quantities of sediments which form huge alluvial fans all along the foot of the mountains. These fans are mostly covered with dense vegetation. The rivers in the foothill part and in the plains have braided streams with wide river beds.

Some of the rivers like Kuru Chu are antecedent rivers represented by deep narrow valleys and undercuts. In upper reaches these rivers have carved u-shaped valleys displaying fine reprints of earlier glacial activity. The perpetual snow line in Bhutan is roughly above 5000m altitude.

The drainage pattern in Bhutan is mainly dendritic and occasionally trellis. The drainage is also controlled by lineaments, master joints, folds, faults and also by due to variation in bedding/foliation trends at places. Structural control and lithological variations of rock formations has resulted in river Wangchu during at places. The drainage density is poor in northern Bhutan in the Granitoid and Gneissic terrain while it is moderate in central Bhutan in the low grade meta-sediments. The drainage density is high in western, eastern and southern parts where relatively softer Tertiary sediments and low grade meta-sediments are present.

At places the river exhibits clear structural control over its course. Many sharp bends exhibited in the upstream part of the basin is controlled by fold patterns, whereas the straight course is by lineaments. The hill slopes are covered under a luxuriant growth of vegetation while rock exposures are generally seen on steep escarpments only.

3.4. Regional Geology

The generalized stratigraphic sequence of the Frontal and Central Crystalline belts, as worked out by the Geological Survey of Indian (1984)* is given below **Table-3.1**:

Table-3.1: Stratigraphic Sequence of Frontal & Central Crystalline Belts of Bhutan.

	Alluvium	Material, Older Alluvium Unconsolidated Terrace.	Quaternary
	Siwalik Group	Mio-Pliocene, Sandstone, Siltstone, Shale and Conglomerate	Mio- Pliocene
----------	**Main Boundary Fault/Thrust**	----------	
	Acid Intrusive	Tourmaline Pranite, Pegmatite.	Tertiary
	Damuda Group	Coal-bearing Sandstone, Shale (Lower Gondwana).	Permian
----------	**Thrust**	----------	
Buxa Group	Manas Formation	Dolomite with minor Carbonaceous Phyllite & Quartzite.	-
	Phuntsholing Formation	Green, Purple, Grey, Phyllite and Quartzite	Middle Paleozoic
	Thungsing Formation	White Gritty Quartzite with thin conglomerate beds, marble and meta-volcanic.	-
----------	**MCT? / Thrust? Gradational Contact**	----------	
Central Crystalline Complex	Paro Formation	Quartzite, Quartz - Mica Schist, Marble and Calcsilicate Rock.	Pre-Cambrian
	Thimphu Formation	Gneisses and Schist's with Migmatite.	Pre-Cambrian

* *Exploratory Brochure on Geological and Mineral Map of Bhutan, November, 1984 published by Director General, Geological Survey of India (GSI).*

The latest Techno-stratigraphic order of superposition in the Bhutan Himalayas (after Bhargava, Year, 1995) is also given below (Geological Survey of India, Special Publication No. 39 on the Bhutan Himalaya, and Edited by Sh. O. N. Bhargava) - **Table-3.2:**

Table-3.2: Techno Stratigraphic Order of Superposition in Bhutan.

Tethyan Succession	Conglomerate, Shale, Siltstone, Sandstone, Limestone, and Volcanics.
---------- **Unconformity** ----------	
Thimpu Group	Gneiss, Migmatite, Amphibolite & High Grade Meta Sediments.
---------- **Thimpu thrust** ----------	
Jaishidanda Formation	Biotite Garnet + Staurolite - Schist with Tectonic Slivers of Granite Gneiss.
---------- **Jaishidanda Thrust** ----------	
Shumar Formation	Quartzite, Phyllite & Chlorite-Mica-Schist, Barsong Limestone a few tectonic slivers of granite-gneiss in lower parts.
----------**Shumar Thrust** ----------	
Diuri Formation	Diamictite , Phyllite and Quartzite.
----------**Unconformity? - Locally Tectonised** ----------	
Buxa Group	Gritty Feldspathic Quartzite, Limestone, Dolomite, Quartzite, Conglomerate, Slate, Phyllite, Tectonic Scales of Permian Seti Khola Formation.
----------**Buxa Thrust** ----------	
Damuda Subgroup	Sandstone, Siltstone, Shale, Coal Beds.
----------**MBT (Main Boundary Thrust)** ----------	
Siwalik Group	Sandstone, Siltstone, Shale, Clay, Conglomerate.
---------- **Fault** ----------	
Quaternary sediments	Sand, Conglomerate, Silt, Clay.

The Wangchu Reservoir Scheme lies within the Frontal Morpho-tectonic Belt **(Refer Table-3.1)** which includes the autochthonous Siwalik group of rocks, the Damuda Group (Gondwana) and unfossiliferous litho-units of Buxa Group. The Buxa Group is in contact with the rocks of the Siwalik Group along the Main Boundary Fault. Rocks of the Damuda Group, wherever present, also have tectonic contacts with the Buxa towards north and with the Siwalik Group towards south.

3.4.1. Siwalik Group

The Siwalik Group comprises immature light grey (Pepper and Salt) sandstone with pebble bands and conglomerates; olivine green siltstone, shale and boulder beds. In the lower part of the succession, the sandstone is fine to medium grained, dirty white to grey in colour and contains thin bands and lenses of olive sandstone and shale and narrow impersistant pebbly horizons. It is essentially made-up of sub-rounded to

sub-angular grains of quartz and feldspar with some detrital heavy grains like biotite, staurolite, tourmaline, etc., occasionally fragments of coal are also seen. The grain size of the sandstone tends to be coarse in the upper parts, where some narrow impersistant pebble and conglomerate beds are present. In the topmost section, the Siwalik is represented entirely by thick conglomerate and boulder beds with highly friable sandy matrix. The mineral assemblage of these rocks indicates the Buxa / Gondwana Groups and the Central Crystalline Complex as the provenance for the Siwalik.

The rocks of the Siwalik Group occur as two narrow strips along the foothills in the south - eastern and south-central part of Bhutan. The eastern strip, extending from Kakulong in the west to the eastern boundary of Bhutan, has a strike length of about 140 Km and is the longest one. It continues beyond in the adjacent Arunachal Pradesh, India. The smaller strip has a strike length of about 40 Km extending from the Pana River in the west to Sarbhang Town in the east. The rocks have a general E-W strike with moderate to steep northerly dips. Though the project lies within the Frontal Belt of Bhutan Himalaya, the Siwalik group of rocks does not occur in the project area.

3.4.2. Damuda Group

A narrow strip of sedimentary rocks comprising sandstone, siltstone, shale and coal seams occur in the south-eastern Bhutan over a strike length of about 85 Km extending from Nanglam in the west to the Bhutan-India boundary in the east. These rocks, which have a general E-W strike with northerly dips, overlie the Siwalik Group of rocks along a thrust plane named the Main Boundary Fault (MBF). The northern boundary of these rocks is marked by another thrust, separating the Damuda Group from the overlying Buxa Group of rocks. The Damuda comprises of medium to coarse grained, white feldspathic sandstones, with thin lensoid coal seams, conglomerate, slaty-phyllite and carbonaceous-shale. Near the thrust contact, the rocks are indurated, mylonitised and silicified and are dark grey in colour. The coal seams are generally lenticular, pulverized, highly sheared and the coal has been rendered anthracitic at places and also admixed with detrital sandy material. This Group of rocks is also absent from the project area.

3.4.3. Buxa Group

Buxa Group of allochthonous rock occurs in the foothill belts of Bhutan and extends in an E-W direction from the west to the east of Bhutan. In the central part of Bhutan, these rocks overlie the Siwalik Group of rocks along the Main Boundary Fault and in

Eastern Bhutan, these rocks overlie the Damuda group (Gondwana) of rocks along a thrust contact. The Buxa Group rocks have a general E-W strike with northerly dip. These rocks show the development of highly apprised, isoclinals, overturned, mesoscale folds. Lithostratigraphic studies by some workers have revealed the Buxa and Daling rocks to be homotaxial in nature and that one changes over to the other along the strike due to facies change. These rocks are exposed in the project area.

Buxa Group of Rocks has been divided into a lower Thungsing Formation; middle Phuentsholing Formation and upper Manas Formation. The brief description of these formations is as below:

3.4.3.a. Thungsing Formation:

A feldspathic and highly gritty quartzite with pebbly and conglomeritic bands containing thin intercalation of grey slate and phyllite, present in eastern Bhutan, is freely referred to in Bhutan Geology as Thungsing quartzite, named after the type area present near Village Thungsing. This formation is traceable from Chenla Ri in the east to the Torsa river in the west over a strike length of about 370 Km except for a small gap of about 15 Km north of Sarbhang. In Western Bhutan, the formation is extensively developed and exposed along Sankosh, Wangchu, Pana and Torsa rivers and at Sinchula. Here the main rock type is medium grained quartzite with occasional conglomerate bands and minor basic meta-volcanic rocks, epidorite sills and marble bands.

3.4.3.b. Phuentsholing Formation:

This formation is younger than the Thungsing Formation, but owing to the overturned, synclinal folds of Buxa rocks, it underlies the rocks of the Thungsing Formation and the contact is conformable. The Phuentsholing Formation comprises green to greenish-grey phyllite, purple phyllite and carbon-phyllite with thin interbands of green and/or purple quartzite. Among all these rock types, grey green phyllites are dominant, followed by purple phyllite and carbon-phyllite. Lateral variations, whereby the litho units change over to one another, is quite common. Narrow epidorite sills, often metamorphosed to amphibolites or chlorite-schist are also sporadically distributed in the unit. In the central foothill belt of Bhutan, between the Manas and Jayanti rivers, the purple phyllites are observed to laterally change over to purple, pink and red quartzite. Similarly, in the eastern foothill belt of Bhutan, east of Manas river, the greenish - grey and carbon - phyllites are observed to become pebbly in natures and are termed as pebble slate or diamictite.

3.4.3.c. Manas Formation:

This formation comprises dolomite with associated carbon - phyllite and quartzite. Dolomite is the most important litho-unit followed by quartzite which occurs as thick interbands within or associated with dolomite. Carbon-phyllite occurs as narrow bands and lenses within dolomite. The formation is named after the Manas river where the various litho-units of formation are best developed. Proceeding from west to east, there is a gradual increase in the development of dolomite, both in size and number of bands and the maximum development is seen to the east of Geylegphug.

The strike length of the individual dolomite bands ranges from 250m to 8.5 Km. The largest single dolomite body is the Manas occurrence which extends eastwards from east of Ai river to the Manas river for a length of 75 Km with a maximum outcrop width of 8.5 Km. In the entire Buxa Group of rocks, only the dolomites have so far yielded organic remains as stromatolite. Recently, some bivalves have been collected from siliceous limestone lenses present in ten thrust slices immediately north of the Main Boundary Fault (MBF). The fossils are yet to be identified.

3.4.4. Central Crystalline Complex

Central Crystalline Complex rocks cover an extensive E-W trending belt which occupies more than half of the area of Bhutan. These rocks overlie the meta-sedimentary rocks of more foothill belt and underlie the rocks belonging to the Tethyan Sedimentary Belt in the north. The Central Crystalline Belt has an outcrop width of about 50-60 Km in the eastern and western parts of Bhutan, while it us bifurcated in the central part into two bands; the southern and the northern, by the intervening thick sequence of the Black Mountain Group. In this part, the southern belt of Crystalline Complex is barely 7 Km wide between Dholpani and Mao Khola. In addition to this extensive occurrence of the Central Crystalline Rocks, there are a few small occurrences of gneissic rocks at Gachang, Jhumo Ri, Jording, Khangpar, etc.

3.4.4.a. Thimpu Formation**:**

The Thimphu Formation includes a variety of granitoid rocks, such as migmatite, augen-gneiss, banded gneiss, granite-gneiss, feldspathic-gneiss and schistose rocks ranging up to sillimanite grade. Minor bands of metapsammite are also common.

3.4.4.b. Paro Formation:

The Paro Formation includes essentially the high grade calcareous rocks and meta-sediments, such as marble-calc-silicate rock, quartz-garnet-staurolite-kyanite-sillimanite schist, graphite-schist, etc. with subordinate feldspathised schist and gneiss.

The rocks of Thimphu Formation have a gradational metamorphic and meta-somatic contact with the rocks of the Paro Formations and are considered to be of amphibolites to granulite facies of metamorphism. The Thimpu gneisses rock constitutes the products of assimilation and granitisation of the meta-sediments of the Paro Formation and the rocks of the Paro Formation are the undigested and non-granitised meta-sediments.

3.5 Tectonic Structures

3.5.1 Thrusts

Major Thrusts / Faults of the Bhutan Himalaya, from south to north, are:

a) The Main Boundary Fault / Thrust (MBF);

b) The thrust between Damuda Group and Buxa Group;

c) The Shumar Thrust between the rocks of Shumar formation and the Buxa Group;

d) The Main Central Thrust (MCT) between the Frontal Belt and the Central Crystalline Belt.

Main Boundary Fault / Thrust separating the Siwalik sediments from the rocks of the Buxa / Gondwana Groups are the most important tectonic feature. It has been mapped between the Pana River and Sarbhang in the west for strike distance of about 40 Km; and again between Kakulong and the Dhansiri River in the eastern Bhutan for a strike distance of about 140 Km with two gaps in between. It is a moderate to steep northerly dipping fault / thrust plane with vertical dips (southerly at places). In Eastern Bhutan, two prominent thrusts have been recognized, viz: -

a) Separating Buxa Group of rocks represented by Duiry pebbly phyllite of the Phuentsholing Formation and the Damuda Group (Gondwana).

b) Thrust separating the rocks of Shumar Formation from those of the Buxa Group.

The contact between the Frontal Belt and Central Crystalline Belt has been regarded as the Main Central Thrust (MCT) in other sectors of the Himalaya. However in Bhutan Himalaya, this contact is regarded as thrusted by some workers and as a gradational metamorphic contact by the others.

3.5.2. Folds

A number of major fold structures have been recognised in Bhutan Himalayas. Folds within the Buxa Group have a general axial trace in E-W direction. Overturned regional anticline and syncline are seen in Mangde Chu and the Sankosh river

sections, where various formations of the Buxa Group are repeated due to the folding. The dolomites of the Manas Formation occupy the core of the syncline where as the quartzites belonging to Thungsing Formation occupy the core of the anticlinal structure.

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4. GEOLOGY OF THE PROJECT AREA

The Wangchu Hydro Electric Project is located in Chukha district of Bhutan. The main components of the project, i.e. dam, diversion tunnel, 60% of HRT and the reservoir area will be located in the Shumar Formation whereas the remaining 40% of HRT, Surge Shaft, Pressure Shaft, Power House and Tail Race Channel will be located in the Buxa Group of Rocks. The litho-stratigraphy of the project area as established from north to south is as under:

Table-4.1: Litho Stratigraphy of Wangchu Project Area.

----------**M.C.T**----------	
Shumar Formation	Quartzite, Phyllite, Chlorite-Mica-Schist, with occasional Carbonaceous Phyllite Bands.
----------**Shumar Thrust**----------	
	Thungsing Formation: Gritty Feldspathic Quartzite with pebbly and conglomerate bands with thin intercalation of Slate, Phyllite and Meta Basics.
Buxa Group	----------**Conformable Contact**----------
	Manas Formation: Dolomite, Quartzite, Carbonaceous-Phyllite.
	Phuntsholing Formation: Green to greenish grey Phyllite, Purple Phyllite, and Carbonaceous Phyllite with thin interbands of green, purple quartzite.

Detailed Geological Mapping on 1:10000 Scale for over 3 Sq. Km. was carried out for the Reservoir, 0.75 Sq. Km. of the Dam site area on 1:1000 Scale,16 Sq. Km of HRT on 1:5000 Scale and 0.85 Sq. Km of Power House, Surge Shaft, Penstock & TRT Area on 1:1000 Scale**.**

The Reservoir Area has been approached from Tala Power House road, trekking down to Wangchu river bed sections on its right bank. The dam site has been approached from Deorali road head, after a treacherous trekking to Gamna and to Wangchu river bed site on the right bank. The northern part of the HRT has been approached from Gijari rock slide road head after trekking about 8 Km and the southern part of the HRT and Power House area has been covered from upstream of Wangchu river after trekking around 5 Km through Bhutan Ghat road head to Piping village on the right bank. Based on the geological mapping it is assessed that

bed rock on both the abutments over which the concrete gravity dam will be founded consists of quartzite with occasional phyllite interbands of Shumar Formation.

The upstream 60% length of the HRT (Adits-1 and 2) will be excavated in Shumar Formation comprising of quartzite, phyllitic quartzite with thin interbands of chlorite - mica-schist and occasional carbonaceous phyllites, whereas the downstream 40% of the HRT (Adit-3 & Adit-4) will be excavated in the Buxa Group of rocks comprising of gritty feldspathic quartzite with pebbly and conglomerate bands, dolomite and carbonaceous phyllites. The surge shaft, power house and tail race channel will lie in the dolomite, quartzitic-phyllite, quartzite, carbonaceous-phyllite, slate rocks of the Manas and Phuentsholing Formations of the Buxa Group.

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5. GEOLOGICAL AND GEOTECHNICAL APPRAISAL OF MAIN CIVIL STRUCTURES

5.1. Dam Site

The dam site is located in the Lesser Himalayan Belt of Bhutan Himalaya. The only approach to the dam site is through the Indo - Bhutan Highway, which near M/S 44Km. links with Tala Hyde Electric Project road, from where a 26 Km long partially metalled and kuchha road joins to Deorali. Thereafter, the dam site is approachable through 7Km. long trekking descending down from El. 1560m to El. 400m river bed of Wangchu dam site, via Gamna.

The Wangchu River flows more or less in a straight course, south-east wards along a gorge section narrowest in this region, measuring about 90m only. This straight stretch is bound by sharp bends in the river, both in the upstream and downstream directions. The left bank of the river has a moderate slope of 45° to 50° while the right bank has 35° to 45° slope. The Wangchu dam site represents typical steep sided young valleys with overlapping spurs. The hill ranges trend in NNW-SSE direction while cross spurs are trending in NE-SW to N-S directions. The mighty Wangchu River is in its active down cutting stage in this stretch of high relief. The overall drainage pattern is of dendritic type, partially controlled by litho-structure.

Figure-5.2: Dam Site View (Looking Upstream).

Mass wasting features and riverine deposits are the major landforms in the dam site area. It includes rock and debris slide which are generally seen on the northern and the

southern slopes of the E-W to NWW-SEE trending ridges. At certain places slide material gets accumulated near the toe of the slope occurring as debris fan. Two such slide debris fan have been mapped lying approximately 100m upstream of the dam axis on its left bank and 250m downstream of the dam axis on its right bank. Riverine deposits at bed level consist mainly of boulder, pebble and cobble size fragments, though gravel and sand particles are comparatively less.

5.1.1. Geology of Dam Site

The dam site area lies in the south-western region of Bhutan and falls within the rocks of Shumar Formation of the Lesser Himalayan Belt of Bhutan Himalayas. Broadly, the Shumar Formation of rocks comprises of an alternating sequence of quartzite and phyllitic-quartzite with mica-schist interbands. The phyllitic quartzite is fine grained, commonly grey to grayish-green and well foliated. However, sporadically due to enrichment of carbonaceous matter it attains dark grey hues. Locally, laminations, defined by alternating quartzose, phyllo-silicate rich layers are well preserved. Essential mineral constituents of pelites are muscovite/sericite, quartz, chlorite and opaque. Quartz veins are wide spread in the sequence. The quartzite is commonly fine grained, white to grayish-white, thin to medium bedded and well jointed. Colour banding defining the bedding is conspicuous and is invariably associated with bedding joint. The concentration of phyllo-silicate minerals along layers as well as the bedding joints imparts a flaggy look to the rock. Locally, the quartzite is almost devoid of phyllo-silicate minerals with inconspicuously developed bedding, imparting a massive look to the litho-unit. The dominant minerals in the quartzite are quartz, muscovite, sericite with rare chlorite and biotite. The quartzite grades into phyllitic-quartzite / micaceous-quartzite with increase in proportion of phyllo-silicate minerals.

5.1.2. Geological Studies at Dam Site

5.1.2. a. Geological Mapping:

An area of about 0.65 Sq. Km. has been covered by geological mapping on 1:1000 Scale from 500m upstream to 500m downstream side of the proposed concrete gravity dam across Wangchu river **(Drg. No.: DAM-WHEP-DPR-GEO-006-02; Volume-IVB).**

The dam site is located in a narrow gorge which abruptly rises at an angle of 45° to 50° to a height of about 170m on the left bank and 40° to 45° to a height of 100m on the right bank, thereafter valley opens up with a relatively gentler slope of 35° to 40° in the right bank and rises with a comparatively moderate slope of 50° on the left bank.

Owing to inaccessibility, dense forest, rock debris cover and limited access path, the surface geological mapping includes the detailed study of outcrops along the foot tracks,

nalla sections and river banks only. The geological mapping on the left abutment is limited and restricted to rock exposures at the river bed level as slopes above are invariability inaccessible. The dam site area exposes white, grey and grayish-green quartzite with subordinate bands of phyllitic-quartzite. The quartzite outcrops stands out as prominent ridges, spurs and form steep valley slopes, while the phyllitic-quartzite outcrops occupy moderate to flattened valley slopes. The rocks have a general N70°W-S70°E to N80°E-S80°W strike, dipping 40° to 60° in N10°E to N20°W direction. An outcrop of phyllitic-quartzite has been mapped as linear band along foot track on right valley slopes of Wangchu River. However, minor swings in foliation trend have been noticed as NE-SW & NW-SE with shallow 30° to 40° dips on either side. Local swing of strike and variable thickness of beds is a common feature in phyllitic bands. The foliations in phyllitic-quartzite exposed on right valley slopes are also having more or less the same trend as that of quartzite rocks.

The quartzite and associated phyllitic-quartzite are invariably traversed by 1 to 10cm thick quartz vein, mostly along the bedding and foliation planes. The quartz vein shows pinching, swelling and boundnage structure due to its involvement in multiphase folding. These folds on major scale probably have influenced the development of planner structure and intense jointing of which the following sets are prominently categorizing into **(i)** Strike Joints or Master Joints **(ii)** Dip Joints and **(iii)** Random Oblique Joints. The strike joints are mostly tensional and open type whereas dip and oblique joints are of compression type and are tight closed joints.

Table-5.1: Details of Discontinuities at Dam Site.

Discontinuity	Dip Amount & Dip Direction		Spacing (Cm)	Aperture (mm)	Fillings	Characteristic	Continuity (m)
	Dip Amt.	Dip Direction					
J1	60°-70°	N10°-20°W	15 to 35	0 to 2	Clay/Open	Smooth Planer	Upto 4
J2	70°-80°	N60°- 70°E	20 to 50	<2 to 5	Clay/Open	Rough Planer, Smooth Planer	Upto 5
J3	40°-50°	S60°- 70°W	15 to 20	1 to 2	Clay / Siliceous Material or Open	Rough Planer	Upto 2
J4	40°-50°	N60°- 75°E	20 to 60	<2 to 5	Open	Rough Planer	Upto 4
J5	50°-70°	N40°-50°W	15 to 40	1 to 5	Open or Clay Filled	Rough Planer	5
J6	70°-85°	W toN80°W	20 to 70	1 to 3	Open	Rough Planer	5

The dam foundation rests dominantly on hard and compact, bedded, moderately jointed quartzite below 15 to 37m thick riverine deposits. Both the abutments are also resting over quartzitic rock of good quality, fairly massive and hard, though jointed and sheared at places. A small shear in quartzite band has been picked up at El. 510 to 540m trending

roughly NE-SW direction on the right valley slope just 200m upstream of dam axis. Another shear zone trending NE-SW has been marked at El. 475 to 510m in quartzite outcrop of left bank just 200m D/s of dam axis.

The geological section along the dam axis has been prepared utilizing the geological mapping data and the sub-surface exploration data by drilling and drifting **(Drg. No.: DAM-WHEP-DPR-GEO-003-00, Volume-IVB).**

5.1.2.b Exploratory Drilling

Total of 15 no's of exploratory drill holes. aggregating to 1150 m of drilling has been done at the dam site, out of which 8 were drilled at the dam axis (DH-1, DH-2, DH-3, DH-7, and DH-8 DH-10A, DH-11A and DH-12A), 3 at the dam body (DH-13, DH-14 and DH-15), 1 drill hole (DH-4) in the bucket section, 1 drill hole (DH-5) in the plunge pool, one at the upstream coffer dam (DH-6) and one at the diversion tunnel outlet area (DH-9).

Table-5.2: Details of the drill holes drilled at the Dam Site.

Drill Hole No.	Location	Ground El. (m)	Coordinates	Total Depth (m)	Overburden / Rock Contact (m)	Bed Rock El./ Depth (m)
DH-1	Dam Axis Right Bank.	407.794	**N:**50060.510 **E:**39916.111	50.0	15.0	392.794
DH-2	Dam Axis Centre of River.	403.199	**N:**50081.800 **E:**39935.155	80.0	37.0	366.199
DH-3	Dam Axis Left Bank.	404.483	**N:**50111.841 **E:**39957.256	80.0	27.0	377.483
DH-4	90m D/s of Dam axis in the centre of the river.	403.085	**N:**50022.370 **E:**40003.320	50.0	26.3	376.785
DH-5	150m D/s of Dam Axis in the centre of the river.	401.210	**N:**49958.110 **E:**40033.920	50.0	27.0	374.210
DH-6	U/s Coffer Dam the centre of the river.	404.283	**N:**50150.353 **E:**39819.734	50.00	19.5	384.783
DH-7	Dam Axis Dam Top Left Abutment.	506.018	**N:**50185.090 **E:**40026.734	140.00	1.5	505.518
DH-8	Dam Axis Dam Top Right Abutment.	486.0	**N:**50000.989 **E:**39846.343	130.00	28.50	457.55
DH-9	Diversion Tunnel Outlet.	455.0	-	50.00	21.0	434.00
DH-10A	Dam Axis Right Bank (Angular).	404.438	**N:**50074.586 **E:**39938.709	75.00	43.50	364.00
DH-11A	Dam Axis - Right Abutment (Angular)	458.424	**N:**50019.783 **E:**39871.911	100.00	28.85	429.575
DH-12A	Dam Axis left bank (River bed)	404.083	**N:**50114.13 **E:**39958.27	75.00	42.00	365.00
DH-13	Right bank, 30 m d/s of dam axis	483.00	**N:**49955.027 **E:**39867.686	50.00	36.00	447.00

DH-14	Left bank, d/s of dam axis	404.00	-	135.00	0.00	404
DH-15	Dam axis right bank	463.00	-	35.00	12.00	451
15 drill hole for a total length of 1150 m						

A summary of all the drill holes done in river bed along dam axis is given below: -

DH-1 (River Bed):

Location: Right Bank on Dam Axis. **Coordinates:** **N:** 50060.510 **E:** 39916.111

Ground El.: 407.784 m **Total Depth:** 50 m

Depth (m)	Elevation (m)	Overburden / Rock	Description
0 to 15.0	407.794 to 392.794	River Borne Material	River borne material (RBM) consisting mainly boulders, cobbles and gravels of pink, white and greenish quartzite along with medium to coarse grained grayish sand.
15.0 - 50.0	392.794 to 357.794	Bed Rock	Bed rock comprising of slightly weathered and jointed white quartzite. Staining has been observed in the rock for all the drilled depth of the hole.
			Core recovery has been consistently on the higher side ranging from 80 to 100%. The RQD values varied between 0 to 83%. The permeability tests indicate turbulent flow characteristics with values ranging from 11.55 to 16.52 lugeons.
The prominent jointed, fractured, shattered and shear zones (depth wise) encountered in the quartzite rock are as follows: - 20.2-20.45m: Shattered Rock 23.8-24 m: Fractured Rock 24.35-25.15m: Fractured & Sheared Rock 28.8-28.9m: Fractured Rock. 29.6-29.7m: Fractured Rock. 30.8-31.10m: Shattered Rock. 32.75-33.4m: Shattered & Closely Jointed Rock 33.6-34.25m: Fractured Rock. 35.25-36.2m: Very Closely Jointed Rock with Shattered Zone 37.25-37.50m: Shattered Rock 41.82-42.6m: Shattered & Jointed. 42.95-43.8m: Very Closely Jointed Rock. 44.3-44.6m: Shattered Rock 48.45-48.5m: Shear Zone with Crushed Rock 48.7-49m: Shattered Rock 49.3-49.75m: Very Closely Jointed & Shattered Rock Zone.			

Detailed Geological log of drill hole DH-1 is enclosed as **Appendix-1; Volume-I.A.**

DH-2 (River Bed):

Location: Centre of the river on Dam Axis. **Coordinates:** **N:** 50081.800 **E:** 39935.155

Ground El.: 403.199 m **Total Depth:** 80 m

Depth (m)	Elevation (m)	Overburden / Rock	Remarks
0 to 37.0	403.199 to 366.199	River Borne Material	Boulders, cobbles and pebbles of quartzite and biotite gneiss along with a sand seam between 27.0 to 37.0m depth.
37.0 - 80.0	366.199 to 323.199	Bed Rock	Bed rock comprising of fine grained, white to light grey coloured quartzite was encountered. Staining has been observed in the rock for all the drilled depth of the hole. Core recovery ranges from 74% to 93.33%. The RQD values varied between 0 to 44%. The permeability tests indicate turbulent flow characteristics with values ranging from 8.42 to 14.65 lugeons.

The prominent jointed, fractured, shattered and shear zones (Depth wise) encountered in the quartzite rock are as follows:

37.0-38.65m: Jointed & Shattered Rock, 40.10-42.30m: Jointed & Shattered rock, 46.15-48.0m: Shattered / fractured / closely jointed rock with a good rock zone in-between, 48.0-55.50m Mixed Zone of good rock and shattered / fractured rock, 55.50-64.50m: Shattered / fractured / closely jointed rock, 67.0- 70.05m: Mixed Zone of Good Rock, Shattered / Fractured Rock & Sheared Rock, 79.0-80.0m Very Closely Jointed & Fractured Rock.

The presence of these poor rock zones in the dam foundation indicates necessity of adequate grouting of the foundation rock.

37.0-38.65m: Jointed & Shattered Rock , 40.10-42.30m: Jointed & Shattered Rock, 46.15-48.0m Shattered / fractured / closely jointed rock with a good rock zone in-between, 48.0-55.50m: Mixed zone of good rock and shattered / fractured rock, 55.50-64.50m: Shattered / fractured / closely jointed rock, 67.0-70.05m: Mixed zone of good rock, shattered / fractured rock and sheared rock.

79.0-80.0m: Very closely jointed and fractured rock, The presence of these poor rock zones in the dam foundation will necessitate adequate grouting of the foundation rock, 37.0-38.65m: Jointed & Shattered Rock, 40.10-42.30m: Jointed & Shattered Rock

Detailed Geological log of drill hole DH-2 is enclosed as **Appendix-2; Volume-I.A.**

Figure-5.3: Photograph showing the quality of the core of DH-2 (RD.48 - 55.5m).

DH-3 (River Bed):

Location: Left bank on Dam Axis. **Coordinates:** **N:** 50111.841 **E:** 39957.256

Ground El.: 404.483 m **Total Depth:** 80 m

Depth (m)	Elevation (m)	Overburden / Rock	Remarks
0 to 27.0	404.483 to 377.483	River Borne Material	River borne material (RBM) consists predominantly boulders, cobbles and gravels of quartzite embedded in a sandy matrix.
27.0 to 80.0	377.483 to 324.483	Bed Rock	Bed rock comprising of fine grained, white to light grey coloured quartzite was encountered. Staining has been observed in the rock for all the drilled depth of the hole. Core recovery ranges from 75.33% to 100%, except for the sheared reach of 52.50 to 58.50m where it ranged from 5.66% to 24%. The RQD values varied between 0 to 68%. The permeability tests indicate turbulent flow characteristics with values ranging from 2.93 to 16.92 lugeons.
The prominent jointed, fractured, shattered and shear zones (depth wise) encountered in the quartzite rock are as follows: - 27.0-30.20m: Jointed and fractured rock. 35.75-38.50m: Very closely jointed rock with shattered zone. 39.80-41.85m: Closely jointed and shattered rock. 42.65-48.40m: Mixed zone of shattered / fractured / closely jointed rock with some good rock zones. 52.50-58.50m: Sheared Rock.			

Detailed Geological log of drill hole DH-3 is enclosed as **Appendix-3; Volume-I.A.**

DH-7 (Left abutment)

Location: Top of Dam Axis **Coordinates:** **N:** 50185.090 **E:** 40026.734

Ground El.: 506.018 m **Total Depth:** 140 m

Depth (m)	Elevation (m)	Overburden / Rock	Remarks
0 to 1.5	506.018 to 505.518	Overburden	Soil.
1.5 to 140	505.518 to 366.018	Bed rock	Bed rock comprising of fine grained, white to light grey coloured quartzite was encountered. Staining and slight weathering in the rock along the joint planes has been observed in the rock from 1.5 to 105.0m depth. Fresh rock was encountered for the remaining drilled depth of 105.0 to 140.0m. Core recovery ranges from 16% to 94%. The RQD values varied between 0 to 36%.
The prominent jointed, fractured, shattered and shear zones (depth wise) encountered in the bed rock are as follows: 1.5-5.0m: Jointed Rock. R9.0-14.75m: Jointed / Fractured Rock. 14.75-20.40m: Shattered / Fractured Rock (mostly <5cm pieces) with some large core pieces. 20.40-24.0m: Jointed rock with a fracture zone (<7cm core pieces) of 15cm. 27.80-42.25m: Shattered / Fractured Rock (mostly 5-7cm pieces) with some large core pieces			

(shear zone of 40cm thickness containing crushed rock encountered at 29.5m depth).

42.25-54.50m: Jointed Rock with fracture zones.

54.50-57.35m: Jointed Rock with some fractured rock (7 cm pieces) zones in between 61.15 - 64.85m fractured rock (7cm pieces) with 2 large core pieces.

69.10-73.20m: Very closely jointed / shattered rock.

73.20-91.25m: Mostly fractured / jointed rock with some fair rock zones in between.

102.70-107.60m: Fractured zone (< 1-7 cm) with some jointed reaches.

125.65-140.0m: Shattered and fractured rock (2-6 cm) with 6 rock pieces (6–11cm).

Detailed Geological log of drill hole DH-7 is enclosed as **Appendix-7; Volume-I.A.**

Figure-5.4: Location of drill hole DH-7 along the dam axis on left bank.

Figure-5.5: Photograph showing quality of the core of DH-7 (RD. 116 - 126m).

Figure-5.6: Photograph showing quality of the core of DH-7 (RD.125 - 133m).

DH-8 (Right Abutment):

Location: Top of Dam Axis **Coordinates:** N: 50000.989 E:39846.343

Ground El.: 486 m **Total Depth:** 130 m

Depth (m)	Elevation (m)	Overburden / Rock	Remarks
0 - 1.0	486 - 485	Overburden	Talus and Soil.
1.0 - 130.0	-	Bed Rock	Bed rock comprising of fine grained, white to light grey coloured quartzite was encountered. Staining and slight weathering in the rock along the joint planes has been observed in the complete drilled depth. Core recovery ranges from 24% to 95%. The RQD values varied between 0 to 44%.

The permeability tests indicate turbulent flow characteristics with lugeon values ranging from 10.12 to 20.34.

The prominent jointed, fractured, shattered and shear zones (depth wise) encountered in the bed rock are as follows:

1.0 - 4.3: Fractured Quartzite. 4.3 - 6.15: White quartzite., 6.15 - 13.5: Mix Zone of fractured and good rock., 13.5 - 28.5: Shattered and fractured rock., 28.5 - 33.0: Shear Zones, 33.0 - 34.5: Jointed and fractured rock, 34.5 - 36.0: Shear Zone, 36.0 - 36.35: Jointed and fractured rock, 36.35 - 40.5: Shear Zone, 40.5 - 42.0: Jointed and fractured rock, 42.0 - 46.5: Shear Zone, 48.0 - 62.50: Jointed and fractured rock with intermittent shear zones, 62.5 - 80.50: Shear Zone, 81.30 - 82.80: Fracture Zone, 83.05 - 84.35: Fracture Zone with some rock pieces, 84.70 - 87.80: Mixed zone of fractured rock and good rock, 88.30 - 96.50: Mostly fractured rock with some rock pieces, 97.50 - 98.15: Fracture Zone, 98.50 - 99.0: Fracture Zone, 99.55 - 107.50: Fractured / shattered Zone, 107.90 - 115.10: Mixed zone of fractured / shattered and moderately jointed rock, 120.0 - 120.90: Fracture Zone, 121.80 - 122.0: Fracture Zone, 122.0 - 122.25: Very Good Rock, 122.25 - 123.30: Fracture Zone, 123.30 - 123.55: Very Good Rock, 123.55 - 124.50: Fracture Zone, 127.0 - 128.05: Fracture Zone.

Detailed Geological log of drill hole DH-8 is enclosed as **Appendix-8; Volume-IVA.**

Figure-5.7: Photograph showing the quality of the core of DH-8 (RD. 88 - 96m).

Figure-5.8: Photograph showing the quality of the core of DH-8 (RD. 121 - 129m).

DH-10A

Location: Right bank of Wangchu river, dam axis **Co-ordinates:** N: 50074.586 E: 39938.70

Elevation: 404.438 m **Total depth:** 75.0 m

Angle with horizontal: 70°

Depth (m)	El.(m)	Overburden /Rock	Remarks
0 to 43.50	404.438 to 360.938	Overburden	Overburden comprising of riverine deposits, mainly boulders of quartzite, biotite-gneiss, amphibolites, etc. along with sand. A silt seam encountered between the depth of 36.10 to 43.50 m.
43.05 to 75.00	360.938 to 329.438	Bed rock	Bed rock comprises mainly of fine grained, white to light grey coloured, moderately jointed quartzite with intermittent closely jointed and shattered/fractured reaches. A shear zone is interpreted between 61.50 m to72.00 m depth. The rock in general has slight staining along the joint planes. Core recovery ranges between 56 to 85%. RQD ranges from 0 to 38.5%. The permeability values range between 13.70 to 18.10 lugeon.
The prominent jointed, fractured, shattered and shear zones (depth wise) encountered in the drill hole are as follows: 46.0-47.60 m Fractured and very closely jointed rock, 61.50-72.0 m Shear zone (crushed rock), 74.0-75.0 m Fractured and very closely jointed rock.			

Detailed Geological log of drill hole DH-10A is enclosed as **Appendix-10; Volume-VIA.**

DH-11A

Location: Right bank of Wangchu river, dam axis **Co-ordinates:** N: 50019.783 E: 39871.911

Elevation: 458.425 m **Total depth:** 100.0 m

Angle with horizontal: 45°

Depth (m)	El.(m)	Overburden/Rock	Remarks
0 to 28.50 m	458.425 to 429.925 m	Overburden	Overburden comprising of slope debris in the form of angular rock fragments, mostly of quartzite along with brownish sand.
28.50 m to 100.0 m	429.925 to 358.425 m	Bed rock	Bed rock comprising of fine grained, light grey/pink coloured, closely to moderately jointed quartzite with shattered and fractured reaches. The rock is stained and slightly weathered throughout the drilled depth. Core recovery ranges between 37 to 100%. RQD ranges from 0 to 44%. The permeability values range between 2.87 to 18.74 lugeon.
The prominent jointed, fractured, shattered and shear zones (depth wise) encountered in the drill hole are as follows: 28.85-40.50 m Crushed rock, 40.50 – 41.50 m Jointed & fractured rock, 41.50-42.0 m Fractured/shattered, 42.65 – 44.0 m Fractured/shattered, 45.05 – 46.40 m Jointed & fractured rock, 47.60 – 48.50 m Fractured/shattered, 62.50-64.0 m Fractured/shattered rock, 70.25-75.85 m Fractured/shattered rock, 94.50-100 m Shattered/fractured rock with some large rock pieces in between			

Detailed geological log of drill hole DH-11a is enclosed as **Appendix-11; Volume-I.A.**

DH-12A

Location: Dam axis, river bed, left abutment Co-ordinates: N: 50114.13 E: 39958.27

Ground elevation: 404.083 m Total depth: 75.0 m

Angle with horizontal: 69°

Depth (m)	Elevation (m)	Overburden /Rock	Remarks
0 to 42.0	404.083 – 364.583	Overburden	River borne material consisting of boulders, cobbles, pebbles and gravels of quartzite, amphibolites, gneiss, etc. with silt seams.
42.0 to 75.0	364.583 – 334.333	Bed rock	Bed rock comprising of fine grained, white to light grey coloured quartzite was encountered. The rock mass in general is moderately to closely jointed with some fractured and shattered reaches.

			Staining and slight weathering in the rock along the joint planes has been observed in the complete drilled depth. Core recovery ranges from 55.33% to 90%.
			The RQD values varied between 0 to 26.6%. The permeability tests indicate turbulent flow characteristics with lugeon values ranging between 10.51 to 17.23.
The prominent jointed, fractured, shattered and shear zones (depth wise) encountered in the bed rock are as follows: 45.35 – 46.50 Fractured/shattered rock, 46.50 – 49.50 m Shear zone, 49.50 – 72.80 m Mixed zone of moderately to closely jointed and fractured/shattered rock.			

Detailed geological log of drill hole DH-12a is enclosed as **Appendix-12; Volume-IVA.**

DH-15

Location: Right abutment, dam axis. Co-ordinates: N:
E:

Ground El.: +- 463.0 m Total depth: 35.0 m

Depth (m)	Elevation (m)	Overburden /Rock	Remarks
0 to 12.0	463.0 to 451.0	Overburden	Talus and soil.
12.0 to 35.0	451.0 to 428.0	Bed rock	Bed rock comprising of fine grained, white to light grey coloured quartzite was encountered. The rock in general is fresh in nature with occasional staining along the joint planes. Core recovery ranges from 54% to 85.55%. The RQD values varied between 0 to 32.22%. The permeability tests indicate turbulent flow characteristics with lugeon values ranging from 6.26 to 9.44.
The prominent jointed, fractured, shattered and shear zones (depth wise) encountered in the bed rock are as follows: 12.0-18.0 m Shear zone, 18.0-23.0 m Closely jointed/shattered rock, 25.50-28.50 m Closely , jointed/shattered rock			

Holes at Dam Body

DH-13

Location: Right abutment, 30 m d/s of dam axis. Co-ordinates: N: 49955.027
E: 39867.686

Ground El.: 483.0 m Total depth: 50.0 m

Depth (m)	El. (m)	Overburden /Rock	Remarks
0 to 36.0	483.0 to 447.0	Overburden	Slope debris in the form of angular rock fragments mostly of quartzite along with coarse sandy material
36.0 to 50.0	447.0 to 433.0	Bed rock	Bed rock comprising of fine grained, white to greyish-white coloured quartzite was

			encountered. A phyllitic-quartzite band was also recorded. The rock mass in general is moderately jointed with a few fractured/shattered reaches. Staining and slight weathering has been observed in the rock for all the drilled depth of the hole. Core recovery in the rock ranges from 66.66% to 85.33%. The RQD values varied between 0 to 55.33%. The permeability values range between 6.27 to 9.06 lugeons. No shear recorded.

DH-14

Location: Left abutment, m d/s of dam axis. Co-ordinates: N:

E:

Ground El.: +- 404.0 m Total depth: 135.0 meter

Depth (m)	El. (m)	Overburden /Rock	Remarks
0 to 135.0	± 404.0 to ± 269.0	Bed rock	Bed rock comprising of fine grained, white to greyish-white coloured quartzite was encountered. The rock mass in general is moderately to closely jointed with some fractured/shattered reaches. Fresh to slight staining/weathering has been observed in the rock for all the drilled depth of the hole (W0 – W1). Core recovery in the rock ranges from 26.66% to 86.66%. The RQD values varied between 0 to 75%. The permeability values range between 4.58 to 14.25 lugeons.
The prominent jointed, fractured, shattered and shear zones (depth wise) encountered in the bed rock are as follows: 0 -2.0 m Closely jointed/fractured rock, 7.50 – 10.50 m Fractured/shattered to closely jointed rock, 10.50 – 29.50 m Crushed rock (silt sized) stained, 61.50 – 64.50 m Mostly fractured/shattered rock with some moderately jointed reaches, 84.0 – 85.50 m Fractured/shattered/closely jointed rock, 123.35 – 135.0 m Closely jointed rock with some fractured/shattered reaches.			

5.1.2.c. Permeability

Water percolation tests were conducted in all the drill holes drilled at the dam site. A minimum value of 2.93 lugeon was recorded in DH-3 drilled along the dam axis at river bed level on the left bank. Similarly, a maximum value of 20.34 lugeon was recorded in DH-8 drilled along the dam axis on the right bank at the dam top level El. 486m. In general the lugeon values derived from the water percolation test ranges between 8 to 17.

The lugeon values indicate turbulent flow conditions and thus the lowest lugeon values occurring at the highest pressure are being reported in the logs. The permeability values

derived from the water percolation tests carried out in the drill holes have been annexed as **Annexure-II of Volume-IVA.**

5.1.2.d Exploratory Drifting:

In order to study the rock conditions in abutments and to evaluate the stripping limits, four drifts, 1.8m (W) x 2.1m (H) diameter have been excavated in the dam abutments. The left abutment has been explored by two drifts, i.e. DL-1 at El. 420 m and DL-2 at El. 460 m, respectively, while the right abutment has been explored by two drift, DR-1 at El. 420 m. and DR-2 at El. 460 m. DR-1 is 100 m long whereas remaining drifts are 70m long. Two cross cuts of 10 m each have been provided at the end of each.

One more drift (PI-1) along Power Tunnel Intake-1 have also been excavated for 50 m length to assess the rock conditions around the intake. 3-D geological logging of these drifts has been carried out on 1:100 scale and are enclosed as **Drg. No.: DAM-WHEP-DPR-GEO-019-00 to GEO-027-00; Volume-I.B.**

The **details of** exploratory drifts at dam site are given below: Table-5.3:

Table-5.3: Exploratory Drifts at Dam Site.

Drift No.	Location	Ground El. (m)	Coordinates	Total Length (m)
DR-1	Dam Axis - Right Abutment.	420.008	**N:** 50043.34 **E:** 39910.33	120.00 (100+20 two cross cuts)
DR-2	Dam Axis - Right Abutment.	460.00	**N:** 50002.276 **E:** 39872.212	90.00 (70+20, two cross cuts)
DL-1	Dam Axis - Left Abutment.	419.88	**N:** 50122.92 **E:** 39980.40	90.00 (70+20, two cross cuts)
DL-2	Dam Axis - left abutment.	458.292	**N:** 50151.332 **E:** 40002.190	90.00 (70+20 cross cuts)
PI-1	Power Intake - Left Abutment.	472.533	**N:** 50206.083 **E:** 39973.472	50.00
-	-	-	**Total Drifting:**	**440.00**

The details of each drift are as under: -

Drift DR-1

Location: Right abutment, 5 m d/s of Dam axis

Co-ordinates: N:50043.34 E:39910.33

Elevation: 420.008 meter

Total length: 100.0 meter

Drift alignment: S60^{0}W

This 100 m long, lower level drift has been excavated in S60^{0}W direction, 5 meter downstream of the dam axis on the right abutment. The whole excavated drift has

encountered fine grained, white to light grey coloured quartzite rock. The bedding/foliation planes strikes N70^{0}W-S70^{0}E to E-W direction and dips 40^0 to 55^0 in N to N20^{0}E direction, i.e. the strike is oblique to the drift alignment and the dips are in upstream direction with respect to the river flow. This trend of the foliation is 50^0 oblique to the dam axis. Root penetration was observed between RD 0 to 5 m. The rock mass is closely to moderately jointed in nature with some closely jointed/fractured reaches between RD's 13.0 to 24.50 m & 49.0 to 70.0 m. Wedge formation due to intersection of 3 or more joint sets observed between RD 46.0 to 55.0 m resulting in over breaks of up to 2.5 m in the crown portion between RD 49.0 to 55.0 m. Wedge formation was also observed between RD 84.0 to 86.0 m in the crown with around one m cavity formation due to intersection of joint sets. Staining along the joint planes was seen in the complete 100 m excavated length of the drift. Slight weathering in the rock was observed between RD 16.0 m to 39.5 m and between 57.0 to 100.0 m. Moist to slight dripping conditions were noticed between RD's 31.0 m to 39.0 m, 43.0 to 50.0 m, 53.0 to 55.0 m and at isolated patches in the crown at RD's 60.0, 62.0, 67.0, 72.0, 76.0, 82.0, 91.0-92.0 & 96.0-97.0 m. Openings along the joint planes was also observed from RD 0 to 5.0 m, RD 54.5 to 57.0 m, 69.0 to 70.0 m and at RD 94.0 m. The drift is self-supportive.

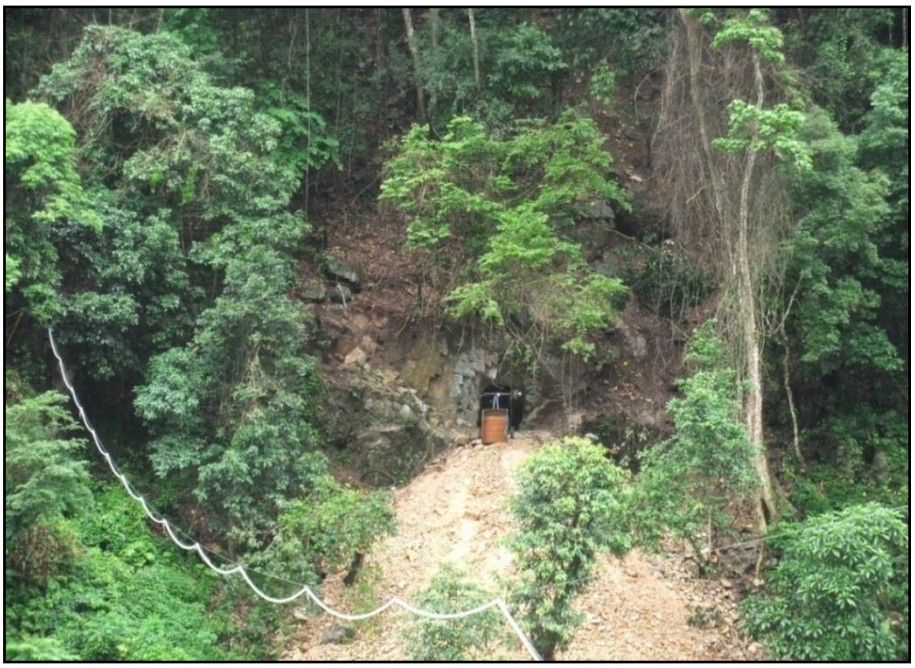


Figure-5.9: Portal of drift DR-1.

The summarized drift log of DR-1 is given below in **Table-5.4:**

Table-5.4: Summarized Log of drift DR-1.

RD's (m)	Rock type	Description
0 to 13.0	Closely to moderately jointed quartzite	Root penetration observed from RD 0 to 5 m. Rock is closely to moderately jointed, stained and with a shear (10-50 cm) at RD 10.0 m. Openings of 1 to 3 mm recorded in joints. Dry seepage conditions.
13.0 to 38.0	Closely jointed quartzite	Closely jointed/fractured right wall between RD 13 to 15.5 m and crown between RD 15 to 24.5 m. Slight weathering in rock noticed between RD 16 to 38.0 m. Three steep, valley dipping shears (10 to 30 cm) recorded at RD's 23.5, 28.0 & 30.5 m containing crushed rock. One shear (5 cm) observed at RD 38.0 m containing clay and crushed rock. The rock mass is intersected by at least 3+R joint sets. Moist to slight dripping conditions encountered between RD 31.0 to 36.0 m.
38.0 to 59.5	Closely to moderately jointed quartzite	Rock is closely to moderately jointed and stained. Dry seepage conditions.
59.5 to 84.0	Closely jointed quartzite	Closely jointed/fractured right wall between RD 59.5 to 62.0 m, at crown between RD 63.0 to 66.0 m and on the left wall between RD 67.0 to 72.0 m. The rock mass is jointed in nature between RD 72.0 to 84.0 m. Several transverse shears dipping in NE'ly direction recorded in this reach. Slight weathering in rock noticed in this reach.

		A steep dipping shear recorded at RD. 61.25 m (1 to 5 cm) containing crushed rock and silt. A low dipping shear encountered at RD 66.0 m (2 to 10 cm) containing crushed rock and silt. Mostly dry conditions with slight dripping at crown at some reaches. Poor to fair rock conditions.
84.0 to 100 m	Closely to moderately jointed quartzite.	The rock mass is closely to moderately jointed. A 30 to 50 cm thick, steep dipping, transverse shear recorded at RD 99.0 m containing crushed rock. Wedge formation observed between RD 84.0 to 86.0 m in the crown with around one m cavity formation due to intersection of joint sets. Mostly fresh rock (W0) with some slightly weathered reaches (W1). Mostly dry conditions with slight dripping at crown at some reaches. Fair rock conditions.

The prominent joint sets recorded in the drift excavation are tabulated below in Table-5.5:

Table-5.5: Prominent joint sets:

Strike direction	**Dip amount and direction**	**Continuity**
N20-45W – S20-45E	40^0-70^0/S45-70W	>5 m
N35W-S35E – N-S	30^0-45^0/N55E - E	2 to >5 m
N55-60E – S55-60W	Vertical	2 – 4 m
N10-45W – S10-45E	60^0-70^0/N45-80E	2 – >5 m
N20-55E – S20-55W	75^0/N35-70W	2 – >5 m
N70W – S70E	35^0/S20W	3 - 5 m

The shears encountered in the drift are tabulated below in Table-5.6:

Table-5.6: Shears encountered in the drift.

R.D. (m)	**Strike direction**	**Dip amount and direction**	**Thickness (cm)**	**Fillings**
3.5	N35W-S35E	65^0/N55E	5	Crushed rock only
10.0	N65W - S65E	60^0/N40E	5 to 50	Crushed rock and clay
23.5	N50W – S50E	75^0-80^0/N40E	20 to 30	Crushed rock only

28.0	N35W – S55E	70^0/N55E	10	Crushed rock only
30.5	N25W – S25E	75^0/N65E	10	Crushed rock only
38.0	N10W – S10E	60^0/N80E	20	Clay and crushed rock
61. 5	N30W – S30E	80^0/N60E	1-5	Crushed rock only
67.0	N60W – S30E	35^0/N30E	5-15	Crushed rock only
71.0	N70W – S70E	40^0/N20E	1-5	Crushed rock only
73.0	N70W – S70E	40^0/N20E	1-5	Crushed rock only
75.5	N60-70W–S60-70E	40^0/N20-30E	1-5	Crushed rock only
79.5	N80E – S80W	50^0/N10W	>2	Crushed rock only
83.0	N60W – S60E	25^0/N30E	1-5	Crushed rock only
91.0	N70-80W–S70-80E	20^0/N10-20E	1-5	Crushed rock only
99.0	N30W – S30E	80^0/N60E	30-50	Crushed rock only

Drift DR-1 upstream cross cut

The summarized log of cross cut in upstream direction ($N35^0W$) of Drift DR-1 is given below **Table-5.6A:**

Table-5.6A: Summarized log of Drift DR-1 U/S Cross cut.

RD's (m)	Rock type	Description
0 – 10.0	Closely to moderately jointed quartzite	The rock mass is white to light grey coloured, fine grained, closely to moderately jointed quartzite. Rock is mainly fresh with some slightly staining. A 25 to 30 cm thick shear, dipping 80^0 in N60-70E direction, containing crushed rock was encountered at RD 7.0 m on the right invert, extending up to RD 10.0 m on the right crown. A 5 to 10 cm thick shear, dipping 80^0 in N20-25E direction, containing crushed rock was encountered at RD 4.0 m on the left invert, extending up to RD 10.0 m on the left haunch. Three sets of intersecting joints were recorded in this section of the drift. Fair to poor rock conditions were encountered in the cross cut. Dry to slight dripping seepage conditions encountered.

Drift DR-1 D/s Cross cut

The summarized log of cross cut in downstream direction (S35^{0}E) of Drift DR-1 is given below **Table-5.6B:**

Table-5.6B: Summarized log of Drift DR-1 D/S Cross cut.

RD's (m)	Rock type	Description
0 – 10.0	Closely to moderately jointed quartzite	The rock mass is white to light grey coloured, fine grained, closely to moderately jointed quartzite. Rock is mainly fresh with some slightly staining. A 20 to 100 cm thick shear, dipping 30-40^0 in N25W direction, containing crushed rock was encountered at the junction on the left invert, extending up to RD 2.0 m on the crown and dipping back on the right haunch and wall at the junction with the main drift. A 3 to 10 cm thick shear, striking parallel to the above shear, containing crushed rock was encountered at RD 7.0 m on the crown. Three sets of intersecting joints were recorded in this section of the drift. Fair to poor rock conditions were encountered in the cross cut. Dry to slight dripping seepage conditions encountered.

Drift DL-1:

Location:	Left Abutment, 5m D/s of Dam Axis.	**Coordinates:**	**N:** 50122.92 **E:** 39980.40
Ground El.:	419.88m	**Total Length:**	70m
		Drift Alignment:	N50^{O}E

This 70m long, lower level drift has been excavated in N50^{0}E direction, 5m D/s of the dam axis on the left abutment. The drift has essentially encountered fine grained, white to light grey coloured quartzite. Root penetration was observed from RD 0 to 14m in the drift along with black humus soil mainly in the sheared rock zones. The bedding / foliation planes trends in N80^{0}W-S80^{0}E to E-W direction and dips 55^0 to 60^0 in N to N10^{0}E direction, i.e. the strike is oblique to the drift alignment and the dips are in upstream direction with respect to the river flow. This trend of the foliation is 60^0 to 70^0 oblique to the dam axis. The rock mass is closely to moderately jointed in nature with some very closely jointed / fractured reaches. Staining along the joint planes was seen in the complete 70m excavated length of the drift. At times black coating along the joint planes was also noticed in some parts of the drift. Slight weathering in the rock was also observed in some reaches of the drift. Moist to slight dripping conditions were noticed between RD's 0 to 25m and 60 to 70m. Openings along the joint planes were observed from RD 0 to 5m. Although the drift is self supporting, but as a precautionary measure,

the reach from RD 0 to 17m needs temporary support due to the fractured and sheared nature of the rock.

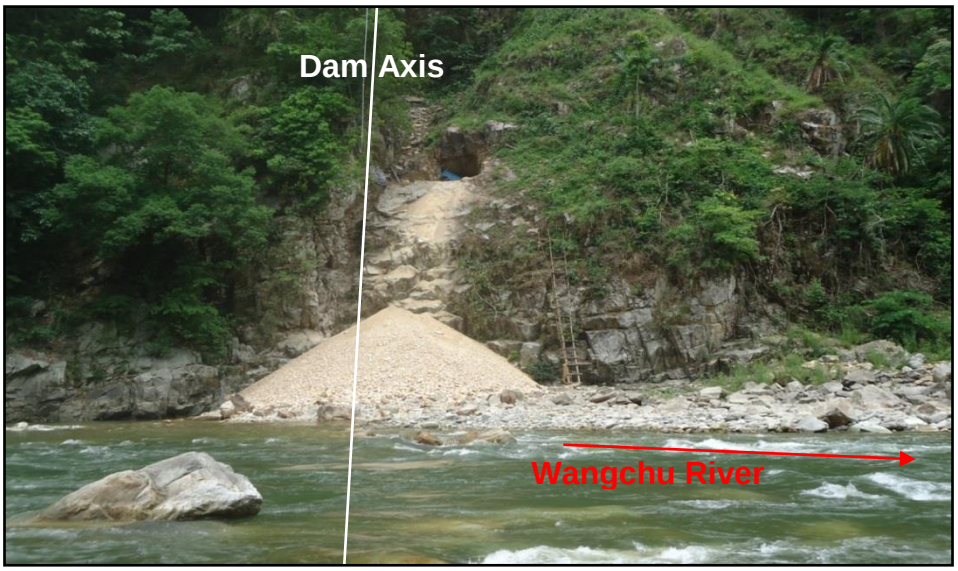


Figure-5.11: Portal of the Drift (DL-1) at RD 70m.

Figure-5.12: Rock Conditions in drift (DL-1) at RD 70m.

The summarized drift log of DL-1 is given below in **Table-5.7:**

Table-5.7: Summarized Log of drift DL-1.

RD (m)	Rock Type	Description
0 - 17.0	Closely Jointed / fractured and Sheared Quartzite.	Root penetration observed from RD 0 to 14m and with black humus soil. Rock is mostly closely jointed / fractured, with multiple shears. Rock is fresh to stain in nature. A longitudinal 5cm thick shear encountered at left spring line. A 25 to 40cm thick shear recorded at RD 9m. A 5cm thick shear running parallel to the above shear recorded on the left wall. A 40 to 100cm thick shear with black soil observed initiating at RD 10.0m on the left invert and ending at RD. 14.5m on the right invert. This shear extends ahead upto RD 12m on the left invert and up to RD 17m on the right invert in the form of

		shattered and fractured rock. Openings of 1 to 3mm recorded in joints. Dripping seepage conditions.
17.0 - 25.0	Moderately to Closely Jointed Quartzite.	Rock is moderately to closely joint in nature with signs of staining along the joint planes. Dry conditions.
25.0 - 40.0	Closely Jointed Quartzite.	The rock mass is closely jointed in nature. Staining along the joint planes observed. Black coloured filling along the shear zone observed (what is this filling). A vertically dipping shear (2 to 5cm thick) recorded on the central crown between RD 25 to 27m. A 100cm thick shear zone encountered at RD 29 to 30m containing black infillings. Two more shears of 2 to 10cm thickness recorded at RD's 32.5 and 38m. Moist seepage conditions.
40.0 - 70.0	Moderately Jointed Quartzite.	Rock is moderately to closely jointed in nature with signs of staining (black colour also) along the joint planes. Moist conditions observed between RD 40 to 46m, dry conditions between 46 to 57m and dripping conditions between 57 to 60m.

The prominent joint sets recorded in the drift are as follows in **Table-5.8:**

Table-5.8: Prominent Joint Sets in the Drift DL-1.

Strike Direction	Dip Amount & Direction	Continuity
N15-45W – S15-45E	50^0-78^0/S45-75W	4 - > 5 m
N65-75W – S65-75E	60^0-80^0/S15-25W	2 to > 5 m
N30-55E – S30-55W	50^0-70^0/S35-60E	2 - >5 m
N45-55W – S45-55E	40^0-70^0/N35-45E	> 5 m
NS – N10E-S10W	20^0/S80E - E	3 - 5 m
N45-50E – S45-50W	Vertical	2 - 4 m
N10W – S10E	40^0/N80E	> 5 m

The following shears were encountered in the drift **Table-5.9:**

Table-5.9: Shears Encountered in the drift DL-1.

RD (m)	Strike Direction	Dip Amount & Dip Direction	Thickness (cm)	Fillings
1.0 - 6.0	N50E - S50W	Vertical	5	Crushed Rock Only
9.0	N45W - S45E	80^0/S45W	25 to 40	-
12.0	N50W - S50E	68^0-70^0/S25W	40 to 100	-
25 - 27	N45E - S45W	Vertical	2 - 5	Crushed Rock Only
29.0	N55W - S55E	75^0/N35E	100	-
32.5	N75W - S75E	78^0/S15W	2 - 10	-
38.0	N65W - S65E	70^0/N25E	2 - 10	-

Drift DL-1 U/s Cross cut

The summarized log of cross cut in upstream direction ($N30^0W$) of Drift DL-1 is given below **5.9A:**

Table-5.9A: Summarized log of Drift DL-1 U/S Cross cut.

RD's (m)	Rock type	Description
0 – 10.0	Closely to moderately jointed quartzite	The rock mass is white to light grey coloured, fine grained, closely to moderately jointed quartzite.

		Rock is mainly fresh with some slightly staining. Three sets of intersecting joints were recorded in this section of the drift. Fair rock conditions were encountered in the cross cut. Dry to slight dripping seepage conditions encountered.

Drift DL-1 D/s Cross cut

The summarized log of cross cut in downstream direction (S40^{0}E) of Drift DL-1 is given below **Table-5.9B:**

Table-5.9B: Summarized log of Drift DL-1 D/S Cross cut.

RD's (m)	Rock type	Description
0 – 10.0	Closely to moderately jointed quartzite	The rock mass is white to light grey coloured, fine grained, closely to moderately jointed quartzite. Rock is mainly fresh with some slightly staining. A 20 to 30 cm thick shear, dipping 60-85^0 in North direction, containing crushed rock was encountered at RD 7.0 m on the right invert, extending up to RD 10.0 m on the left crown. Three sets of intersecting joints were recorded in this section of the drift. Fair to poor rock conditions were encountered in the cross cut. Dry to slight dripping seepage conditions encountered.

Drift DL-2:

Location: Left Abutment, 5m D/s of Dam Axis.
Coordinates: **N:** 50151.332 **E:** 40002.190
Ground El.: 458.292m
Total Length: 70m
Drift Alignment: S38^0 37'W

This 70m long, upper level drift has been excavated in N42^{0}E direction, 5m D/s of the dam axis on the left abutment. The drift has essentially encountered fine grained, white to light grey coloured quartzite. The bedding / foliation planes trends in N-S to N60W-S60E direction and dips 65^0 to 70^0 in N to N30^{0}E direction, i.e. the strike is askew to the drift alignment and the dips are in upstream direction with respect to the river flow. The rock mass is closely to moderately jointed in nature with some very closely jointed reaches. The most prominent joint set recorded in the drift is the valley dipping joint, striking across the drift alignment, with dips ranging from 40^0 to 70^0 and dipping in S30 - 65W direction. This joint set is parallel to the hill slope and could be the most vulnerable joint from the point of view of hill slope failure. Staining along the joint planes was seen in the complete 70m excavated length of the drift. Slight weathering in the rock was also observed in some reaches of the drift. Moist to dripping conditions was observed in the whole excavated reach of the drift. Openings along the joint planes were observed from RD 0 to 5m. The drift is self supported.

The summarized drift log is given below in **Table-5.10:**

Table-5.10: Summarized Log of drift DL-2.

RD (m)	Rock type	Description
0 - 17	Moderately Jointed / Fractured and Sheared Quartzite.	The rock mass is moderately jointed. Rock in general is fresh but staining has been recorded at joints. A 10 to 30cm thick shear was encountered between RD 9.0, striking oblique to the drift alignment and dipping 75^0 - 80^0/N10W direction containing clay and crushed rock. A 5 cm to 15 cm thick shear was recorded at RD 15.50m. Openings of 1 to 5mm recorded in joints upto RD 5m.
17 – 40	Closely Jointed / Fractured and Sheared Quartzite.	The rock mass is closely to moderately jointed in nature and staining has been observed along the joint planes in this reach. A vertically dipping shear of 5 to 15cm thickness was recorded at RD 38.25m. Moderate to slight dripping conditions have been observed at the crown area in this reach.
40 – 45	Moderately Jointed Quartzite	The rock mass observed is moderately to closely jointed in nature with staining along the joint planes. Heavy dripping conditions were observed in this reach. A shear of 1-5 cm thickness was observed at RD 41.50m.
45 - 55	Close to Moderately Jointed Quartzite.	The rock mass is closely jointed in nature and stained. Dripping conditions has been observed at the crown area.
55 - 70	Closely Jointed Quartzite with Shear Zones at places.	The rock mass observed is closely jointed and stained. Slight dripping conditions have been observed at the crown area at places. Shears of thickness 1-5cm observed at RD's 56m, 59.75m, 66m, and 69m.

The prominent joint sets recorded in the drift excavation are as follows in **Table-5.11:**

Table-5.11: Prominent Joint Sets in the Drift DL-2.

Strike Direction	Dip Amount & Dip Direction	Continuity	Prominence
N25 to 60W - S25 to 60E	40^0-70^0/S30-65W	2 to >5 m	Very Prominent.
N60 to 80W - S60 to 80E	65^0-70^0/N10-30E	2 to 5 m	Prominent
N10W to N40E/S10E to S40W	Vertical	1 to 4 m	Prominent
N60 to 80E - S60 to 80W	30^0-60^0/N10-30W	2 to 3 m	Less Prominent.
N10 to 30E - S10 to 30W	50^0-85^0/N60-80W	2 to 3 m	Less Prominent.
N35 to 60W - S35 to 60E	20^0-35^0/S30-55W	2 to >5 m	Least Prominent.

The following shears were encountered in the drift **Table-5.12:**

Table-5.12: Shears Encountered in the drift DL-2.

RD (m)	Strike Direction	Dip Amount & Dip Direction	Thickness (cm)	Fillings
9.0	N80E - S80W	75^0 - 80^0 / N10W	10 to 30	Crushed Rock
15.5	N60W - S60E	65^0 / N30E	5 to 15	Crushed Rock
34.0 - 37.0 (Left Spl.)	N35E - S35W	Vertical	5 to 15	Crushed Rock

38.25	E - W	Vertical	5 to 15	Crushed Rock
41.5	N60W - S60E	60^0 / N30E	1 to 5	Crushed Rock
56.0	N20W - S20E	70^0 - 80 ^{0} / N70E	1 to 5	Crushed Rock
59.75	N40W - S40E	85^0 / N50E	1 to 5	Crushed Rock
65.80	N60W - S60E	70^0 / N30E	1 to 5	Crushed Rock
69.40	N75W - S75E	65^0 / N15E	1 to 5	Crushed Rock

Drift DL-2 U/s Cross cut

The summarized log of cross cut in upstream direction (N40^{0}W) of Drift DL-2 is given below **5.12A:**

Table-5.12A: Summarized log of Drift DL-2 U/S Cross cut.

RD's (m)	Rock type	Description
0 – 10.0	Closely to moderately jointed quartzite	The rock mass is white to light grey coloured, fine grained, closely to moderately jointed quartzite. Rock is mainly fresh with some slightly staining. Three sets of intersecting joints were recorded in this section of the drift. Fair rock conditions were encountered in the cross cut. Dry to slight dripping seepage conditions encountered.

Drift DL-2 D/s Cross cut

The summarized log of cross cut in downstream direction (S50^{0}E) of Drift DL-2 is given below **Table-5.12B:**

Table-5.12B: Summarized log of Drift DL-2 D/S Cross cut.

RD's (m)	Rock type	Description
0 – 10.0	Closely to moderately jointed quartzite	The rock mass is white to light grey coloured, fine grained, closely to moderately jointed quartzite. Rock is mainly fresh with some slightly staining. Three sets of intersecting joints were recorded in this section of the drift. Fair rock conditions were encountered in the cross cut. Dry to slight dripping seepage conditions encountered.

Drift DR-2:

Location: Right abutment, 5 m d/s of Dam axis Co-ordinates: N: 50002.2766,
E: 39872.212

Elevation: +- 463.271 meter Total length: 70.0 meter

Drift alignment: S60^{0}W

This 70 m long, lower level drift has been excavated in S60^{0}W direction, 5 meter downstream of the dam axis on the right abutment. The initial 21.0 m length of the drift was excavated in overburden and has been supported by steel ribs, at 1 m c-c with

wooden shuttering and back filled with rock pieces. Thereafter the drift has encountered fine grained, white to light grey coloured quartzite rock. The bedding/foliation planes strikes N70^{0}W-S70^{0}E to E-W direction and dips 40^0 to 55^0 in N to N20^{0}E direction, i.e. the strike is oblique to the drift alignment and the dips are in upstream direction with respect to the river flow. The rock mass is closely to moderately jointed in nature with some closely jointed reaches between RD's 21.0 to 34.0 m & 40.0 to 46.0 m. Staining along the joint planes was seen in the complete 70 m excavated length of the drift. Slight weathering in the rock was observed between RD 21.0 m to 34.0 m. mostly dry conditions prevail in the drift with slight dripping at crown at RD 69.0 m. The drift is self-supportive from 21.0 m to 70.0 m.

Figure-5.12a Portal of drift DR-2

The summarized log of drift is given below in Table 5.12C :

Table-5.12C: Summarized Log of drift DR-2.

RD's (m)	Rock type	Description
0 to 21.0	Overburden	Steel ribs provided at 1 m c-c with wooden shuttering.
21.0 to 34.0 m	Closely jointed quartzite.	Closely jointed/fractured rock. Three valley dipping shears recorded at RD's 21.0 (5 to 50 cm thick with crushed rock and clay), RD 25.50 m (700/S15E, 5 to 25 cm thick with crushed rock and clay) & at RD 29.0 m (600/N20E, 5 to 40 cm thick with crushed rock and clay). A 100 cm thick fractured zone encountered in crown between 25.50 to 29.0 m between the two shear zones. The rock mass is intersected by at least 3+R joint sets. Slight weathering (W1) in rock noticed throughout this reach. Dry conditions in this reach.

		Poor rock conditions.
34.0 to 40.0 m	Moderately jointed quartzite.	Rock mass is moderately jointed. Fresh to slightly weathered rock (W0 – W1). Dry conditions. Good to fair rock conditions.
40.0 to 46.0 m	Closely to moderately jointed quartzite.	Closely jointed/fractured rock. Two vertical shears recorded at RD's 42.50 m (Vertical, N50W-S50E, 5 to 30 cm thick with crushed rock and clay) & at RD 45.0 m (850/S50E, 4 to 13 cm with crushed rock and clay). The rock mass is intersected by at least 3+R joint sets. Mostly fresh rock (W0) with some slightly weathered reaches (W1). Dry conditions in this reach. Fair to poor rock conditions.
46.0 to 70.0	Moderately jointed quartzite.	Rock mass is moderately jointed. A 2 to 15 cm thick shear zone encountered at RD 64.0 m dipping 30-400/S70W containing crushed rock and clay infillings. Mostly fresh rock (W0) with some slightly weathered reaches (W1). Mostly dry conditions with slight dripping at crown at RD 69.0 m. Good to fair rock conditions.

The prominent joint sets recorded in the drift excavation are tabulated below **Table-5.12D:**

Table-5.12D: Prominent joint sets in the drift DR-2

Strike direction	**Dip amount and direction**	**Continuity**
N20-60W – S20-60E	20°-60°/S30°-70°W	2 to 4 m
E-W to N40W-S40E	60°-75°/N to N50°E	2 to >5 m
N-S to N18E – S18W	20°-30°/W to N72°W	2 to 4 m
N40-75E to S40-75W	70°-85°/S15°-50°E	2 to 4 m
N-S to N20E – S20W	Vertical	2 to 4 m

Details of shears encountered in the drift DR-2 are tabulated below: **Table-5.12E:**

Table-5.12E: Shears encountered in the Drift DR-2

R.D. (m)	**Strike direction**	**Dip amount and direction**	**Thickness (cm)**	**Fillings**	**Remarks**
25.0	N75E – S75W	70°/S15E	5 to 25	Crushed rock	Hill side dip
29.0	N70W – S70E	60°/N20E	5 to 40	Crushed rock only	Valley side dip
42.70	N50W – S50E	Vertical	5 to 30 cm	Crushed rock only	
45	N40E – S40W	75°/S50E	4 to 13 cm	Crushed rock only	Valley side dip

64	N20W – S20E	30-40/S70W	2 to 15 cm	Crushed rock only	Hill side dip

Drift DR-2 U/s Cross cut

The summarized log of cross cut in upstream direction (N300W) of Drift DR-2 is given below **Table-5.12F:**

Table-5.12F: Summarized log of Drift DR-2 U/S Cross cut.

RD's (m)	Rock type	Description
0 – 10.0	Closely to moderately jointed quartzite	The rock mass is white to dark grey coloured, fine grained, closely to moderately jointed quartzite. Rock is mainly fresh with some slightly staining. A 5 to 40 cm thick shear, dipping 35^0 in N20W direction, containing crushed rock was encountered at RD 6.5 m on the invert, extending up to RD 9.0 m on both the left and right inverts. Three sets of intersecting joints were recorded in this section of the drift. Good to fair rock conditions (RD 0 to 5 m) and poor rock conditions between RD 5 to 10 m were encountered in the cross cut. Dry seepage conditions encountered.

Drift DR-2 D/s Cross cut

The summarized log of cross cut in downstream direction ($S15^0E$) of Drift DR-2 is given below **Table-5.12G:**

Table-5.12G: Summarized log of Drift DR-2 D/S Cross cut.

RD's (m)	Rock type	Description
0 – 10.0	Closely to moderately jointed quartzite	The rock mass is white to dark grey coloured, fine grained, closely to moderately jointed quartzite. Rock is mainly fresh with some slightly staining. A 10 to 100 cm thick shear, dipping 35^0 in N30W direction, containing crushed rock was encountered at 7.0 m on the crown, extending up to RD 2.0 m on both the left and right inverts. Three sets of intersecting joints were recorded in this section of the drift. Fair to poor rock conditions were encountered in the cross cut. Dry seepage conditions encountered.

Drift: PI-1

Location:	Left Bank along Power House Intake-1 (U/s Intake).	**Coordinates:**	**N:** **E:**
Ground El.:	472m	**Total Length:**	50m
		Drift Alignment:	$N62^0E$

The drift has encountered fine grained, white to light grey coloured, closely to moderately jointed quartzite rock. The rock shows signs of staining throughout the drift

length. The drift is normally dry but minor dripping along the crown was observed at RD 17 m along the shear zone.

The foliation in general dips 50 - 55^0 in N to N10^{0}E direction, i.e. into the hill. Moist and damp conditions were observed near the shear between RD 34 to RD 36m and also between RD 44 to RD 50m. No root penetration was recorded in the drift. Shears of 1cm to 10cm thickness with crushed rock and thin black coloured clay gouge fillings were recorded at RD's 4.50m, 17m, 35m, 44m and RD 49m. All the shears are hill dipping.

The summarized drift log is given below in **Table-5.13:**

Table-5.13: Summarized Log of drift PI-1.

RD's (m)	Rock Type	Description
0 - 18	Moderately Jointed / Fractured & Sheared Quartzite	Rock is fresh but staining has been recorded at joints. Rock is moderately jointed. A 5cm thick vertically dipping shear was encountered at RD 1.0m along the left wall. Transverse shears of 1 to 5cm thickness at RD's 4.50m and 17.0m were also recorded. Openings of 1 to 3mm recorded in joints near the portal. Fractured rock with black soil filling observed in some reaches.
18 - 33	Closely to Moderately Jointed / Quartzite	The rock mass is closely to moderately jointed in nature and staining has been observed along the joint planes. Slight to moderate dripping condition have been observed in this reach.
33 - 50	Closely Jointed Quartzite with Sheared / Jointed Fractured Reaches	The rock mass is closely jointed with staining observed along the joint planes. A shear zone of 1 to 10cm thickness observed at RD 35m. Shear zones of 1 to 5cm at RD's 44 and 49.0m observed. Fractured rock with black soil filling observed on the left wall between RD 49 to 50m.

The rock in the drift is traversed by the following joints **(Table-5.14):**

Table-5.14: Prominent Joint Sets in the drift PI-1.

Joint Set No.	Strike Direction of the Joint	Dip Amount and Direction of Joint Plane	Continuity
J1	N50-70 W - S50-70 E	30-45^0/S10-40^{0}W	2 to > 5 m
J2	N50-70E - S50-70W	70-80^0/N20-40W	-
J3	N30-40E - S30-40W	Vertical	-
J4	E - W	Vertical	2-3 m
J5	N20^0-40W - S20^0-40 E	50-70^0 /S50-70^{0}W	-

The following shears are encountered in the drift **(Table-5.15):**

Table-5.15: Shears Encountered in the drift PI-1.

Strike Direction	Dip Amount & Dip Direction	Thickness (cm)	Fillings
N40W - S40E	80°/N50°E	1-5	Crushed Rock
N42W - S42E	80°/N48°E	1-5	Crushed Rock

N35W - S35E	78°/N55°E	1-10	Crushed Rock
N75W - S75E	30°/N15°E	1-5	Crushed Rock
N30W - S30E	70°-75°/N60°E	1-5	Crushed Rock

Figure-5.13: Portal of Power Intake Drift (PI-1).

Figure-5.14: Rock Conditions in Power Intake Drift (PI-1).

5.1.2.e. Rock Mechanic Tests & Petrography:

The following laboratory tests for estimation of strength of rocks and physical properties of rocks on 22 numbers of core samples from the dam site area were got done from IIT, Bombay.

The results of tests are tabulated below in **Table-5.16 (Part-I to IV):**

Table-5.16 (Part-I): Physical Properties of Rock at Dam Site.

Sample No.	Location	Rock Type	Bulk Density (g/cc)	Grain Density (g/cc)	Porosity (%)
DH-1(1)	River Bed, Right Bank.	Quartzite	2.64	2.67	0.15
DH-1(2)	River Bed, Right Bank.	Quartzite	-	-	0.14
DH-1(3)	River Bed, Right Bank.	Quartzite	2.63	2.64	-
DH-2(1)	River Bed, Centre of River.	Quartzite	2.62	2.63	0.21
DH-2(2)	River Bed, Centre of River.	Quartzite	-	-	0.18
DH-2(3)	River Bed, Centre of River.	Quartzite	-	-	-
DH-3(1)	River Bed, Left Bank.	Quartzite	-	-	4277
DH-3(2)	River Bed, Left Bank.	Quartzite	2.64	2.68	0.18
DH-3(3)	River Bed, Left Bank.	Quartzite	-	-	-
DH-4(1)	River Bed, Bucket Area.	Quartzite	2.67	2.69	0.20
DH-4(2)	River Bed, Bucket Area.	Quartzite	-	-	-
DH-4(3)	River Bed, Bucket Area.	Quartzite	-	-	0.17
DH-5(1)	River Bed, Plunge Pool.	Quartzite	2.61	2.67	0.15
DH-5(2)	River Bed, Plunge Pool.	Quartzite	-	-	0.18
DH-6(1)	River Bed, U/s Coffer Dam.	Quartzite	-	-	4476
DH-6(2)	River Bed, U/s Coffer Dam.	Quartzite	2.68	2.69	0.19
DH-6(3)	River Bed, U/s Coffer Dam.	Quartzite	-	-	-
DH-7(1)	Dam Top, Left Bank.	Quartzite	-	-	0.15
DH-7(2)	Dam Top, Left Bank.	Quartzite	2.65	2.67	-
DH-7(3)	River Bed, Dam Top, Left Bank.	Quartzite	-	-	0.22
DH-7(4)	River Bed, Dam Top, Left Bank.	Quartzite	-	-	-
DH-7(5)	River Bed, Dam Top, Left Bank.	Quartzite	2.66	2.67	0.20

Table-5.16 (Part-II): Geo-mechanical Properties of Rock at Dam Site.

Sample No.	Location	Rock Type	Ultrasonic Wave Velocity (m/sec) Dry		Ultrasonic Wave Velocity (m/sec) Wet	
			P-wave	S-wave	P-wave	S-wave
DH-1(1)	River Bed, Right Bank.	Quartzite	4157	2512	-	-
DH-1(2)	River Bed, Right Bank.	Quartzite	-	-	4011	2487
DH-1(3)	River Bed, Right Bank.	Quartzite	-	-	-	
DH-2(1)	River Bed, Centre of River.	Quartzite	4434	2560	-	-
DH-2(2)	River Bed, Centre of River.	Quartzite	-	-	4079	2456
DH-2(3)	River Bed, Centre of River.	Quartzite	-	-	-	-
DH-3(1)	River Bed, Left Bank.	Quartzite	2419	3819	2389	-
DH-3(2)	River Bed, Left Bank.	Quartzite	-	-	-	-
DH-3(3)	River Bed, Left Bank.	Quartzite	-	3912	2367	
DH-4(1)	River Bed, Bucket Area.	Quartzite	4512	2711	-	-
DH-4(2)	River Bed, Bucket Area.	Quartzite	-	4012	2481	
DH-4(3)	River Bed, Bucket Area.	Quartzite	-	-	-	-
DH-5(1)	River Bed, Plunge Pool.	Quartzite	4534	2689	-	-
DH-5(2)	River Bed, Plunge Pool.	Quartzite	-	-	4121	2467
DH-6(1)	River Bed, U/s Coffer Dam.	Quartzite	2617	-	-	-

DH-6(2)	River Bed, U/s Coffer Dam.	Quartzite	-	-	3817	2341
DH-6(3)	River Bed, U/s Coffer Dam.	Quartzite	-	-	-	-
DH-7(1)	Dam Top, Left Bank.	Quartzite	4226	2513	3978	2351
DH-7(2)	Dam Top, Left Bank.	Quartzite	-	-	-	-
DH-7(3)	River Bed, Dam Top, Left Bank.	Quartzite	4234	2555	3998	2456
DH-7(4)	River Bed, Dam Top, Left Bank.	Quartzite	-	-	-	-
DH-7(5)	River Bed, Dam Top, Left Bank.	Quartzite	-	-	-	-

Table-5.16 (Part-III): Geo-mechanical Properties of Rock at Dam Site.

Sample No.	Location	Rock Type	Poisson's Ratio	Elastic Modulus (E) (GPa)	Tensile Strength (MPa)
DH-1(1)	River Bed, Right Bank.	Quartzite	0.24	21.5	21.35
DH-1(2)	River Bed, Right Bank.	Quartzite	-	-	-
DH-1(3)	River Bed, Right Bank.	Quartzite	0.24	21.98	20.84
DH-2(1)	River Bed, Centre of River.	Quartzite	0.23	21.24	-
DH-2(2)	River Bed, Centre of River.	Quartzite	-	-	20.78
DH-2(3)	River Bed, Centre of River.	Quartzite	-	-	-
DH-3(1)	River Bed, Left Bank.	Quartzite	-	-	22.07
DH-3(2)	River Bed, Left Bank.	Quartzite	0.24	22.65	-
DH-3(3)	River Bed, Left Bank.	Quartzite	-	-	21.34
DH-4(1)	River Bed, Bucket Area.	Quartzite	-	2.69	21.94
DH-4(2)	River Bed, Bucket Area.	Quartzite	0.24	22.57	-
DH-4(3)	River Bed, Bucket Area.	Quartzite	-	-	22.03
DH-5(1)	River Bed, Plunge Pool.	Quartzite	-	-	20.85
DH-5(2)	River Bed, Plunge Pool.	Quartzite	0.23	22.68	-
DH-6(1)	River Bed, U/s Coffer Dam.	Quartzite	-	-	20.98
DH-6(2)	River Bed, U/s Coffer Dam.	Quartzite	0.23	22.75	-
DH-6(3)	River Bed, U/s Coffer Dam.	Quartzite	-	-	21.08
DH-7(1)	Dam Top, Left Bank.	Quartzite	0.24	21.35	-
DH-7(2)	Dam Top, Left Bank.	Quartzite	-	-	19.98
DH-7(3)	River Bed, Dam Top, Left Bank.	Quartzite	-	-	164.67
DH-7(4)	River Bed, Dam Top, Left Bank.	Quartzite	0.24	21.54	-
DH-7(5)	River Bed, Dam Top, Left Bank.	Quartzite	-	2.67	20.05

Table-5.16 (Part-IV): Geo-mechanical Properties of Rock at Dam Site.

Sample No.	Location	Rock Type	UCS (MPa)		Triaxial Test	
			Dry	Wet	Cohesion (Mpa)	Angle of Internal Friction(^{0})
DH-1(1)	River Bed, Right Bank.	Quartzite	166.27	-	34.12	39.5
DH-1(2)	River Bed, Right Bank.	Quartzite	157.76	-	-	-
DH-1(3)	River Bed, Right Bank.	Quartzite	169.38	-	-	-
DH-2(1)	River Bed, Centre of River.	Quartzite	164.43	-	34.24	39.5
DH-2(2)	River Bed, Centre of River.	Quartzite	163.98	-	-	-
DH-2(3)	River Bed, Centre of River.	Quartzite	-	154.94	34.35	41
DH-3(1)	River Bed, Left Bank.	Quartzite	-	-	36.37	-
DH-3(2)	River Bed, Left Bank.	Quartzite	171.95	-	-	-

DH-3(3)	River Bed, Left Bank.	Quartzite	-	159.67	-	-
DH-4(1)	River Bed, Bucket Area.	Quartzite	171.84	-	-	-
DH-4(2)	River Bed, Bucket Area.	Quartzite	-	160.87	36.25	-
DH-4(3)	River Bed, Bucket Area.	Quartzite	-	-	-	-
DH-5(1)	River Bed, Plunge Pool.	Quartzite	-	158.07	35.97	-
DH-5(2)	River Bed, Plunge Pool.	Quartzite	170.37	-	-	-
DH-6(1)	River Bed, U/s Coffer Dam.	Quartzite	171.42	-	-	-
DH-6(2)	River Bed, U/s Coffer Dam.	Quartzite	-	-	35.36	-
DH-6(3)	River Bed, U/s Coffer Dam.	Quartzite	-	161.06	-	-
DH-7(1)	Dam Top, Left Bank.	Quartzite	165.35	-	-	-
DH-7(2)	Dam Top, Left Bank.	Quartzite	-	153.97	-	-
DH-7(3)	River Bed, Dam Top, Left Bank.	Quartzite	-	34.86	41.5	-
DH-7(4)	River Bed, Dam Top, Left Bank.	Quartzite	-	156.08	-	-
DH-7(5)	River Bed, Dam Top, Left Bank.	Quartzite	166.08	-	35.27	42

In addition petrography of rock core samples collected from the drill holes drilled at the dam site were got done from IIT, Bombay. The Petrographic studies were done after preparing 0.03 mm thin sections and studying them under Leica microscope under transmitted light. The results are given below in **Table-5.17:**

Table-5.17: Rock Types at Dam Site after Petrography.

Sample No.	Location	Rock Type	Remarks
DH-1	River Bed, Right Bank.	Quartzite	White in color
DH-2	River Bed, Centre of River.	Quartzite	White in color
DH-3	River Bed, Left Bank.	Quartzite	White in color
DH-4	River Bed, Bucket Area.	Quartzite	White in color
DH-5	River Bed, Plunge Pool.	Quartzite	White in color
DH-6	River Bed, U/s Coffer Dam.	Quartzite	White in color
DH-7	Dam Top, Left Bank.	Quartzite	Last two samples show the light grey colour with minor amounts of pyrite minerals

The report above studies titled “Geo-mechanical Properties of Bore Hole Samples, By IIT, Bombay” is enclosed as **Annexure-III of Volume-IVA.**

5.1.2.f. Geophysical Survey (Seismic Refraction Survey):

Seismic Refraction Surveys was conducted at the dam site along the right bank of Wangchu River by AIMIL Limited, New Delhi. Due to the presence of large boulders on the right bank, the seismic survey was confined to two profiles only 115m and 72m length (E-E’, F-F’). No studies were carried out on the left bank because of the presence of the rock exposures.

Three layers have been deciphered from the seismic survey for the 115m length profile while only two layers are deciphered due to the small length in the seismic line of 72m.

The first layer with compression velocities in the range of 400m/sec to 1500m/sec could be related to unconsolidated overburden materials as clay, silt and sand.

The layout of the lines is given below in **Figure-5.15:**

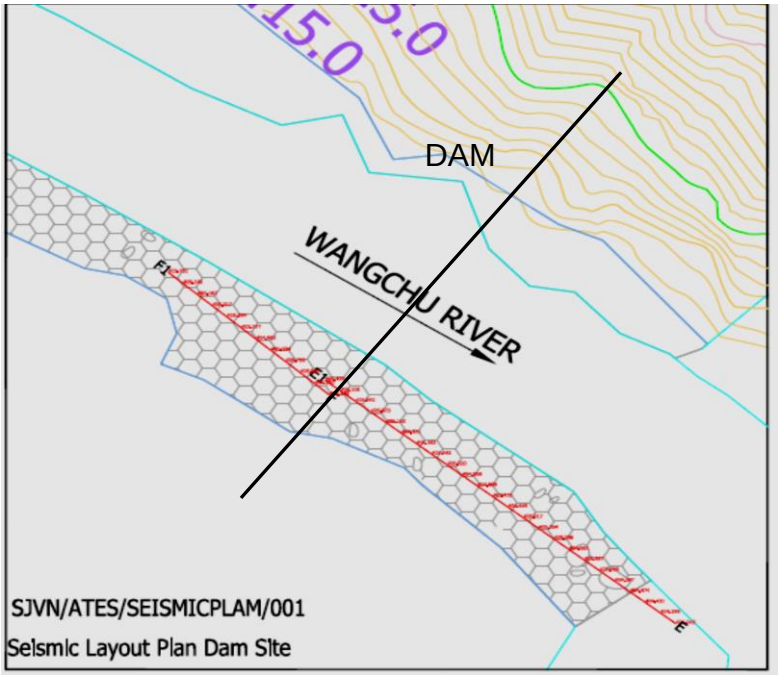


Figure-5.15: Seismic Layout Plan Dam Site.

The second layer with recorded P-wave velocity in the range of 1500m/sec to 3000m/sec indicates the mixture of fine sand with pieces of rock fragments, weathered boulders of quartzites and phyllites etc. The third layer with recorded velocity in a range of 3000m/s to 4000m/s indicates the presence of sound bed rock, consisting of quartzite, phyllites with various degrees of weathering and fracturing. The rock line was interpreted to be present between El. 364 to 370m along E-E' Line and El. 365 to 373m along F-F' Line.

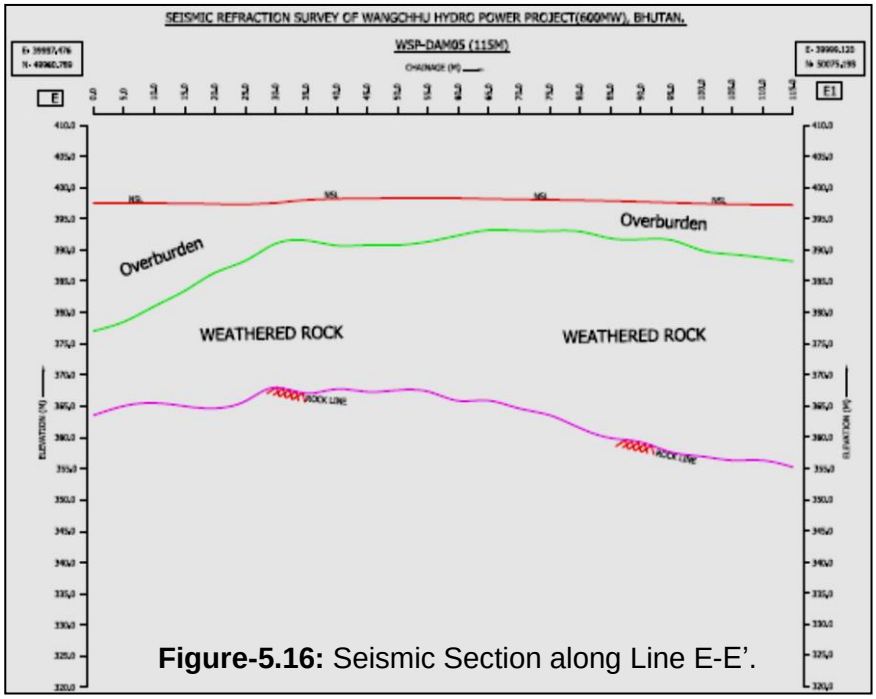


Figure-5.16: Seismic Section along Line E-E'.

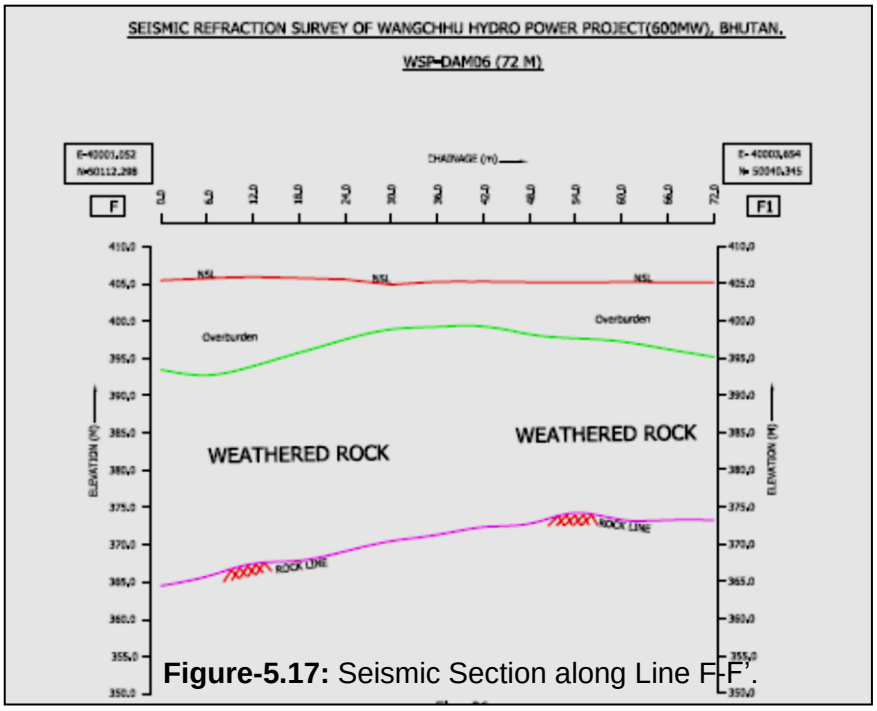


Figure-5.17: Seismic Section along Line F-F'.

The result of the field studies and conclusions titled "Report on Seismic Refraction Survey for WHEP, By AIMIL Limited, New Delhi" is enclosed as **Annexure-IV of Volume-IVA.**

5.1.2.g. Photo-geological Studies:

Photo-geological Studies of Tala Hydro Electric Project and Wangchu Hydro Electric Project was carried out by GSI, Eastern Region (in the Year, 1993) **Annexure-VA & VB of Volume-IVA.** No prominent lineament has been identified at the dam site.

5.1.2.h. Seismic Studies:

A preliminary seismic study was done by Central Water and Power Research Station, Pune in July, 1993 using past data on earthquake occurrences and knowledge of various tectonic and geological features of the region from which design seismic forces were evaluated in terms of acceleration response spectra. The report on the study is enclosed as **Annexure-VII; Volume-IVA.** Additionally, Central Water and Power Research Station (CWPRS), Pune has been assigned the work of Seismic Studies. The details are dealt in Civil Design, Chapter-VII of Volume-I.

5.1.3. Geotechnical Appraisal of Dam Site

Based on the drill hole data done at the dam site, the rock levels in the river bed has been inferred and are given below in **Table-5.18:**

Table-5.18: Bedrock Level in the river at dam site inferred from the drill holes.

Drill Hole No.	Location	Ground El. (m)	Overburden / Rock Contact (m)	Bed Rock El. (m)	Rock type
DH-1	Dam Axis - Right Bank	407.794	15.0	392.794	White to light grey coloured quartzite
DH-2	Dam Axis - Centre of River	403.199	37.0	366.199	White to light grey coloured quartzite
DH-3	Dam Axis - Left Bank	404.483	27.0	377.483	White to light grey coloured quartzite
DH-4	90m D/s of Dam axis in the centre of the river.	403.085	26.3	376.785	White to light grey coloured quartzite
DH-5	150m D/s of Dam Axis in the centre of the river.	401.210	27.0	374.210	White to light grey coloured quartzite
DH-6	U/s Coffer Dam the centre of the river.	404.283	19.5	384.783	White to light grey coloured quartzite
DH-10A	Dam Axis Right Bank (Angular).	404.438	43.50	364.00	White to light grey coloured quartzite
DH-12A	Dam Axis left bank (River bed)	404.083	42.00	365.00	White to light grey coloured quartzite
DH-14	Left bank, d/s of dam axis	404.00	0.00	404	White to light grey coloured quartzite

The geological data collected through various investigations have been interpreted to arrive at the geological conditions in the dam foundation and dam abutment.

5.1.3.a. Foundation Condition:

Detailed Geotechnical Investigations were carried out at the foundation level at the dam by 9 drill holes indicating the depth of riverine deposits range between 15 to 37m. The riverine deposits consist mainly of boulders, cobbles and pebbles of quartzite, biotite-gneiss, granitic-gneiss and mafic rocks alongwith medium to coarse silt / sand seams. The rock encountered in these drill holes is white to light grey coloured, hard and compact quartzite which is mostly moderately to closely jointed. The quartzite rock is at times fractured and shattered and sheared in some reaches. Core recovery in the rock ranges between 47 to 100%. The RQD values ranged between 0 to 83.33%. Staining along the joint planes was recorded in the three drill holes for the complete drilled depths. Slight sign of weathering was also noticed in the drill cores in some reaches.

The presence of hard compact and strong quartzite with high compressive strength (164 to 172 Mpa), weathering limited to some reaches only, suggests good foundation condition in the riverbed. Stripping depth at bed level is confined to the stained and fractured / jointed reach which is observed to lie within 1.5 to 6 m depth as recorded from the core data with around 2m stripping at the deepest level. The deepest foundation level thus arrived at is El. 364m. However, the permeability values ranging from 8 to 17 lugeon in general with

one or two values below 3 indicating that the foundation will not be very tight and will require effective grouting.

5.1.3.b. Abutment Condition:

The right abutment slopes vary from 35^0 to 45^0. The quartzite rock is exposed between El. 412m (bed level) to El. 450m and above elevation 550m as picked up in the geological mapping. The reach between the El. 450 to 550m is covered with loose slope wash material consisting mainly of quartzitic-phyllite / quartzite boulders.

In the right abutment, the drift DR-1 at El. 420m has shown weathering in rock in the some reaches and staining throughout with varying intensity. The stripping limit as assessed from the data is inferred to be of the order of 10 to 12m approximately at the lower elevation (El. ±420m). At the higher elevation a drift (DR-2) is proposed at El. 460m. But there is no data available and thus the stripping limit will be in line with the lower level drift profile and angle of the cut slopes. However, there is 8 to 10m of overburden at El. 460m; the foundation grade rock is expected between 20 to 23m from NSL. The encountering of few valley dipping shears in the drift DR-1 indicates that the right bank slopes are likely to become unstable during excavation and will need concurrent support during excavation.

Two vertical holes(DH-8 & DH-15) and one inclined hole (DH-11A) done at right bank along the dam axis has indicated presence of multiple shears between depths 34.5 to 37.50m, shear zone between depths 37.5 to 46.5m & 62.5 to 80.5m supposedly along a steep inside dipping joint. These multiple shears & shear zones are located deep inside the abutment, about 55m to 85m inside the NSL between El. 440 & 404m respectively. The true width of each zone is about 2.5 to 6m. A vertical hole drilled from El. 463 (DH-15) has indicated presence of maximum depth of 30 m overburden on the abutment in between El. 445 to 480m.

Based on the drift data of DL-1 (El. 420m) on the left bank, wherein a valley dipping shear 40 to 100cm thick and containing black soil has been encountered, in the form of shattered and fractured rock; the stripping limit shall be of the order of around 17m on the left bank at El. 420m. The extension of this shear zone on the ground profile at the dam axis on the left bank is distinct in the form of broken profile below El. 450m. The abutment rises steeply above El. 450m which can be attributed to the slope failure along the shear. The second drift at left bank El. 460m (DL-2) has good rock conditions, except for the staining throughout the excavated length. A stripping of 5m to 10m around elevation 460m is suggested. A vertical hole DH-7 drilled from El. 506.01 for a depth of 140m has indicated presence of bed rock comprising of fine grained, white to light grey coloured quartzite with occasional shattered & fractured zones. The presence of valley dipping joints on this bank makes it vulnerable to failures and will require concurrent support during excavation.

5.1.3.c. Bucket Area:

Geological mapping in the bucket area has revealed a narrow ledge of quartzite rock exposure extending from the dam to upto 15m D/s at the river level on the right bank. The area beyond 15m has overburden of slope wash deposits on a gentle hill slope (22^0 to 25^0).

The bucket area has been explored by drill hole DH-4 located 90m downstream of the dam axis in the river towards the right bank. A geological section has been prepared at the bucket area along the drill hole DH-4 **(Drg. No.: DAM-WHEP-DPR-GEO-008-01; Volume-IVB).**

A brief summary of the drill hole DH-4 is given below:

DH-4 (River Bed):

Location:	Bucket Area, 90m D/s of Dam Axis.	**Coordinates:**	**N:** 50022.370 **E:** 40003.320
Ground El.:	403.085 m	**Total Depth:**	50m

Depth (m)	Elevation (m)	Overburden / Rock	Remarks
0 to 27.0	403.085 to 376.085	River borne material	River Borne Material (RBM) consisting of predominantly boulders, cobbles and gravels of white to greenish quartzite. Some biotite-gneiss and granitic gneiss material was also encountered along with medium to coarse grained grayish sand.
27.0 to 50.0	376.085 to 353.085	Bed Rock	Bed rock comprising of fine grained, white to light grey colored quartzite was encountered. Staining has been observed in the rock for all the drilled depth of the hole. Core recovery ranges from 63 to 100%. The RQD values varied between 0 to 87%. The permeability tests indicate turbulent flow characteristics with values ranging from 12.45 to 15.01 lugeons. The prominent jointed, fractured and shattered (depth wise) encountered in the quartzite rock are as follows: 27.0-28.5m: Closely jointed rock with a fractured / shattered zone between 27.7 to 28.40 m depth. 31.6-32.6m: Very closely jointed and fractured rock. 38.2-38.5m: Shattered rock. 38.5-40.5m: Jointed rock. 42.0-42.3m: Very closely jointed rock. 44.8-46.08m: Closely to very closely jointed rock. 49.85-49.93m: Shattered Rock

Geological log of drill hole DH-4 is enclosed as **Appendix-4; Volume-IVA.**

Figure-5.18: Photograph showing drill cores of drill hole DH-4 (RD. 27 – 36m).

Based on the drill hole it is inferred that the foundation rock will be white to light grey, hard and compact, stained and slightly weathered quartzite under riverine deposit of 26.30m toward right bank which may increase in the middle of the river. The high in-situ permeability values of 12.45 to 15.10 lugeons indicate open nature of joints. Also, due to the presence of occasional closely jointed and fractured zones in the foundation rock, effective consolidation at depth would be called for.

The left bank slopes are 45° to 50° with a hump of shattered rock between the elevations 420 to 450m. Rock is exposed on the left bank slopes & will need support during excavation.

The right bank slopes are gentle and with an overburden cover of 10 to 12m. No problem of slope failure is foreseen during the excavation of the right bank slope.

5.1.3.d. Plunge Pool:

Geological mapping in the plunge pool area has revealed quartzite rock exposure at the upstream end of the plunge pool area on the right bank. On the downstream portion a seasonal Nallah is seen with a gentle slope (22^{0} to 25^{0}). The left bank however, has quartzite exposures throughout the plunge pool area a part of which intrude into the river channel which needs to be removed. The area has been investigated by a drill hole DH-5, located 150m D/s of the dam axis in the river channel towards the right bank. A brief summary of the drill hole DH-5 is given below:-

DH-5 (River Bed):

Location:	Plunge Pool Area, 150m D/s of Dam Axis.	**Coordinates:**	**N:** 49958.110 **E:** 40033.920
Ground El.:	401.210m	**Total Depth:**	50m

Depth (m)	Elevation (m)	Overburden / Rock	Remarks
0 to 24.0	401.210 to 377.210	River Borne Material	River Borne Material (RBM) consists of predominantly boulders, cobbles and gravels of white quartzite. Some biotite-gneiss material was also encountered along with medium to coarse grained grayish sand.
24.0 to 50.0	377.210 to 351.210	Bed Rock	Bed rock comprising of fine grained, white to light grey colored quartzite was encountered. Staining has been observed in the rock for all the drilled depth of the hole. Core recovery ranges from 30 to 100%. The RQD values varied between 0 to 59%. The permeability tests indicate turbulent flow characteristics with lugeons values ranging from 11.62 to 14.95.
The prominent jointed, fractured and shattered zones (depth wise) encountered in the quartzite rock are as follows: 27.0-29.0m: Jointed Rock, 29.0-31.5m: Fractured and Jointed Rock, 32.45-33.80m: Closely JointeD/shattered Zone, 34.75-36.3m: Fractured and Jointed Rock, 46.25-47.8m: Fractured / Shattered Zone, 47.8-48.7m: Closely Jointed Rock, 48.7-49.35m: Fractured Zone, 49.8-50.0m: Fractured Zone.			

Figure-5.19: Photograph showing drill cores of drill hole DH-4 (RD. 39 - 45m).

Based on the drill hole it is assessed that the foundation rock in the plunge pool area will be white to light grey coloured, hard and compact, stained quartzite under river deposit of 24m towards the right bank which will increase towards middle of the river. The high in-situ permeability values of 11.62 to 14.95 lugeons indicate presence of open joints. In addition, due to the presence of occasional closely jointed and fractured zones in the foundation rock, effective consolidation in the foundation will be required.

A geological section has been prepared at the plunge pool area along the drill hole DH-5 located at the upstream edge **(Drg. No.: DAM-WHEP-DPR-GEO-009-00; Volume-IVB).** The left bank however, has quartzite exposures throughout the plunge pool area. A hump of shattered rock between the elevations 440 to 480m is seen on the left bank slope. A rocky ledge intrudes into the river channel which needs to be removed to accommodate

the plunge pool. During excavation, concurrent support will be required. As a long term stability measure, the rock slopes above the plunge pool will require strengthening.

Figure-5.20: Rock Ledge Protruding on left bank at the Plunge Pool Area (View Looking Downstream).

The right bank slopes overlooking the plunge pool area are covered by nallah (seasonal) deposits and slope debris with very few rock exposures. Although the right bank slope is quite gentle, still a lot of drainages and slope protection work will be required.

5.2 Diversion Tunnel

During the construction stage, the river water will be diverted through two 421 m (DT-1/river side) and 536 m (DT-2/hill side) long, 10 m diameter, horse-shoe shaped diversion tunnels on the right bank which will cater to a maximum discharge of 2284 cumecs. The inlet portals will be at an El. of 416.0 m while the outlet portal will be at an El. of 408.0 m. The diversion tunnel is located between an area 180 m upstream and 300 m downstream of dam axis on the right bank. The upstream coffer dam is about 110 m upstream of dam axis with a dam top elevation of 1542 m. The diversion tunnel alignment is traversed by three *nallahs.* The first *nallah* from the inlet end is deeply incised which can possibly be structurally controlled and could be the source of water seepage in the diversion tunnel. The maximum rock cover above the diversion tunnel is around 150 m.

The hill profile is high from the inlet end and gentle outs towards the outlet end with a maximum rock cover of about 150 m above the diversion tunnel (el. 540 m).

Geological studies:

Only a few rock exposures of white to light grey coloured, fine grained quartzite rock are exposed along the DT alignment which otherwise is dominated with slope debris/overburden material. The bedding/foliation planes in the area trend in N80W-S80E and dip 40^0 to 50^0 in N to N10^0E direction. Three or more joint sets intersect the quartzite rock in the diversion tunnel area similar to the dam site.

The inlet portals will be encountering slightly weathered, blocky quartzite rock from the river bed level to up to a height of about 16 to 35 m in case of DT-2 and DT-1, respectively. Thereafter, a thick slope debris/overburden cover (5 to 15 m) is present on the northern slope of the hill (inlet side). The three *nallahs* are present on the south-eastern slope of the hill. Intermittent quartzite rock exposures are mapped in this reach.

The DT outlet portal area has been explored by a drill hole DH-9 drilled at RD 503.5 m (DT-2) at an elevation of 455.0 m to ascertain the bed rock level and the rock conditions at the outlet portal area. The drill hole has indicated a rock cover of 19 m above the DT overt (el. 415 m) consisting of quartzite rock.

A brief summary of the drill hole DH-9 is given below:

DH-9 (Right bank)

Location: Diversion Tunnel - Outlet

Ground El.: 455.0 meter

Co-ordinates: N: E:

Total depth: 50.0 meter

Depth (m)	El. (m)	Overburden /Rock	Remarks
0 to 21	455.0 to 434.0	Overburden	Slope debris in the form of angular rock fragments mostly of quartzite along with coarse sandy material
21.0 to 50.0	434.0 to 405.0	Bed rock	Bed rock comprising of fine grained, white to light grey/blue coloured quartzite was encountered. Staining and slight weathering has been observed in the rock for all the drilled depth of the hole. Core recovery in the rock ranges from 44 to 88.66%. The RQD values varied between 0 to 26%. The permeability tests indicate turbulent flow characteristics with lugeon values ranging from 6.58

			to 16.10. The prominent jointed, fractured and shattered zones (depth wise) encountered in the quartzite rock are as follows: *21.0-21.50 m Fractured zone* *23.50-28.65 m Jointed/fractured rock zone* *32.65-38.90 m Mostly shattered/fractured zone with some jointed rock* *39.7-40.1 m Fracture zone* *40.5-43.95 m Fracture zone* *48.55-50.0 m Fractured and very closely jointed rock mass.*

Geological sections have been prepared along the diversion tunnels **(Drawing no: DAM-WHEP-DPR-GEO-11&11A -00, Volume-IV-A)**.

5.2.2 Geotechnical Appraisal

Inlet Portals

The inlet portals of the two DT's will be encounter slightly weathered, blocky quartzite rock from the river bed level to up to El. 442 m and 433 m for inlet portals of DT-1 and DT-2, respectively. A rock cover of about 26 m and 16 m is available at the portals of the inlet tunnels DT-1 and DT-2 which increases to 40 m and 33 m, respectively at the inlet portal end - DT junctions. Wedge formation will be a common phenomenon during the excavation, mainly due to the blocky nature and weathered joint planes which would be requiring extensive rock bolting. Ground water seepage is also foreseen during the excavation of the inlets mainly along the bedding shears.

Outlet Portal: From the drill hole data of hole DH-9 done at the outlet portal, it is evident that the first 22 to 30m of excavation from the outlet portals will be through cut and cover due to the presence of thick overburden almost upto tunnel level. After which the portals can be established. Considerable removal of overburden and its stabilization will be required above the portals.

Diversion tunnel:

The diversion tunnels in general will encounter slightly weathered, hard, blocky quartzite rock which will be dissected by three to four joint sets and may need extensive pattern rock bolting throughout the length.

DT-1

The bedding/foliation planes will have a favourable orientation from the inlet end of the diversion tunnel to up to RD 100 m as the angle between the strike direction of the bedding/foliations and the tunnel alignment will be almost 70° to 90°. But as there is overburden above tunnel, weathered rock conditions and flow of water is expected in this reach. A bedding shear is expected to be encountered at RD 18 m which could also be a possible source of channelizing ground water into the DT.

The intermediate reach between RD 100 m to 340 m will have a 45° to 60° angle between the strike direction of the bedding/foliations and the tunnel alignment. The profile above tunnel has good rock cover with rock exposed invariably. This part of the tunnel will offer better tunneling media except in and around the first nallah which can be a structurally controlled feature and can be a potential source of seepage. The rock cover below the nallah is around 45 m. Poor rock conditions due to this feature can be expected between RD 285 to 305 m.

The reach of the diversion tunnel from RD 340 m up to the outlet portal end will be unfavourable for excavation as the strike direction of the bedding/foliations will be almost parallel to the tunnel alignment. Moreover, the rock conditions as recorded in the drill hole DH-9 has mostly fractured to closely jointed quartzite rock in this reach. DT-1 will be having a rock cover of around 20 to 35 m in this reach with the lesser cover towards the DT - outlet junction. The end portion of the DT and outlet portal has to be an open structure or will have to be highly reinforced.

The RD wise rock mass classification (optimum guess) along the diversion tunnel DT-1 alignment is as follows:

Table 5.19: Rock mass classification for the diversion tunnel DT-1 (river side), inlet and outlet.

RD (m)	Length (m)	% of length	Rock class	Remarks
0 – 26 (Inlet)	26	100	III & IV	Inlet of DT in weathered and blocky quartzite. Wedge formation very common. Ground water seepage anticipated.
0 – 60	60	14.25	III & IV	Initial part of DT in weathered and blocky quartzite. Thick overburden cover, weathered and blocky rock mass, wedge formation very common.

60 - 285	225	53.44	II & III	Moderately jointed rock mass, wedge formation common, thin shears anticipated.
285-305	20	4.75	V	Wide nallah cross the DT alignment, possible shear zone, ground water problems.
305-410	105	24.94	II & III	Moderately jointed rock mass, wedge formation.
410-421	11	2.61	IV & V	Low rock cover, thick overburden cover, ground water problems, jointed to shattered rock mass.
(0 - 21) Outlet	21	100	V	Low rock cover, thick overburden cover, ground water problems, jointed to shattered rock mass.

The overall rock mass classification is as under: -

Table: - 5.20 Rock Mass Classification along DT-1 only

Class	Length	Percentage
II	165	39.2% +-20%
III	195	46.31% +-20%
IV	35.5	8.43% +-20%
V	25.5	6.05% +-20%
Total	421	

DT-2

The bedding/foliation planes will have a favourable orientation from the inlet end of the diversion tunnel to up to RD 130 m as the angle between the strike direction of the bedding/foliations and the tunnel alignment will be almost 70° to 90°. But as there is overburden above tunnel, weathered rock conditions and flow of water is expected in this reach. A bedding shear is expected to be encountered at RD 45 m which could also be a possible source of channelizing ground water into the DT.

The intermediate reach between RD 130 m to 400 m will have a 45° to 60° angle between the strike direction of the bedding/foliations and the tunnel alignment. The profile above tunnel has good rock cover with rock exposed invariably. This part of the tunnel will offer better tunnelling media except in and around the first nallah which can be a structurally controlled feature and can be a potential source of seepage. Poor rock conditions due to this feature can be expected at RD 320 to 340 m.

The reach of the diversion tunnel from RD 400 m (DT-2) up to the outlet portal end will be unfavourable for excavation as the strike direction of the bedding/foliations will be almost parallel to the tunnel alignment. Moreover the rock conditions as recorded in the drill hole DH-9 has mostly fractured to closely jointed quartzite rock.

DT-2 will have sufficient rock cover at RD 536 m (around 60 m), but this will reduce significantly towards the DT - outlet junction. A rock cover of 2-D will be available at the drill hole location, i.e. at RD 503.5 m, wherein after the DT and outlet portal has to be an open structure or will have to be highly reinforced.

The RD wise rock mass classification (optimum guess) along the diversion tunnel DT-2 alignment is as follows:

Table 5.20A: Rock mass classification for the diversion tunnel DT-2 (hill side), inlet and outlet.

RD (m)	Length (m)	% of length	Rock class	Remarks
0 – 26 (Inlet)	26	100	III & IV	Inlet of DT in weathered and blocky quartzite. Wedge formation very common. Ground water seepage anticipated.
0 – 90	90	16.8	III & IV	Initial part of DT in weathered and blocky quartzite. Thick overburden cover, weathered and blocky rock mass, wedge formation very common.
90 - 320	230	42.91	II & III	Moderately jointed rock mass, wedge formation common, thin shears anticipated.
320 - 340	20	3.73	V	Wide nallah cross the DT alignment, possible shear zone, ground water problems.
340 - 460	120	22.38	II & III	Moderately jointed rock mass, wedge formation.
460 - 536	76	14.17	IV & V	Thick overburden cover, ground water problems, jointed to shattered rock mass.
(0 - 21) Outlet	21	100	V	Low rock cover, thick overburden cover, ground water problems, jointed to shattered rock mass.

The overall rock mass classification is as under: -

Table: - 5.20B Rock Mass Classification along DT-2

Class	Length (m)	Percentage
II	175	32.64% +- 20%
III	220	41.04% +- 20%

IV	83	15.5% +- 20%
V	58	10.82% +- 20%
Total	536	

5.2. A. Upstream Coffer Dam

To facilitate the construction of the main Dam and Power Intake structure, the Wangchu river will have to be diverted through a diversion tunnel on the right bank. The details of the diversion arrangements have been shown in **Drg. No.: DAM-WHEP-DPR-GEO-010-00; Volume-IVB.**

The coffer dam has been located 130m upstream of the proposed dam axis in a narrow gorge with steep abutments.

Massive, bedded quartzite though highly jointed with minor thin bands of quartzitic-phyllite is exposed on both the abutments. The general foliation trend is N80^{0}W – S80^{0}E with 50^0 northerly dip i.e. dipping in up stream direction. The important set of joints recorded in quartzite outcrop trends in **i)** E – W with 70^0 N dip, **ii)** N 20^{0}W – S20^{0}E with 80^0 Southerly dips, and **iii)** N40^{0}E-S40^{0}W with 20^0 dip towards SE.

Competent, jointed quartzite rock is available on either banks almost at surface or at a very shallow depth. However in the river bed which will accommodate the maximum length of the dam, up to 19.5m thick riverine material has been found above the bed rock based on bore hole (DH-6) data.

The summarized log of the drill hole is as follows:

DH-6 (River bed)
Location: At U/s Coffer Dam in river.
Ground El.: m
Co-ordinates: **N:** **E:**
Total depth: 50.0m

Depth (m)	Elevation (m)	Overburden /Rock	Remarks
0 to 19.5m	-	River Borne Material	River Borne Material (RBM) consists predominantly boulders, cobbles and gravels of white quartzite. Some biotite-gneiss material was also encountered along with medium to coarse grained grayish sand.
19.5 to 50.0m	-	Bed rock	Bed rock comprising of fine grained, white coloured quartzite with some light grey coloured quartzite was encountered. Staining has been observed in the rock from 19.50 m to 46.20 m depth. Core recovery ranges from 68.33 to 100%. The RQD values varied between 0 to 83.75%. The permeability tests indicate turbulent flow characteristics with lugeon values ranging from 12.44 to 17.36.

			The prominent closely jointed and fracture zones (depth wise) encountered in the quartzite rock are as follows: Fractured zones 19.45-19.55 m, 20.30-20.80m and 21.45-22m. Very closely jointed reaches 24.0-25.50, 30.45-31.90 & 45.20-46m.

The bed rock shows open joints and has high permeability values ranging between 12.44 to 17.36 lugeon for which special deep grouting is required to control seepage for safety of Coffer Dam.

5.3. Power Tunnel Intake

5.3.1. Geological Studies

The 7.5m diameter, twin intake structure with invert at El. 472m is located on the left abutment, 50m U/s of the dam axis in hard, blocky quartzite rock. The hill at the intake slopes at 40^0 to 45^0.

The intake area has been geological mapped on 1:1000 Scale and explored by a drift of 50m length at an elevation of 472m to access the rock conditions likely to be encountered. The intake portals have rock exposures of quartzite from El. 420m to above 550m. The drift has encountered fine grained, white to light grey coloured, closely to moderately jointed quartzite rock. The rock shows signs of staining throughout the drift length. The drift is normally dry but minor dripping along the crown was observed at RD 17m along the shear zone. Moist and damp conditions were observed near the shear between RD 34 to RD 36m and also between RD 44 to RD 50m. No root penetration was recorded in the drift. Shears of 1cm to 10 cm thickness with crushed rock and thin black coloured clay gouge fillings were recorded at RD's 4.50 m, 17m, 35m, 44m and RD 49m. All the shears are hill dipping.

The foliation joints have orientation 50° / N10E dipping into the hill and are quite prominent. The other joint sets in the order of their prominence are given in **(Table-5.21):**

Table-5.21: Prominent Joint Sets in Power Tunnel Intake Area.

Dip Direction	Characteristic	Prominence
N30E-S30W	Vertically Dipping Joints	Prominent.
70^0/N20W	Hill Dipping Joints	Prominent.
70^0/S15E	Valley Dipping Joints	Less prominent.
75^0/S20W	Valley Dipping Joints	Less prominent.

Figure-5.22: Portal of Power Intake Drift (PI-1).

Figure- 5.23: Rock Conditions in Power Intake Drift (PI-1).

5.3.2. Geotechnical Appraisal

Intersection of various joint sets will give rise to wedge failures during excavation of the intake structure. In view of the same, excavation for the power intake portal structure is apprehended to result in planar failure along the steep, valley dipping joints which will need to be contained by suitable length of rock bolts for maintaining stability of the portal. The loosely lying shallow slope wash material above 450m elevation can also pose problem during construction.

5.4. Reservoir Study

The catchment area of Wangchu River system is of the order of 4184.16 Sq. Km. upto dam site at Pakshina and Silli Village. The river drains in a glaciated terrain of greater Himalayas with sedimentary litho file of Tethayan Belt, Para gneisses and meta sediments of the Crystalline Complex & meta sediments of Shumar Formation. The area is dotted

with drift material by mountain glaciers in past, stung at different levels. Moreover, as evident from nature of river borne material and occurrence of land scars, a large number of active land slides are present in the catchment area.

The Wangchu Reservoir at the proposed FRL of 494m would impound 53.58 x 10^6 cum of water spreading over an area of 159.58 Hectare Area, upto the Tail Race Tunnel Outfall level of the Tala Hydro Electric Project.

5.4.1. Geological Mapping

An area of about 3.20 Sq. Km. on 1:5000 Scale of the Wangchu Reservoir Scheme has been geologically mapped. The reservoir area mapped extend as linear bay in NWW direction from the proposed dam axis to near TRT outfall of the Tala Hydro Electric Project for a length of about 8 Km with width falling in between 520m contour levels **(Drg. No.: WHEP-DPR-GEO-018-02; Volume-IVB).** However geological mapping at places upto 700m contour levels have been carried out to accommodate rock slides **(Figure-5.24 & 5.25),** escarpment faces and shear zones features of geological interest.

Figure-5.24: View of Rock Slide on Left Bank at 2350m U/s of Dam Axis.

Figure-5.25: View of Rock Slide within Shumar Formation in Baisi Khola Nallah.

The linear bay widens near east of village Aiga and near intersection of Baisakhola, Samachina, and Khamjelung Nalla of the right bank beside unnamed Nalla on the left bank of the Wangchhu Reservoir which is now occupied by talus, slope wash, drift material and riverine deposits. A rock slide on left bank of Baisi Khola Nallah is exposed before its joining with the Wangchu River **(Figure-5.25)**. In most of the reaches the reservoir will remain contained within steep valley gorge, excepting immediately 6 Km U/s of the dam site where valley slightly opens up with a prominent declivity and the reservoir has a maximum width of the order of 560m; minor valley widening is also exhibited near 750m, 1600m and 4500m U/s of the dam site due to cross valley drainages containing drift material showing signature of creep, at places river borne material and terrace deposits later concealed by drift material.

These materials at times with poor shear characteristics have resulted in slope failure/debris avalanches on imposition of partial submerged conditions, In the rocky slope section, the reservoir rim is beset with longitudinal and diagonal joints with steep values. At places, these sets dip into the Reservoir forming potential planes for rock slide, the rock glide. The rocks on left bank near 4750m, 3100m, 2400m and upto 750m upstream from dam site are traversed by these sets of joints. The geological map of the reservoir area is completely devoid of any Karstic formation. As such, the formation of solution cavities in arenaceous rock assemblage to act as underground conduit out of reservoir water is not possible. No major fault, shear or other mega fractures have been noticed. The minor open fractures/shear recorded in the drifts and right and left abutments of the dam site needs due care by consolidation and curtain grouting. The left bank of the reservoir shows

sign of instability along valley ward dipping shears and joints. This process may be further abetted by drawdown. It is imperative therefore to contemplate effective remedial measures to arrest these slopes, particularly in the dam abutment and adjacent areas. The mapping has also located a wide seepage zone near west of Samachina village possibly along the lithological contact of quartzites and phyllitic quartzite **(Figure-5.26)** with its overlying quartzite with slivers of Thimphu Crystalline **(Figure-5.27)** marked by highly sheared and pulverized seepage zone forming part of the Shumar Formation.

Figure-5.26: Sheared and Pulverised Zone near Lithological Contact of Quartzite with slivers of Thimphu Formation of Shumar Group (Baisi Khola Nallah).

Figure-5.27: Shumar Quartzite with slivers of Thimphu Crystalline on Left bank Reservoir Area close to MCT (Near Tala TRT Outfall).

The rock mass on both the banks of the reservoir are identical, comprising mainly of quartzite, highly jointed and fractured with occasional bands of phyllitic quartzite, schistose quartzite **(Figure-5.28 & 5.29)** and carbonaceous phyllitic quartzite.

Figure-5.28: Chevron Fold within Schistose Quartzite of Shumar Formation.

Figure-5.29: Highly Jointed White Quartzite of Shumar Formation.

The foliation of rocks trend from N70W - S70E to E-W with moderate dips of 40 ^{O} to 55 ^{O} in northerly direction. Few minor shears recorded are trending in N50W - S50E to N65W -

S65E with shallow to steep dips of 35° to 75 ^{O} in northeasterly direction. The Shumar quartzites at places are exhibiting tight Synformal Fold as exposed along road section of Silli Village **(Figure-5.30)**.

Figure-5.30: Tight Synformal Fold within Quartzite of Shumar Formation.

5.4.2. Reservoir Treatment Plan

The reservoir treatment plan is formulated to mitigate the geo-environmental hazards in the project areas especially reservoir area. Geo-environment hazards may be defined as those extreme events induced by geological setup of the region, which exceed the tolerable magnitude within or beyond certain time limits, make adjustment difficult, result in catastrophic losses of property, income and lives. In any development project, planning of geo-environment hazard is as important as the construction of the project structures. Therefore, importance should be given to the geo-environmental aspects.

The main objectives behind the Reservoir Treatment action plan is to check the sedimentation in the reservoir caused by the loose debris on critical slopes, landslides etc.

5.4.2a <u>Aims & Objectives of the Treatment Plan</u>

The aim of the action Plan is to check sedimentation in the reservoir, and therefore to Mitigate the effects of debris flows on extreme slopes, extreme events such as landslides. In general the aims and objectives for Reservoir Treatment Plan are as follows:

1. To prevent land degradation / soil erosion
2. To stabilize the landslides and landslip zones around the reservoir.

5.4.2.b Geo-environmental Hazards

The WANGCHHU H.E project area has one main major active landslide areas at RD-2500 and some minor and dormant landslides the whole area of the 7 Km of the reservoir length. Geological mapping reveals that one large landslide is present within boundary of reservoir. The slide activated from the base of the riverbed to an elevation of 150 to 200m with steep slope of angle 60 to 70^0 and with partly barren and no vegetation cover.

5.4.2.c Drainage network in the reservoir area

There are about 13 tributaries draining directly into the reservoir. Most of the tributaries are very small and seasonal. A large tributary which drains into reservoir is Samachina khola and 3 unnamed khola to the reservoir area.

5.4.2d Mitigatory measures or treatment /safety measures

The step in fixing the existing landslides is a comprehensive assessment of factors that led to the initial and subsequent down-slope movements of the land mass involving detailed field investigations of geologic, soils, hydrologic, topographic, meteorological and seismic factors which collectively produced the landslide. Further Assessments may include/done by the detailed geotechnical analysis and monitoring of selected landslides. In WANGCHHU H.E project considering the magnitude of landslide near the reservoir, the following measures are suggested to control it; however expertise may be taken if required.

i) The water to be captured and drainage of surface water flowing into the slide area

The following are the actions suggested for controlling the land slides in the project area.

i). the impact of landslide on the project could be managed by arresting the potential landslides zones through suitable engineering treatments, afforestation etc.

ii). Landslide Control with Coir-Geo-textiles.

iii) Biological measures

Engineering Measures

i) The rock mass/soil in the slide proven area is to be kept free of moisture by prospecting catch water drains on its suitable fraction of the steep slope and line them with black vulnerable sheeting, brick or stone. Bitumen mulching some location of the slide zone is recommended in keeping down surface percolation into the hill face which includes injection of cement or hydrated lime slurry into soil mass under pressure forces the grout through path of least resistant moving along fracture ,bedding plane, seams, roots and fracture created by jetting slurry .

iii) Toe Protection Works Consist of rendering the face of hill in contact with forces of erosion non-erode able. This is commonly done by erecting mass concrete masonry or crated bolder walls. Slide is prevented from moving by RCC mass concrete wall are also provided to prevent the erosion. Dry stone wall in wire crate are suitable when placed on uncertain foundation.

iii) Reducing the angle of the slope face of landslides and open cracks in the upper sides of landslides to be filled with cemented spray and other compact materials etc.

Use of Coir Geotextiles

Coir geotextiles is product which is used for erosion control and is used for slope stabilization applications due to the mechanical strength necessary to hold soil together. It is been proven that coir geotextiles last for approximately 3 – 5 years depending on the weight, and by the time the product degrades, it converts itself into humus, which enriches the soil. The convex part of the land slide will be treated with coir geo-textiles. They are biodegradable and over a time period they are useful for plant species. The wedge shaped trenches are to be dug to anchor the coir nets.

Biological Measures

Vegetation cover is an important factor which would minimize the magnitude of landslide in a landslide area. It plays very important role in stabilizing the loose soils and controls the hydrological and mechanical effects on the soils and slopes. Biological measures will be carried out with coir netting. The seed of locally available plants having soil arresting capacity will be used in the slide areas. Seeds of the hedges like Bambusa tulda etc would have to be sown in the Reservoir area. The seeding will be used in coir netting while in the periphery of slides saplings of above species will be planted.

5.5. Head Race Tunnel

A 12.35 Km long, 8.50m diameter, horse-shoe shaped head race tunnel has been proposed along the left bank of Wangchu River. The HRT will have a discharge capacity of 206.25 cumecs, with an average slope of 1:240. Four kinks have been provided in the HRT alignment so that a sufficient rock cover is available above the tunnel grade. The layout of the tunnel and the adits is given in **(Drg. No.: HRT-WHEP-DPR-GEO-014-03; Volume-IV.B).**

The HRT is initially aligned in N62°E direction for a length of 1588.35; N71^{O}E from 1588.35 to 2715.75; S55^{O}E from 2715.75to 4946.00; S43^{O}E from 4946.00 to 7330.05m; S03E from 7330.05m to 7810.25m; S60^{O}E from 7810.25m to 11107.73m and S41^{O}E from 11107.73m to 12357 (Bottom of surge shaft) with bend portions in between. The first kink

in the HRT alignment has been given to enable it to cross major drainage Zilung and its tributary at RD. 1562.45 and 2785m.

The L-section along the HRT indicates a maximum cover of ± 565m at RD 845.21m and minimum cover of 93m, 100m, 122.92m at RD's 1562.45m, 2785.00m and 4815.67m respectively above the tunnel grade. These low cover zones are the locations of topographical depressions / nalla. To facilitate the excavation of HRT, four intermediate adits have been proposed along the HRT alignment. A fifth adit is proposed at the HRT - Surge Shaft Junction. The adits have been provided with reverse gradients for maintaining self draining capacity. The lengths of the five proposed adits and their junction with the HRT are tabulated below in **Table-5.22:**

Table-5.22: Adit Lengths and their Junction with HRT.

Adit No.	Adit Length (m)	Adit Junction with HRT RD (m)
Adit 1	437.92	1811.57
Adit 2	644.95	4109.65
Adit 3	507.68	7603.91
Adit 4	283.67	12322.43

5.5.1. Geological Studies

5.5.1.a. Geological Mapping

The hill slopes spanning the proposed tunnel alignment are largely covered, densely forested and dissected by a number of cross drainages. The terrain is very rugged and is mostly inaccessible.

The geological traverses were restricted along a few foot tracks & approach communication paths and along Nalla only. The downstream half of the HRT area has been approached from Bhutanghat (on Indo - Bhutan Boarder) following Raidak river upto power house site to Piping Village and then to Baikinza Village located on the left bank of the Wangchu river. The U/s part of the HRT Area was approached starting from the right bank through old abandoned Gedu - Bhutanghat road upto Gijari slide. Thereafter, the approach is through a 10 Km long, treacherous foot track descending down slope from 1500m road head to 338m river bed of Wangchu and crossing over to the left bank by temporary ropeway for reaching HRT area passing through Thana, Sachigaithan, Baikuna and Baikinza Villages.

The 12.357 Km long HRT alignment was surveyed on 1:5000 / 10000 Scale with 5 m contour interval. This survey was utilized for surface geological mapping along the present alignment. The geological mapping was carried out by taking detailed field traverses and

picking up rock outcrops on the contour plan along with litho-logical details, structural details and other rock characteristics required for rock mass classification. As the majority of the area along the tunnel alignment is under dense vegetation cover and slope wash, the bed rock information could be gathered mainly along existing footpaths and along the local drainages. An area of about 16 Sq. Km. along the HRT alignment has been geologically mapped on 1:5000 Scale. The geological map of HRT and cross sections along HRT has been prepared and are available in **(Drg. No.: HRT-WHEP-DPR-GEO-014-03 & GEO-015-03; Volume-IVB).**

Strati-graphically the head race tunnel will pass through the rocks of Shumar Formation in the North and Buxa Group of rocks in the South with a tectonic base designated as 'Shumar Thrust' dividing the two. The detailed geological mapping indicating that quartzite and phyllitic-quartzite with thin Interbands of chlorite-mica-schist with occasional carbonaceous-phyllite belonging to Shumar Formation, while gritty feldspathic-quartzite, dolomite, quartzite, conglomerate, slate, phyllite and metabasic belong to Buxa Group will constitute the tunneling media of HRT. The Geological details as gathered in the HRT area on the surface are given below:

1) <u>Intake to Adit-1 (RD. 0.00 - 1811.57m):</u>

The rock exposed on the HRT alignment from Intake to Adit-I belong to Shumar Formation comprising of bedded quartzite, highly jointed, fractured and shear at places upto U/s arm of Zilung Nallah (RD. 1555m) and thereafter phyllitic schistose quartzite with thin interbands of carbonaceous phyllites.

The foliation plane dips 50° towards N to $N10^{O}E$ direction. The other joint sets recorded are $45^{O}/S14^{O}E$; $58\text{-}60^{O}$ $/S70^{O}\text{-}80^{O}W$ and $35^{O}\text{-}55^{O}/N40^{O}W$. Zilung Nallah, U/s branch (RD. 1555m) is a perennial nallah and is a low cover zone above the HRT with a cover of ±100m. This Nallah has been explored by a drill hole 75m deep (HRT-1).

The hole has indicated a rock cover of more than 3D above the HRT consisting of phyllitic quartzite with shears.

Figure-5.31: Massive White Quartzite of Shumar Formation exposed along the left bank of Wangchu River.

2) <u>Adit-1 to Adit-2 (RD. 1811.57to 4109.65m):</u>

The rock exposed between Adit-1 and Adit-2 is predominantly phyllitic quartzite and schistose quartzite with thin interbands of carbonaceous phyllite **(Figure: 5.32).** The foliation plane recorded starting from Adit-1 dip 50° towards $N10^{O}E$ and, near Adit-2 the foliation dips 30°-50° towards $N20^{O}W$ direction. The other joints recorded are $45^{O}/N65^{O}EL$; 40°–$70^{O}S20^{O}E$ to $S10^{O}W$; $38^{O}/S80^{O}E$; 25°-$70^{O}/S65^{O}W$ to $S70^{O}W$. In addition vertical joints striking $N60^{O}E$-$S60^{O}W$ to E-W have also been encountered. Zilung Nallah, D/s branch (RD. 2511m) is a perennial Nallah and is a low cover zone above the HRT with a cover of ±100m. This Nallah has been explored by a drill hole (HRT-2) for a depth of 75m.

Figure-5.32: Phyllitic Quartzite of Shumar Formation East of Baikuna Village.

3) Adit-2 to Adit-3 (RD. 4109.65 to 7603.91m):

The rocks exposed from Adit-2 towards Adit-3 are phyllitic quartzite and quartzite belonging to Shumar Formation and thereafter phyllitic quartzites of Buxa Formation **(Figure-5.33).** There are some overburden patches in-between. The foliation plane recorded at the surface from Adit-2 towards Adit-3 dips 30°/N20^{O}W direction; 60°/N5^{O}W and 50°/N30^{O}W direction. The other joint sets recorded are 75°-84°/S50^{O}-60°E; 35°-45°/S69^{O}-80°E; 60°/S20^{O}E-60°-70°/N25^{O}E & 70°/S62^{O}W.

Figure-5.33: Sheared Phyllitic Quartzite of Shumar Formation near Shumar Thrust.

Figure-5.34: Nallah following highly sheared & fractured phyllitic quartzite along the Shumar Thrust.

This zone has a low cover reach at Tallang Nallah (RD. ±4900m) wherein over cover of ±123m is available above the tunnel. A Techtronic Feature named Shumar Thrust separating the Shumar Formation from Buxa Formation is exposed on the surface at RD. ±7400m **(Figure-5.34) .** This feature is represented in the field by highly sheared and fractured quartzite. The affected zone of this thrust may vary from 200 to 500m.

4) Adit-3 to bottom of Surge Shaft (12357m):

No rock is exposed from Adit-3 to RD. 8833m at the surface. Between RD. 8833m to 12357m rock belonging to Thungsing Formation and Mansa Formation of Buxa Group are exposed. The rock exposed is quartzite of Thungsing formation upto RD. 11000m. The foliation joints dips 45°-55° in N50^{O}W direction. The other joints are 75°/N$22^{O}40^{O}$E; 35°/S60^{O}E; 70°/S70^{O}E. The surface profile is quite uniform and maximum cover above the HRT is in this reach. No prominent low cover zone is present in this reach except little drainage which appears to have sufficient cover above the HRT.

Figure-5.35: Massive gritty-feldspathic-quartzite of Thungsing Formation, East of Baikinza Village.

Highly disturbed rock consisting of dolomites with bands of quartzites (at river level) belonging to Manas Formation are exposed between RD. 11570 to bottom of the surge shaft. No rock exposures have been seen between RD. 10848 to 11570m in the HRT. These two rock formations are supposed to be separated by a lineament referred as Nunpani Tear Fault, which has been mapped at the river level. This feature is NE-SW trending located on NW of Piping Village and is represented by steep rock scarp, slicken sided joint surfaces, fracturing and possible displacement of dolomite and quartzite bands. When this feature is extended along the strike it appears to cut the HRT alignment

at RD. 11175m at the surface. These rocks are generally folded into first set of tight overturned regional anticline and syncline with E-W axial trace and second set of younger broad open folds with their axis trending almost in N-S direction. The dolomite of the Manas Formation occupies the core of the syncline whereas the quartzite of the Thungsing Formation occupies the core of the anticline structure. The foliation planes recorded in this reach of the HRT dips 30°-35° in N10^{O}-20E direction. The other joint sets recorded are 30°-35° / N10^{O}-20°E; 75°/S80^{O}E; 40°/N53^{O}W; N45^{O}W-S45^{O}E. Adit-4 is at RD. 12322.43m.

Figure-5.36: Rock Debris at toe of quartzite scarp near Nunpani Tear Fault.

Figure-5.37: View of Dolomite Rock of Manas Formation, South - West of Nunpani.

Two important structural discontinuities / lineaments have been picked up along the HRT during the geological mapping. These are as follows: -

a) The regional Shumar Thrust trending more or less in N65^{o}W-S65^{o}E direction with shallow hade of 30° to 40° to the North, separating the quartzite, phyllitic-quartzite rocks of the Shumar Formation from the underlying gritty feldspathic-quartzite and pebbly conglomerate bands of the Thungsing Formation of Buxa Group. This lineament will cut across the HRT alignment near NW of Baikinza village, though no distinct evidence is seen in field except intense shearing and fracturing of phyllitic - quartzite zone along its contact.

b) The tear fault near Nunpani, trending NE-SW, NW of Piping Village. This fault cuts across the HRT alignment close to the fourth bend of the HRT. The steep scarp of quartzite, slicken - sided nature of quartzite, fracturing of quartzite and possible displacement of dolomite and quartzite bands along this lineament by several hundred meters is indicative of this tear fault. No clear evidence is available on the age of movement on this fault, it conforms to similar NE - SW trending fault and fractures recorded from Land set imagery studies elsewhere beside Kaleswar Tear Fault in adjoining Torsa valley of Bhutan which are of recent age.

5.5.1.b. Exploratory Drilling

220 m drilling has been done in the HRT alignment by drilling three holes, one in HRT-Zilung Nallah U/s branch crossing (HRT-1), another hole at the HRT- d/s arm of the Zilung Nallah crossing and third hole towards the d/s end of HRT (near Nunpani), i.e. HRT-3. The summary of drill holes is given below: **Table-5.22A:**

Table-5.22A: Details of the drill holes drilled along HRT alignment.

Drill Hole No.	Location	Ground El. (m)	Coordinates	Total Depth (m)	Overburden / Rock Contact (m)	Bed Rock El./ Depth (m)
HRT-1	HRT Zilung nalla (u/s arm) crossing	550.00	**N:**51040 **E:**41580	75.00	13.90	536.10
HRT-2	HRT Zilung nalla (d/s arm) crossing	555.075	**N:**51650.051 **E:**42535.504	75.00	25.00	530.075
HRT-3	HRT Nunpani fault crossing	463.00		70.00	21.00	441.00

Figure-5.38: Photograph showing the quality of the core of HRT-1 (RD 18 - 24m).

Summarized drill hole logs of HRT-1, HRT-2 & HRT-3 are as followed:

HRT-2

Location: HRT – Zilung nala (d/s arm) crossing **Coordinates:** N: 51650.051
E: 42535.504

Elevation: 557.075 m **Total depth:** 75.0 m

Depth (m)	Elevation (m)	Overburden / Rock	Remarks
0 – 25.0	557.075 – 532.075	Overburden	Nallah deposit consisting of sub-angular to sub-rounded rock fragments mainly of white and light grey phyllitic-quartzite, quartzites and nallah silt.
25.0 – 75.0	532.075 – 482.075	Rock	Bed rock comprising of greenish-grey coloured phyllitic-quartzitic rock with quartz veins and lenses (0.5 to 1.5 cm thick) was encountered. The rock is fresh. Core recovery in bed rock ranges from 19.33% to 86.66%. RQD ranged between 0 to 9.33% in the rock. The prominent jointed, fractured, shattered and shear zones (depth wise)) encountered in the bed rock are as follows: *58.90 – 60.0 m Fractured rock (1-2 cm core pieces)* *61.20 – 61.50 m Fractured rock (1-2 cm core pieces)* *62.85 – 63.05 m Fractured rock (1-2 cm core pieces)*

HRT-3

Location: HRT – Upstream of surge shaft in nallah **Coordinates:** N:
E:

Elevation: +- 462.0 m **Total depth:** 70.0 m

Depth (m)	Elevation (m)	Overburden / Rock	Remarks
0 – 21.0	462.0 - 441.0	Overburden	Nallah deposit comprising of sub-angular to sub-rounded rock fragments mainly of phyllitic-quartzite, quartzite and

			dolomite along with nallah silt.
21.0 – 70.0	441.0 – 392.0	Rock	Bed rock comprising of light to dark grey coloured slate with two quartzitic-phyllite bands encountered between 21.0 to 34.50 m. Thereafter, quartzitic-phyllite encountered in the remaining drilled depth up to 70.0 m. The slate in general is closely jointed and shattered/fractured in nature with intermittent shear zones. The quartzitic-phyllite rock is shattered/fractured in nature with intermittent shear zones. The slate in general is fresh while the quartzitic-phyllite shows sign of staining along the joint planes. Core recovery in bed rock ranges from 53 to 98%. No RQD was recorded in the rock. The prominent jointed, fractured, shattered and shear zones (depth wise)) encountered in the bed rock are as follows: *21.0 – 28.0 m Closely jointed*/fractured rock. *28.0 – 28.50 m Shear zone.* *28.50 – 35.50 m Closely jointed*/fractured rock. *35.50 – 36.0 m Shear zone.* *36.0 – 38.50 m Shattered/fractured rock.* *38.50 – 39.0 m Shear zone.* *39.0 – 40.0 m Shattered/fractured rock.* *40.0 – 41.0 m Shear zone.* *41.0 – 42.0 m Shattered/fractured rock.* *42.0 – 42.50 m Shear zone.* *42.50 – 44.0 m Shattered/fractured rock.* *44.0 – 45.0 m Shear zone.* *45.0 – 46.0 m Shattered/fractured rock.* *48.0 – 49.50 m Shear zone.* *49.50 – 51.0 m Shattered/fractured rock.* *51.0 – 53.0 m Shear zone.* *53.0 – 54.0 m Shattered/fractured rock.*

			54.0 – 55.50 m Shear zone. *55.50 – 70.0 m Shattered/fractured rock.*

Geological log of drill hole HRT-1, HRT-2, HRT-3 are enclosed in VOL-IVA.

5.5.1.c. Rock Mechanic Tests:

Various laboratory tests were carried out on 20 No. drill core samples to obtain the physical and geo-mechanical properties. Out of 20 samples, 15 samples (Sample No. 1 to 15) were of the cores of the holes drilled at the right bank of the dam of Wangchu Reservoir Scheme. This dam site now falls along the HRT of the present scheme. The remaining 6 samples were from the cores of the drill hole HRT-1 (at the U/s arm of the Zilung Nallah).

The Physical and Geo-mechanical Properties of the drill core samples is given in **Table-5.23 (Part-1 & Part-2):**

Table-5.23 (Part-1): Physical and Geo-mechanical Properties of Rock.

Sample No.	Rock Type	Poisson Ratio	Elastic Modulus (E) (GPa)	Tensile Strength (Mpa)	UCS (MPa)		Triaxial Test	
					Dry	Wet	Cohesion (Mpa)	Angle of Internal Friction (^{0})
HRT-1*	Slate	0.23	19.45	10.08	82.81	75.93	20.24	38
HRT-2*	Slate	-	-	9.84	-	76.12	-	-
HRT-3*	Dolomite	-	6.76	65.12	-	15.12	39	
HRT-4*	Dolomite	0.23	16.67	-	-	55.35	-	-
HRT-5*	Dolomite	-	7.93	66.03	-	-	-	
HRT-6*	Quartzite	0.24	22.13	15.67	-	-	35.65	41
HRT-7*	Quartzite	-	-	-	167.92	153.95	-	-
HRT-8*	Quartzite	-	-	168.09	159.47	35.47	41	
HRT-9*	Quartzite	0.24	22.43	19.86	166.98	-	-	-
HRT-10*	Slate	0.23	19.47	13.54	64.87	-	15.37	37
HRT-11*	Slate	-	65.19	47.96				
HRT-12*	Quartzite	0.23	20.43	16.42	-	47.82	29.45	38
HRT-13*	Quartzite	-	-	16.46	94.36	-	-	
HRT-14*	Quartzite	0.23	19.98	10.67	-	79.34	-	-
HRT-15*	Quartzite	-	-	-	96.24	81.34	28.87	38
HRT-16	Quartzite	2.58	-	159.62	-	34.76	41	
HRT-17	Quartzite	0.24	21.34	17.34	-	148.56		
HRT-18	Micaceous-phyllite	0.22	11.56	6.23	39.18	14.69	7.46	38
HRT-19	Micaceous-phyllite	-	-	-	40.12	-	-	-
HRT-20	Micaceous-phyllite	11.68/0.22	2.83	5.97	-	13.95	-	-

* *Samples of drill holes done at the dam site of Reservoir Scheme (Year, 1995).*

Table-5.23 (Part-2): Physical and Geo-mechanical Properties of Rock.

Sample No.	Rock Type	Bulk Density (g/cc)	Grain Density (g/cc)	Porosity (%)	Wave Velocity (m/sec) Dry		Wave Velocity (m/sec) Wet	
					P-wave	S-wave	P-wave	S-wave
HRT-1*	Slate	2.62	2.71	1.86	-	-	5535	2816
HRT-2*	Slate	2.63	2.74	1.93	6158	3395	-	-
HRT-3*	Dolomite	2.59	2.64	2.13	-	3125	1934	1934
HRT-4*	Dolomite	-	-	-	3690	2341	3094	1925
HRT-5*	Dolomite	-	2.61	2.03	3586	2258	-	-
HRT-6*	Quartzite	2.58	2.61	0.16	4334	2721	3817	2489
HRT-7*	Quartzite	2.63	2.67	-	-	-	-	-
HRT-8*	Quartzite	2.59	2.65	0.20	-	-	3796	2376
HRT-9*	Quartzite	-	-	4504	2819	-	-	-
HRT-10*	Slate	2.68	2.78	0.11	6145	3356	5516	2713
HRT-11*	Slate	-	-	0.17	-	-	-	-
HRT-12*	Quartzite	2.66	2.63	-	-	-	-	-
HRT-13*	Quartzite	2.67	2.62	0.21	4487	2413	-	-
HRT-14*	Quartzite	2.63	2.59	-	-	3872	2367	2367
HRT-15*	Quartzite	-	-	4158	2612	3765	2017	2017
HRT-16	Quartzite	2.62	2.58	0.18	-	-	-	-
HRT-17	Quartzite	2.5	2.61	0.13	4120	2448	3821	2314
HRT-18	Micaceous - phyllite	2.52	2.79	1.75	3678	2334	3214	1989
HRT-19	Micaceous -phyllite	-	-	-	3517	2219	3345	2112
HRT-20	Micaceous -phyllite	2.68	2.83	1.83	-	-	-	-

***** *Samples of drill holes done at the dam site of Reservoir Scheme (Year, 1995).*

In addition the petrography of rock core samples collected from the drill holes drilled at the left bank of dam site of earlier reservoir scheme and from the drill holes HRT-1 were got done from IIT, Bombay. The Petrographic studies were done after preparing 0.03mm thin sections and studying them under Leica microscope under transmitted light. The Lithology arrived at the Petrographic Studies is given in **Table-5.24:**

Table-5.24 Rock Types along HRT after Petrographic Studies.

Sample No.	Rock Type	Remarks
HRT-1*	Slate	Blach coloured with Platy texture
HRT-2*	-do-	-do-
HRT-3 *	Dolomite with impurities	Dark Grey Colour Rock with carbonate layers in between
HRT-4 *	-do-	-do-
HRT-5 *	-do-	-do-
HRT-6 *	Quartzite	Light Green quartzite

HRT-7*	-do-	-do-
HRT-8 *	-do-	-do-
HRT-9 *	-do-	-do-
HRT-10 *	Slate	Black colour with slaty cleavage
HRT-11 *	-do-	-do-
HRT-12 *	Quartzite	Light green quartzite
HRT-13 *	-do-	-do-
HRT-14 *	-do-	-do-
HRT-15 *	-do-	-do-
HRT-16	-do-	-do-
HRT-17	-do-	Grey quartzite with pyrite minerals
HRT-18	Micaceous-phyllite	Dark green coloured phyllite with foliation
HRT-19	-do-	-do-
HRT-20	-do-	-do-

***** *Samples of drill holes done at the dam site of Reservoir Scheme (Year, 1995).*

The detailed report is enclosed as **Annexure-III; Volume-IVA.**

5.5.1.d.Photo-geological Studies

Photo-geological Studies of the project and surrounding area was carried out by the Photo-geology and Remote Sensing Division, Geological Survey of India, Eastern Region for Tala Hydro Electric Project and Wangchu Reservoir Scheme to access the regional set up, the lineament, joint and fracture pattern and to map the broad geo-morphological land forms. This study has been submitted as an interim report comprising of data generated mainly from the study carried out in the laboratory with the help of aerial photographs. The report has been titled “A note on photo geological study of the area around Tala Hydro Electric Project (Chukha Stage-II) and Wangchu Reservoir scheme (Chukha Stage-III), Bhutan, by S. Basu Mallick, Sr. Geologist”. The report is submitted as **Annexure-IVA; Volume-IVA.**

Field Studies were subsequently carried out by the author and the results have been submitted in the form of a report titled “Final note on photo geological study of the area around Tala Hydro Electric Project (Chukha Stage-II) and Wangchu Reservoir scheme (Chukha Stage-III), Bhutan, By S. Basu Mallick, Sr. Geologist”. The report is submitted as **Annexure-IVB; Volume-IVB.**

The major inferences made from the report are as follows:

Structure, Lineament and Fracture Planes:

Two lineaments were picked up in the studies which would be intersecting the HRT at RD ±6876m and ±11169.70m. The lineament intersecting the HRT at RD ±6876m m is aligned

in N-S direction while the lineament intersecting the HRT at RD ± 11169.70m is aligned in E-W direction.

Another fracture lineament NW of Piping trending in NE-SW direction forms a steep scarp on the quartzite. No evidence of faulting is seen along both the flanks of this lineament during the field check. This lineament is likely to cut the HRT alignment at bend 4.

The density of fractures is more in Unit No.-1 as compared to Unit No.-2. The downstream reach of the HRT beyond RD 12,400m upto the end reach of HRT is densely fractured which can pose tunneling problems.

Lithology:

The Unit No.-1 from the aerial photographs is quartzite only with minor amount of interbedded phyllite. A thick (400m) conglomerate band is seen in Unit No.-1 in the northern bank, east of the cliff on way, about 2 Km from Piping to dam site. Outcrops of dolostone, calc-silicate rock and carbonaceous-phyllite are seen in the road cuttings.

The Unit No.-2 consists mainly of quartzite and phyllite with calc-silicate rocks. The dip facets are frequently seen in Unit No.-2 which means that Unit No.-2 has greater amount of dip than Unit No.-1.

Geomorphology:

Not many geo-morphological units were seen in the aerial photographs. Three distinct levels of terraces were identified besides the present day surface.

Geotechnical Assessment:

a) HRT U/s of Shumar Thrust will comprise of Unit No.-2 which will encounter mainly quartzite and phyllite with calc-silicate rocks. HRT D/s of Shumar Thrust will comprise of Unit No.-1 which will encounter quartzite only with minor amount of interbedded phyllite, conglomerate, dolostone, calc-silicate, carbonaceous-phyllite rock.

b) Two lineaments are likely to be encountered in the HRT at RD 500m and 4300m (NeW RD), aligned in N-S direction and E-W direction, respectively.

c) A fracture lineament NW of Piping trending in NE-SW direction will be encountered in the HRT alignment near bend 4.

d) The density of fractures is more in Unit No.-1 as compared to Unit No.-2 which is likely to result in difficult tunneling conditions, particularly beyond RD 12,400m (New RD) upto the end reach of HRT.

5.5.1.e. No Geo-physical Survey was done along the HRT.

5.5.2. Geotechnical Appraisal of the Head Race Tunnel

The hill slopes spanning the proposed tunnel alignment are largely covered, densely forested and dissected by a number of cross drainages. The terrain is very rugged and is mostly inaccessible. The geological traverses were restricted along few foot tracks & approach/ communication paths and along Nalla only. The rock exposures on the steep scars could not be mapped for want of approach. In addition, due to long rainy season spell, the field work was restricted to one fair weather period of the year. Despite all the above constraints, the best possible efforts were made to collect maximum geological. This limited data available from the field was used to interpret the rock conditions at the tunnel level. The above facts need to be kept in the mind while looking at the classification & tunneling conditions. Further due to the multi folding in the area, the orientation of the foliation joints may vary at depths from what has been conceived and can affect the rock classification accordingly.

The geological mapping has revealed the following lithological units likely to be encountered during the excavation of the HRT **(Table-5.25):**

Table-5.25: Percentage and Length of Litho Units along HRT.

Rock Type	Length (m)	Percentage of HRT Length
Quartzite	8220.35	66.50 %
Phyllitic-Quartzite	3074.17	24.87 %
Dolomites, Phyllite, Slate, Carbonaceous-phyllite etc.	1063.05	8.63 %

The rocks along the HRT alignment can broadly be divided into two different types based on the stratigraphic sequence in the project area, i.e. Shumar Formation and Buxa Group of rocks. The Shumar thrust divides the two rock types. Within these two formations there are different rock types encountered. The surface data collected is depicted in the geological plan of HRT **(Drg. No.: HRT-WHEP-DPR-GEO-014-03; Volume-IVB)** & projected at the tunnel grade in the geological section **(Drg. No.: HRT-WHEP-DPR-GEO-015-03; Volume-IVB).** The stretch-wise details of the rock type to be encountered and their expected behavior along with the tentative rock class in the HRT is given below: -

5.5.2.a Intake to Adit-1 (RD 0.0 to 1811.57m):

The rock exposed from the intake to the upstream branch of Zilung Nallah (±1500m) is quartzite and thereafter, phyllitic quartzite is exposed upto Adit-1.The quartzite is massive to highly jointed with fractures and shears at places. The foliation plans dip 50° in N to $N10^{O}$ E direction and will strike almost 40° to 50° with respect to the HRT direction which will be favorable for tunneling but few other joints present in the reach will be unfavorable. The reach before Zilung Nallah is expected to have long standup time but due to

anticipated persistence of long continuity joints & fractures and minor shears, appreciable ground water flow may be possible. Last 300m reach of this stretch will be in the vicinity of Zilung Nallah which is a perennial stream. A drill hole HRT-1 has proved more than 3D rock cover above the HRT in the Nallah section comprising of quartzite / Phyllitic quartzite with shears. The 200m reach below the Nallah can have very poor tunneling conditions (with high seepage) with 100m on either side of fair to poor rock conditions. The expected tunneling conditions are given in **Table-5.26:**

Table-5.26: Expected Tunneling Condition in HRT (Most Optimum Guess) Between Intake to Adit-1.

RD (m) Approximate	Rock Type	Rock Class	Remarks
0 - 1500	Quartzite of Shumar Formation	In general Fair with some Good rock.	Less favorable foliation planes
1500 - 1600	Quartzite of Shumar Formation	Fair to Poor (Mostly Poor)	Nallah Zone (U/s arm of Zilung), ground water inflow and Less favorable foliation planes. Shear Zone (bedding) above crown
1600 – 1811.57	Phyllitic-quartzite of Shumar Formation	Mostly Very Poor with few Poor reaches	Nallah Zone (U/s arm of Zilung), low rock cover (100 m), ground water inflow, shear Zone (DH- HRT-1), Adit-1 junction (RD 1756.06m).

5.5.2.b Adit-1 to Adit-2 (RD 1811.57 to 4109.65m):

The rock exposed between Adit-1 to Adit-2 is predominately phyllitic quartzites and schistose quartzite with thin bands of carbonaceous phyllites. The foliation planes have dip of 50° in $N10^{O}E$ direction in the initial reaches and dip of 30°-50° /$N20^{O}W$ direction near Adit-2. The strike of the foliation planes with respect to HRT alignment will be favorable in the initial and last reaches with in-between reaches of unfavorable foliation. The in-between reach with unfavorable foliation have more jointing as compared to other two reaches which have three to four joint sets.

The first 100m reach will be affected by the Zilung Nallahh upstream arm and will have fair to poor rock tunneling conditions.

The next ± 700m and last ±700m length of this reach(RD. 1900-4100m) consists of phyllitic quartzite with favorable orientation of foliation and will offer Fair tunneling media with some Good reaches. The area with more carbonaceous phyllites may need immediate support. The in-between ±800m long reach have unfavorable rock conditions and a Nallahh zone (D/s arm of Zuling Nallahh). 200m zone below Zuling Nallahh will offer mostly very poor tunneling conditions, whereas 200m length U/s of nallahh & 500m length

D/s of nallahh will have Fair to Poor conditions owing to unfavorable orientation of foliation. The tunneling conditions are given in the table below **(Table-5.27):**

Table-5.27: Expected Tunneling Condition in HRT (Most Optimum Guess) Between Adit-1 to Adit-2.

RD (m) Approximate	Rock Type	Rock Class	Remarks
1800 - 1900	Phyllitic-quartzite of Shumar Formation	Fair to Poor (Mostly Poor)	Nallah Zone, ground water inflow
1900 - 2550	Phyllitic-quartzite of Shumar Formation	Fair with some Good rock.	Less favorable orientation of foliation planes. Start of bend-1 in HRT (RD 2511.78 m)
2550 - 2700	Phyllitic-quartzite of Shumar Formation	Fair to Poor (Dominantly poor).	Unfavorable orientation of foliation planes, bend in HRT. End of bend-1 in HRT (RD 2692.18 m)
2700 - 2950	Phyllitic-quartzite of Shumar Formation	Mostly Very Poor.	Nallah Zone (D/s arm of Zilung), low rock cover (100 m), ground water inflow, possible shear Zone (bedding).
2950 – 3450	Phyllitic-quartzite of Shumar Formation	Fair to Poor (Mostly Poor).	Unfavorable orientation of foliation planes
3450 – 4109.65	Phyllitic-quartzite of Shumar Formation	Fair with some Good reaches.	Favorable orientation of foliation planes. Adit-2 Junction RD. 4109.65m

5.5.2.c Adit-2 to Adit-3 (RD 4109.65m - 7603.91m):

Rock expected in this reach is phyllitic quartzite in the initial reach followed by quartzite and then again phyllitic quartzite. The foliation planes vary from 30°/N10^{O}E to 60°/N5^{O}W to 50°/N30^{O}W from Adit-2 towards Adit-3.

From point of view of tunneling conditions this reach can be dividing into two reaches, first 2400m reach comprising of phyllitic quartzite & quartzite with a Nallahh zone and, last 1200m reach encompassing Shumar Thrust and its affected zone.

The first reach of 2300m (except for 200m of Nallahh Zone) will lie in phyllitic quartzites(with carbonaceous phyllites interbands) and, well bedded and jointed quartzite(with fracture and minor shears) and will offer Fair tunneling media with some Good reaches. Very few Poor Rock zones are expected in this zone. The 200m zone below Tallung Nallahh is a low cover zone and may pose difficult tunneling conditions with considerable seepage.

The second reach of 1200m represents a zone encompassing Shumar Thrust which separates the rocks of Shumar formation from Buxa Group. The Shumar thrust is reported to have a very low hade, thereby expected to affect quite a long reach of HRT. Out of this 1200m zone, 550m length is expected to cross the thrust zone consisting of highly sheared and fractured quartzite. This reach appears to be tectonically more disturbed and show comparability more shearing and weathering. Very poor rock conditions with limited standup time requiring immediate support is anticipated. Ground water and squeezing/flowing conditions are not ruled out. Further the D/s and u/s reaches of this Thrust (200 & 400m respectively) may be affected by the thrust and may offer mostly poor tunneling conditions. The tunneling conditions are given in **Table-5.28:**

Table-5.28 : Expected Tunneling Condition in HRT (Most Optimum Guess). Between Adit-2 to Adit-3.

RD (m) Approximate	Rock Type	Rock Class	Remarks
4109.65–4750	Phyllitic-quartzite of Shumar Formation	Fair with some Good reaches.	Favorable orientation of foliation planes.
4750 – 4950	Phyllitic-quartzite of Shumar Formation	Very Poor	Nallah Zone (Talung), low rock cover (100 m), ground water inflow, possible shear Zone (bedding). Bend-2 in HRT (RD 4914.95 to 4928.58m)
4950 - 6400	Quartzite of Shumar Formation	Fair with some Good reaches.	Favorable foliation planes
6400 - 6650	Quartzite of Shumar Formation	Fair to Poor (Mostly Poor).	Possible effect of Shumar thrust which has a low hade.
6650 - 7200	Quartzites of Shumar in the u/s and quartzites of Buxa in the D/s	Very Poor	Shumar thrust (strike N65^{o}W-S65^{o}E) with low hade (30 to 40°), water inflow
7200- 7603.91	Quartzites of Buxa Group	Fair to Poor (Mostly Poor).	Possible effect of Shumar thrust which will be above the crown. Adit-3 junction (RD 7603.91 m). Bend-3 in HRT (RD 7281.64 to 7376.92 m)

5.5.2.d Adit-3 to bottom of Surge Shaft; 12357.55m:

This reach can be divided into two:

First reach upto ± 10550m RD. has mostly quartzite rock with foliation joints dipping 45˚-55˚ towards N50˚W direction. In addition three other joint sets are present. Although foliation trend is favorable, other joint sets may pose some problem during tunneling. By

and large this reach is expected to offer good to fair tunneling media, except for some low cover zone which can be problematic at times.

Table-5.29: Expected Tunneling Condition in HRT (Most Optimum Guess). Between Adit-3 to Adit-4.

RD (m) Approximate	Rock Type	Rock Class	Remarks
7600 - 10550	Quartzites of Buxa Group	Fair to Good	Favorable orientation of foliation planes.

In the second reach the first 650m of HRT will pass through quartzite rocks of Thungsing Formation encompassing an lineament called Nunpani Fault, whereas the other 1100m reach will essentially consists of phyllitic quartzite, phyllite, dolomite, slate and carb. phyllites belonging to Manas Formation. The foliation plane dips 30-35° in N10°-20° E direction, besides three other joint sets. Orientation of the foliation is quite unfavorable in this reach. Out of the 650m initial reach, first 500m will be an affected zone of the tear fault and, with unfavorable foliation, may pose mostly poor tunneling conditions. The reach of 150m of the tear fault will offer very poor tunneling conditions. The last 1100m of the HRT will pass through folded and refolded sequence of rock. With unfavorable foliation this reach (1100m Length) would offer poor tunneling conditions with some reaches having fair & very poor conditions. Adit -4 is at RD. 12322.43m.

Table-5.30: Expected Tunneling Condition in HRT (Most Optimum Guess). Between 10550 to bottom of the Surge Shaft.

RD (m) Approximate	Rock Type	Rock Class	Remarks
10550 – 11000	Quartzites of Buxa Group	Fair to Poor (Mostly Poor).	Possible effect of Nunpani Tear Fault
11000 - 11250	Quartzites of Buxa in the u/s and dolomite, slate, carbonaceous-phyllite in the D/s (Manas formation)	Very Poor.	Nunpani Tear Fault with vertical hade. Intersecting HRT at RD 11170 m.
11250 -12357.55	Phyllitic-quartzite, phyllite, dolomite, slate, carbonaceous-phyllite (Manas formation)	Mostly Poor (With Occasional Fair and very poor reaches)	Fracture lineaments, heterogeneous rock and unfavorable foliation planes.

Ground water and squeezing / flowing condition are not ruled out in a cumulative length of 1900 m. The relatively softer bands of phyllite, carbonaceous phyllite and slate are expected to have poor arch action leading to roof collapses. In weathered and saturated conditions, these bands will tend to flow in. The tunneling will be still more hazardous where carbonaceous phyllite trend along tunnel alignment or occur at its crown. Difficult tunneling conditions are anticipated in this reach with limited stand up time, which will be

requiring immediate support. Tunneling in Shumar Thrust zone & Nunpani tear fault may pose challenges.

There are 7 to 8 main cross drainages cutting across the HRT alignment. The fractured nature of the rock mass and deep weathering condition may facilitate deep permeation of annual rainfall experienced by the area, thereby, creating pockets of ground water. During tunneling, many such ground water pockets are expected particularly along major structural weak zones of long continuity, comparatively more in harder rocks like quartzite.

The anticipated rock mass classification along the HRT is given in **Table-5.31:**

Table-5.31: Rock Mass Classifications along HRT.

Class	Length	Percentage
II	1654.64	13.4 ± 20%
III	5979.99	48.4% ± 20%
IV	2840.92	22.98 % ± 20%
V	1882.00	15.23 % ± 20%
Total:	**12357.55**	**100 %**

The above prediction of rocks encountering the HRT is a tentative estimate worked out on the basis of surface geological studies and very limited sub-surface information. It gives only a general idea of the overall rock condition but may be different during actual tunneling.

The geological section along four nos. proposed construction adits are enclosed in VOL-IVB.

5.6. Power House Complex

Power House Complex comprises of 148.50m deep, 20m dia circular surge shaft with top El. 559m; 2 No. 4.8m dia 852.5m long circular pressure shaft and a surface power house measuring 124m x 41.5m x 44.5m on the left bank of the Wangchu River near its confluence with Piping Nallah.

The Power House Site near confluence of Wangchu & Pipingchu is approached from Phuentsholing via Alipurduar through NH-31C which links Rajabhatkhawa with Bhutan Ghat on Indo – Bhutan border. From Bhutan Ghat an 8 Km long trekking along upstream Raidak River leads Piping site of geological investigation.

The geology around Power House and Surge shaft sites from part of a folded metasedimentary rocks of Baxa Group, Broadly, the rocks of Baxa Group are tectonically sandwitched dominantly between the Shumar Formation in the north & Siwalik Group in the south. The lower contact with the Siwalik Group is defined by the MBT while the upper contact is marked by the Shumar thrust.

The Baxa Group in general include white grey quartzite, green, purple, grey siltstone, phyllite, phyllitic quartzite, pink quartzite and dolomite with minor carbonaceous phyllite & quartzite bands. The regional strike of the formation is E-W with northerly dips of 25^0 to 60^0.

5.6.1. Geological Studies at Power House Complex

5.6.1.a.Geological Mapping

An area of about 1700 m (l) x 500 m (w) i.e. 0.85 Sq. Km. have been mapped on 1:1000 Scale to classify the different rock types & their geological set up along the NNW-SSE trending ridge between Wangchu and Piping Chu confluence near Piping village where location of Surgeshaft, pressure tunnel and power house are earmarked.

The following sequence of Buxa Group rocks have been delineated around the Power House area while mapping from south to north.

An outcrop of grayish, fine grained bedded quartzite hillock is exposed on the left bank of Piping river at its confluence with Wangchu. The quartzite is intercalated with thin phyllite bands and permeated with thin quartz veins in criss–cross fashion. The general foliation trend observed is E-W / 25^0 N.

These quartzites are overlain by rhythmic variegated shale / phyllites in alternating maroon – purple colors in the lower part which passes upward to grey – green with minor purple colors. The shale / phyllite is often thinly (0.3 cm to 15 cm) interstratified with siltstone / fine grained quartzite of the same colour and are continuously exposed on its either banks at the river bed level along upstream Piping river near rope crossing bridge. The foliation in general trend $N70^0$ w – $S70^0$ E with northerly 50^0 to 65^0 dips. A minor fold shows plunging at 55^0 in N 20^0 E direction.

These shale/phyllite sequences are overlain by a thick sequence of grey, greenish grey, quartzite with phyllitic quartzite interbands exposed upstream on either banks of the river bed level of the Piping river from near temple location.

These phyllitic quartzite bands are succeeded by buff white quartzite which is mostly covered under thick debris / talus and hill wash cover along the foot hill slopes of the NNW-SSE trending ridge. Few outcrops of this quartzite band have been delineated along the foot paths at contour elevation of 290m, 325m & 375m. The strike varies from $N70^0$E – $S70^0$W/35^0 N to $N70^0$ W – $S70^0$E / 30^0N. A mega fold in quartzite at contour elevation of 375 m along foot path shows recumbent nature of the fold.

The buff white quartzite are overlain by a thin (3m to 5 m) persistent band of sheared carbonaceous phyllite near 400 m contour elevation on foot path which in turn is

succeeded by a thick sequence of dark grey massively bedded dolomitic rock, which in general strikes N70^{0}W – S70^{0}E with shallow northerly dips of 35^0. The dolomite near contour elevation of 480m is found to be highly fractured and sheared and crushed to white powdery material. The dolomite occupies the ridge beyond height of 650m and continues further upward towards NNW along the ridge.

Mass wasting features and terraces are the major landforms in the area. Mass wasting features have been mapped on the southern foot hill slopes of the NNW – SSE trending ridge and are mainly controlled by joints. These include rock slides, hill wash and debris, the slided materials have mostly accumulated near toe of the slopes and constitutes mainly of phyllitic boulders in the lower reaches and quartzite in the middle reach upto elevation 290m, where the first outcrop of quartzite is observed. The steep nala courses also carry number of older slided material from their head reach and stacked over the hill slopes.

River terraces are common and extensively mapped on the left bank of Wangchu and right bank of Piping Chu confluence. They consist of boulders and cobble size material less of gravel. Sandy layer is confined to the top 1.0m to 1.5m gravelly layer. T_0 terrace is confined within the channel section and present day flood level and occur at approximately river level. It has been mapped on left bank of Wangchu as linear strip sand which is between T_1 terrace and present day river borne material.

T_1 terrace occurs at about 1.5m to 2.0m above T_0 terrace level, and has extensive deposit, most of the maize field and hutments are located on this terrace. It is quite long, wide and fiat and mapped all along the left bank of Wangchu.

T_2 terrace occur at about 3.0m above T_1 terrace level and is the next extensively developed terrace close to the foot hill base in the area, the power house is located partially on this terrace.

T_3 terrace is the older one located mostly eastward adjoining the power house site on higher level of the right bank of Piping Chu to base of hill. It is quite long and wide extends upstream along right bank of Piping Chu. A partially developed T_3 terrace has also been mapped on westward side adjoining T_2 terrace.

5.6.1.b. Exploratory Drilling

Power House Complex has been explored by 16 nos. of drill holes; including 1 drill hole along the surge shaft (SS-1), 4 drill holes along the penstock alignment; 10 drill holes at the power house site and one in drill hole at the Tail Race Channel; totaling to 913.49 m.

Out of these 16 drill holes; 11 holes have been drilled by SJVN Limited during the Year 2010-12, whereas 5 drill holes were drilled by M/s WAPCOS Limited in the Year 1995. The details of the drilling are given in **Table-5.32 & 5.33:**

Table-5.32: Summary of drill holes drilled at Power House Complex by **SJVN Limited (2010-2013).**

Structure	No. of Holes	Drill Hole number	Depth (m)
Surge Shaft	1	SS-1	183.50
Penstock	3	PS-2 to PS-4	205.00
Power House	6	PH-5 to PH-10	260.00
Tail race Channel	1	TRC-1	30.00
-	**11Nos.**	**Total Drilling:**	**678.50**

Table-5.33: Summary of drill holes drilled at PH Site by M/s WAPCOS (1995).

Structure	No of Holes	Drill Hole Number.	Depth (m)
Penstock	1	PS-1	50.25
Power House	4	PH-1 to PH-4	184.74
-	**5 Nos.**	**Total Drilling**	**234.99**

Details of the drill holes at the Power House Complex are given in Table-5.34.

Table-5.34: Details of drill holes drilled at Power House Complex.

Drill Hole No.	Location	Ground El. (m)	Coordinates	Total Depth (m)	Overburden / Rock Contact (m)	Bed Rock El./ Depth (m)
PH-1*	Along the long axis of Power House.	179.041	N:44715 E:49835	39.92	14.47	164.57
PH-2*	Along the long axis of Power House.	178.529	N:44772 E:49925	39.50	12.50	166.03
PH-3*	Along the short axis of Power House (Valley Side).	178.445	N:44761 E:50005	39.42	16.16	162.285
PH-4*	Along the short axis of power house (Hill Side).	187.83	N:44722 E:49935	65.90	21.65	166.18
PH-5	Centre of Power House.	± 179.0	N:44702.833 E:49926.654	50.0	12.0	167.0
PH-6	100m U/s of PH-5.	±179.82	N:44677.392 E:49829.944	50.0	19.5	160.32
PH-7	Longer Axis of Power House, d/s side	179	N:44699.5002 E:49949.2785	40.0	13.0	166.0
PH-8	Shorter axis of power house, valley side	179	N:44683.280 E:49904.858	40.0	16.75	162.25
PH-9	Shorter axis of power house, hill side	179	N:44715.28 E:49904.6999	40.0	15.50	163.50

PH-10	Longer axis of power house, u/s side	179	N:44699.0632 E:49860.9046	40.0	13.0	166.0
PS-1*	Penstock Slope.	±430.15	N: 45063 E: 49865	50.25	0 .0	430.15
PS-2	Penstock Slope.	±214.71	N:44804.353 E:49900.015	75.0	24.0	190.71
PS-3	Penstock Slope.	±372.41	N:45005.681 E:49847.121	50.0	2.0	370.41
PS-4	Penstock Slope.	480.0	N:45185.455 E: 49817.401	80.0	1.5	478.50
TRC-1	Along Tail Race Channel.	175.03	N: 49947 E: 44630	30.0	12.0	163.03
SS-1	Surge Shaft.	± 560.0	N:45339.176 E:49873.960	183.50	1.50	577.00

* *Drill Holes done by M/s WAPCOS Limited in the Year, 1995.*

5.6.1.c. Rock Mechanic Tests & Petrography

Laboratory Tests for estimation of strength of rocks and physical properties of rocks on 22 numbers of core samples from the power house area were got done from IIT, Bombay. The results are given in **Table-35 (Part-1 & Part-2):**

Table-5.35 (Part-1): Physical and geo-mechanical properties of rock

Sample No.	Rock Type	Poisson Ratio	Elastic Modulus (E) (GPa)	Tensile Strength (MPa)	UCS (MPa)		Triaxial Test	
					Dry	Wet	Cohesion (Mpa)	Angle of Internal Friction(^{0})
PH-2	Quartzite	0.23	21.23	19.64	159.05	151.02		
PH-3	Quartzite	2.65	17.58	157.98	148.56	33.99	39	
PH-4	Phyllite	0.22	12.22	5.96	42.96	28.94	7.89	39
PH-5	Quartzite	0.23	22.46	18.78	158.96	149.96	-	-
PH-6	Quartzite	0.24	22.45	19.02	161.58	150.97	34.35	40
PH-7	Quartzite	-	-	-	-	34.67	40	
PH-8	Dolomite	0.23	16.54	6.65	62.89	-	-	-
PH-9	Dolomite	-	-	-	26.67	16.25	39	
PH-10	Dolomite	-	8.27	64.67	-	-	-	
PH-11	Dolomite	0.23	17.12	12.4	80.78	67.15	18.45	40

Table-5.35 (Part-2): Physical and geo-mechanical properties of rock

Sample No.	Rock Type	Bulk Density (g/cc)	Grain Density (g/cc)	Por-osity (%)	Ultrasonic Wave Velocity (m/sec) Dry		Ultrasonic Wave Velocity (m/sec) Wet	
					P-wave	S-wave	P-wave	S-wave
PH-1	Phyllite	2.78	2.70	1.76	3346	2412	2596	1623
PH-2	Quartzite	2.64	2.69	0.16	-	-	-	-
PH-3	Quartzite	2.62	2.65	0.15	4782	2812	4245	2567

PH-4	Phyllite	2.79	2.69	1.98	3426	2317	2613	1734
PH-5	Quartzite	2.65	2.64	0.17	4723	2893	4213	2492
PH-6	Quartzite	2.66	2.63	0.21	-	-	4014	2315
PH-7	Quartzite	2.65	2.62	0.12	-	-	-	
PH-8	Dolomite	2.72	2.78	-	3527	2245	-	
PH-9	Dolomite	-	-	2.12	-	-	3012	
PH-10	Dolomite	2.70	2.66	1.92	4241	2617	3412	
PH-11	Dolomite	-	-	-	-	-	-	

In addition the petrography of rock core samples collected from the drill holes drilled at the dam site were got done from IIT Bombay. The Petrographic studies were done after preparing 0.03 mm thin sections and studying them under Leica microscope under transmitted light. The Lithology arrived at after Petrographic Studies is given in **Table-5.36:**

Table-5.36: Interpreted Rock Type at the Power House Site after Petrography.

Sample No.	Rock Type	Remarks
PH-1	Phyllite	Greenish, foliated
PH-2	Quartzite	Light grey in colour
PH-3	Quartzite	Light grey in colour
PH-4	Phyllite	Greenish, foliated
PH-5	Quartzite	-
PH-6	Quartzite	-
PH-7	Quartzite	-
PH-8	Dolomite with impurities	Dark grey colour rock with carbonate layers in between
PH-9	Dolomite with impurities	Dark grey colour rock with carbonate layers in between
PH-10	Dolomite with impurities	Dark grey colour rock with carbonate layers in between
PH-11	Dolomite with impurities	Dark grey colour rock with carbonate layers in between

5.6.1.d. Geo-physical Survey (Seismic Refraction Survey)

Refraction Seismic survey was got conducted at the Power House Site (3 lines) and Tail Race Channel Alignment (1 line) on the left bank of Wangchu river from AIMIL, New Delhi. Total Station Survey team of SJVN Limited marked the seismic lines on the ground provided with pegs at every 5m interval. A total of 700m of Seismic Survey was done.

The detailed result of the field studies and conclusions drawn are given in the report which is enclosed as **(Annexure-IV; Volume-IVA).**

5.6.2. Geo-technical Appraisal of Civil Structures in Power House Complex

5.6.2.a. Surge Shaft

Geology:

Geological Mapping of 148.50m deep, 20 m diameter surge shaft has been carried out on 1:1000 scale. The site for the surge shaft is located at an El. 580 m where the slopes are 35° to 45°. Surface geological mapping have revealed that the area around surge shaft is

covered with overburden comprising blocks of dolomite underlain by jointed dolomite striking N12°W-S12°E and dipping at 42° towards N78°E. In general, the dolomites at the surface are highly jointed and fractured and appear like stacked blocky mass liable to easy crumbing. The bedding planes strike swings between N60°W- S60°E to N50°E-S50°W and dip at 45°/N 30°E to 25°/N 70°W indicating that the rocks are intricately folded close to surge shaft location. The prominent sets of joints recorded in the area are as below: **Table-5.37:**

Table-5.37: Orientation of Joints in Surge Shaft and Penstock Area.

Joint Set	Strike	Dip Amount & Dip Direction	Characteristic of joints
I	N63°W-S63°E	32°/N27°E	Smooth, bedding shear > 5 m
II	N58°W-S58°E	43°/S32°W	Smooth, valley ward dipping. Slumping along this joint has been observed
III	N20°W-S20°E	38°/N70°E	Smooth undulating, long continuity > 20 m
IV	N10°E-S10°W	60°/S80°E	Valley ward dipping joint
V	N80°W-S80°E	58°/S10°W	Rough, undulating, continuity >10 m
VI	N20°W-S20°E	50o/S70°W	Valley ward dipping joint
VII	N65°E-S65°W	54°/N25°W	Rough

One drill hole (SS-1) located in the center of the surge shaft at El. 580 m has been drilled for a length of 183.50 m, to evaluate the rock conditions to be encountered in the surge shaft **(Drg. No.: PH-WHEP-DPR-GEO-016-01; Volume-VB).** Drill hole has encountered overburden of 1.5 m of pit material followed by grey colored shattered / fractured, sheared and jointed dolomite with calcite along the entire length of the hole. Geological log of drill hole SS-1 is enclosed in Volume-VA.

The summarized log of the drill hole SS-1 is as follows:

Location: Surge shaft **Coordinates:** N: 45329.176 E: 49873.960

Elevation: +- 580.0 m **Total depth:** 183.50 m

Depth (m)	Elevation (m)	Overburden / Rock	Remarks
0 – 1.5	580.0 – 578.50	Overburden	Angular rock fragments.
1.50 – 183.50	578.50 – 396.50	Bedrock	Bed rock comprising of grey coloured dolomite with white calcite was encountered from 1.50 m (El. 578.50 m) down to the entire drilled depth of 183.50 m (El. 396.50 m). The rock is mostly fresh with slight staining along some joint surfaces. Core recovery in bed rock ranges from 26.66% to 90%.

			RQD ranges from 0% to 28%. The prominent jointed, fractured, shattered and shear zones (depth wise)) encountered in the bed rock are as follows: *1.5 – 10.0 m: Shear zone (washings only)* *10.0 – 10.50 m: Fractured/shattered rock (1 – 3 cm)* *10.50 – 25.50 m: Shear zone (washings only)* *25.50 – 29.85 m: Fractured/shattered rock (1–5 cm)* *29.85 – 40.35 m: Mixed zone of moderately to closely jointed rock with fractured and shattered reaches.* *40.35 – 46.0 m: Shear zone (crushed rock)* *46.0 – 51.50 m: Mostly fractured and shattered rock (1 – 5 cm) with a jointed reach between 46.90 to 47.35 m depth.* *51.50 – 54.0 m: Shear zone (washings only)* *54.0 – 67.0 m: Mostly fractured and shattered rock (1 – 5 cm) with some moderately jointed reaches.* *74.0 – 76.0 m: Mostly fractured/shattered and closely jointed rock (2 – 7 cm).* *76.0 – 92.50 m: Shear zone (crushed rock)* *92.50 – 96.40 m: Fractured/shattered rock (< 1 – 8 cm)* *99.0 – 104.0 m: Fractured/shattered rock (1 – 4 cm mostly)* *105.45 – 112.0 m: Fractured and shattered rock (1 – 7 cm)* *112.0 – 120.0* *120.0 - 138.50 m: Fractured and shattered rock (1 – 4 cm) with few moderately jointed reaches.* *138.50 – 143.0 m: Shear zone (crushed rock)* *143.25 – 165.0 m: Fractured and shattered rock (< 1 – 5 cm) with few jointed reaches.* *165.0 – 170.0 m: Shear zone (crushed rock)* *170.0 – 171.50 m: Fractured and shattered rock (1 – 5 cm)* *171.50 – 173.0 m: Shear zone (crushed rock)* *173.0 – 179.0 m: Mixed zone of moderately jointed rock with fractured and shattered reaches.* *179.0 – 180.50 m: Shear zone (crushed rock)* *180.50 – 183.50 m: Fractured and shattered rock (1 – 5 cm)*

Geotechnical Appraisal

The surge shaft hill will have to be cut down from El. 616.38 m to the surge shaft top level El. 559 m. This 57.38 m of hill slope will lie in jointed and fractured dolomites and will require concurrent support during excavation. The surge shaft from its top 559 m will have 2-D cover and beyond El. 547 m more than 3-D cover. The entire surge shaft would lie in highly jointed and fractured dolomite bands with occasional bedding shears of 1.5 to 16.5 m thickness. The intersections of various joint sets will results in wedge formation which will have a tendency to fall during the excavation of the surge shaft. In addition failure along few joints cannot be ruled out. Therefore, regular support is required during the excavation. A geological section from Surge Shaft to Tail Race Channel is enclosed as **Drg. No.: PH-WHEP-DPR-GEO-017-01; Volume-VB.**

Based on the drill hole data the surge shaft is expected to be excavated 10 to 20% in good rock mass, 35 to 45% in fair rock mass and 35 to 55% in poor to very poor rock mass.

5.6.2.b. Penstock Slopes

Geology

The project envisaged 2 Nos., 4.8m dia, 852m long circular pressure shafts, each bifurcating into 2 Nos., 3.3m dia, 44.80m long to feed four units. The penstock slope has been geologically mapped on 1:1000 Scale. The penstock slopes are 35° to 45° and are covered with loose slope wash materials consisting mainly of quartzitic phyllite/quartzite boulders in the lower reaches and quartzite and dolomite boulders in the middle reaches upto an El 305m. Between El. 305 and El. 400m the slopes expose purple and white, highly fractured, jointed and blocky quartzite. In general, the rock is available below a shallow cover (2 to 3m) of the talus material dislodged from the parent rock mass. Above elevation 400m the ridge is occupied by bedded and fractured dolomite and dolomite quartzite Interbands up to elevation 810m **(Drg. No.: PH-WHEP-DPR-GEO-016-01; Volume-IV.B).**

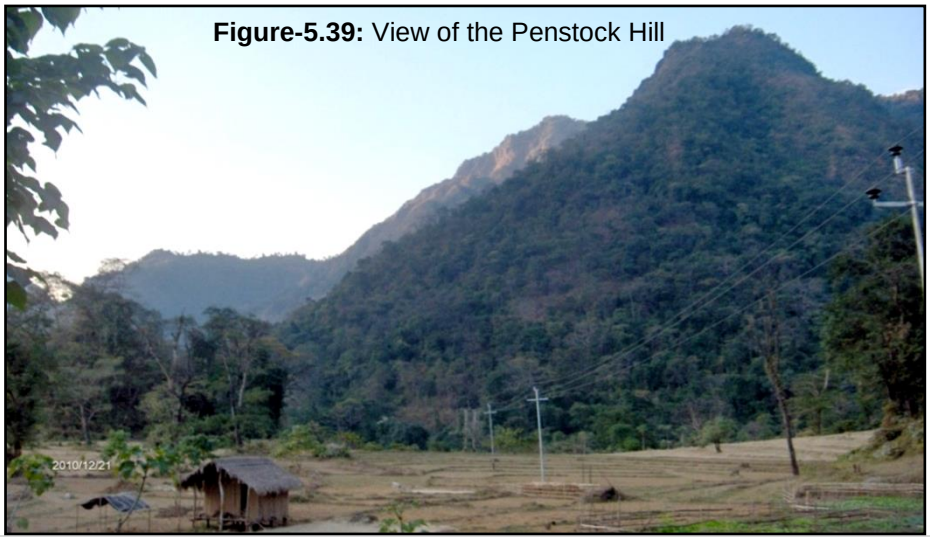


Figure-5.39: View of the Penstock Hill

The presence of 3 - 4 joint sets **(Refer Table No.-5.37)** has rendered the rock, exposed along penstock ridge, very blocky in the top 5 to 7m thick zone running parallel to the slope profile. The most significant joints as far as the slope stability are concerned are 32°/N27°E (smooth, bedding shear > 5 m); 58°/S10°W (rough undulating, continuity >10 m); 50°/S70°W (valley dipping joint)

The penstock slopes have been explored by four drill holes, i.e. PS-1* (drilled earlier by WAPCOS Ltd. in Year, 1993), PS-2, PS-3 and PS-4 (present drilling by SJVN Ltd.) for a total length of 255.25m for studying the nature of the rock. The detailed drill logs are attached as Appendix 11 to 13, Vol-IVA. The purpose of drill hole PS-1* was to study the contact of dolomite-slate contact which is sheared. The drilling indicates that the penstock slope has a shallow talus cover above elevation 355.0 m. The drill hole PS-1 has proved sheared and shattered zone from 32.50 to 50.25 m depth. The rock mass encountered in the remaining three drill holes is mainly fractured and shattered rock, traversed by several shears ranging in thickness from 15 cm to 18 m. The poor core recovery in the drill holes can be partly attributed to the sheared and shattered nature of the rock and partly due to the location of the drill hole in disturbed zone. No RQD was recorded in the drill holes.

Table-5.38: Details of Geology along drill holes at the Penstock Alignment.

Drill Hole No.	Ground Elevation (m)	Overburden Depth (m)	Bedrock Elevation (m)	Rock type
PS-1*	430.150	Nil	430.150	Shattered and fractured dolomite and Sheared slate/carbonaceous phyllite
PS-2	214.71	24.71m	190.0	Dark grey to green coloured, sheared carbonaceous phyllite.
PS-3	372.41	2.41	370.0	Light grey to white coloured, shattered, fractured and at times sheared quartzite.
PS-4	480.0	1.5	478.5	Greenish grey coloured, shattered, fractured and at times sheared dolomite.

The summarized logs of the drill holes drilled along the penstock alignment slope are as follows:

PS-1

Location: Along Penstock Alignment. **Coordinates:** **N:** 45063 **E:** 49865

Ground El.: 430.15m **Total Depth:** 50.25m

Agency M/s WAPCOS Ltd.

Depth (m)	Elevation (m)	Overburden /Rock	Remarks
0 to 50.25	430.15	Bed Rock	Bed rock comprising of shattered and fractured dolomite (1-2 cm pieces) encountered between 0 to 37.0m depth. Thereafter sheared slate/carbonaceous phyllite (1-2cm pieces) was encountered. No RQD was recorded in the entire drilled depth in rock.

PS-2

Location: Along Penstock Alignment. **Coordinates:** **N:** 44804.353 **E:** 49900.015

Ground El.: 214.71m **Total Depth:** 75.0m

Agency SJVN Limited

Depth (m)	Elevation (m)	Overburden /Rock	Remarks
0 to 24.0	214.71 to 190.71	Overburden	Talus/slope debris consisting of angular rock fragments, mainly of quartzite and some phyllite pieces were encountered in this reach.
24.0 to 75.0	190.71 to 139.71	Bed rock	Bed rock comprising of dark grey to greenish grey coloured carbonaceous phyllite was encountered. The rock is mostly sheared in nature with some fracture zones. No sign of weathering was observed in the rock. No RQD was recorded in the entire drilled depth in rock. The nature of the bed rock recorded with depth is as follows: 24.0 – 37.50 m Shear zone (washings only) 37.50 – 67.2 m Sheared rock (crushed rock & clay gouge) 67.2 – 69.2 m Sheared & fractured rock (crushed rock only) 69.2 – 71.0 m Fractured, jointed & sheared rock (crushed rock only) 71.0 – 75.0 m Sheared rock (clay gouge only)

Figure-5.40: Photograph showing the quality of the core of PS-2 (RD 46.5 - 55.5).

PS-3

Location: Along Penstock Alignment. **Coordinates:** **N:** 45005.681 **E:** 49847.121

Ground El.: 372.41 **Total Depth:** 50m

Agency SJVN Limited

Depth (m)	Elevation (m)	Overburden / Rock	Remarks
0 to 2.0	372.41 to 370.41	Overburden	Soil

2.0 to 50.0	370.41 to 322.41	Bed rock	Bed rock comprising of light grey to white coloured quartzite encountered. The rock is mostly fractured, shattered and sheared. The core pieces recovered in rock are mostly < 7 cm in length. The shears have been interpreted on the basis of the washings recovered. Staining and slight signs of weathering noticed in rock. Core recovery in rock ranges between 6 to 56%. No RQD was recorded in the entire drilled depth in rock. The nature of the bed rock recorded with depth is as follows: 2.0 – 2.3 m Shattered and fractured rock (<7 cm pieces of rock) 2.3 – 7.5 m Shear zone (washings) 7.5 – 9.0 m Shattered, fractured (< 7 cm pieces of rock) and sheared rock (washings) 9.0 -10.5 m Shattered and fractured rock (< 7 cm pieces of rock) 10.5 – 12.0 m Shattered, fractured (< 5 cm pieces of rock) and sheared rock (washings) 12.0 – 13.5 m Shear zone (washings) 13.5 – 15.0 m Shattered, fractured (< 6 cm pieces of rock) and sheared rock (washings) 15.0 -16.5 m Shear zone (washings) 16.5 – 19.5 m Shattered and fractured rock (< 6 cm pieces of rock) 19.5 – 22.5 m Shattered, fractured (< 5 cm pieces of rock) and sheared rock (washings) 22.5 – 24.0 m Shattered and fractured rock (< 5 cm pieces of rock) 24.0 -24.5 m Jointed rock 24.5 – 25.5 m Shattered, fractured (< 4 cm pieces of rock) and sheared rock (washings) 25.5 – 27.0 m Shattered and fractured rock (<5 cm pieces of rock) 27.0 – 30.0 m Shattered, fractured rock (< 4 cm pieces of rock) and sheared rock (washings) 30.0 – 36.0 m Mainly crushed rock & shattered and fractured rock (< 5 cm pieces of rock) 36.0 -45.0 m Shear zone (washings) 45.0 – 46.5 m Mainly CR & shattered and fractured rock (< 4 cm pieces of rock) 46.5 – 50.0 m Shear zone (washings)

PS-4

Location: Along Penstock Alignment. **Coordinates:** **N:** 45185.455 **E:** 49817.401

Ground El.: ±480m **Total Depth:** 80m

Agency SJVN Limited

Depth (m)	Elevation (m)	Overburden /Rock	Remarks
0 to 2.0	480.0 to 478.0	Overburden	Soil

2.0 to 80.0	478.0 to 400.0	Bed rock	Bed rock comprising of greenish grey coloured dolomite was encountered. The rock is mostly fractured, shattered and sheared along with some jointed reaches. The core pieces recovered in fractured/shattered rock are mostly < 5 cm in length. The rock is mostly fresh with slight staining along some joint surfaces. Core recovery in rock ranges from 34% to 86.66%. RQD ranges from 0 to 12%. The nature of the bed rock recorded with depth is as follows: 2.0-7.5 m Shear zone (washings) 7.5 – 9.0 m Jointed and sheared rock 9.0-31.5 m Fractured/shattered rock (< 8 cm pieces of rock) along with moderately to closely jointed rock 31.5 – 34.5 m Shear zone (crushed rock) 34.5 – 36.0 m Fractured/shattered rock (< 4 cm pieces of rock) 36.0 – 39.0 m Shear zone (crushed rock) 39.0 – 58.0 fractured/shattered (< 5 cm pieces of rock) with some closely jointed rock. 58.0-78.0 m Shear zone (crushed rock) 78.0 – 80.0 m fractured/shattered rock (< 5 cm pieces of rock).

Figure-5.41: Photograph showing the quality of the core of PS-4 (RD. 22.5-28.5m)

Geotechnical Appraisal

The surface geological mapping and drill hole data have indicated that the upper horizontal reach (185m length) of the pressure shaft starting from the bottom of the surge shaft (El. 402m) will encounter fractured and jointed dolomites with a thick shear zone (45 - 50m depth). The top ±100m of vertical pressure shaft will essentially lie in jointed dolomite with foliation shears. The lower ±100m length of the vertical pressure shaft will pass through jointed quartzites with bedding shears with a shear zone (20 to 25m) at the lower portion. In-between these two reaches a 32 - 35m thick highly sheared and crushed

zone of dolomite, slate, and carbonaceous phyllite will be encountered separating the upper dolomite reach and lower quartzite reach. The D/s horizontal reach (472m) will pass through quartzite with dolomite bands having foliation shears with 100m of carbonaceous phyllite reach. Last few meter of the pressure shaft will lie essentially in overburden. In addition the horizontal portion of the pressure shaft in the vicinity of the power house will have low vertical and side cover adequate slope stability measure have to be taken during the construction of this reach. The Rock Mass Quality Index 'Q' generally ranges from 1.8 to 5.5 in closely jointed dolomite, 2.5 to 8.6 in thinly bedded quartzite and quartzitic phyllite and 0.2 to 0.72 in sheared and shattered rock. The pressure shaft after excavation may immediately be supported by steel rib - cast concrete - fibre crete to avoid chances of collapses in the sheared and shattered rock zone. The quartzite phyllite and quartzite may be taken care of by rock bolting and shotcreting.

The presence of open joints (few mm upto 10cm) with yellowish brown infiltrated clayey material fillings in the exposed rock on the penstock slope, can pose slope stability problems, especially movements along these planes are anticipated under adverse hydrostatic and / or seismic vibrations of magnitude upto 7.5. An elaborate treatment for the stabilization of the pressure shaft has to be formulated.

5.6.2.c. Power House Site

Geology

A Surface Power House measuring 124m x 41.5m x 44.5m is proposed to be located over the middle level terrace namely T2 terrace at the foot of NN-W SS-E trending reach near Piping Village close to Wangchu - Piping River confluence. This terrace has R.L's reduced ranging from 177.30 to 180.40m.

Figure-5.42: Surface Power House Terrace.

The river side wall of the power house will be 90 to 110m away from the river edge. Besides T2, there are two more levels of terraces; namely, the oldest T3 terrace located eastward adjoining the power house site on the right bank of Piping River and the younger T1 terrace close to the Piping bridge, south of terrace T2. The top surfaces of the two terraces have R.L's 185m and 176m respectively. Terrace T3 is quite extensive flat ground and may be advantageously utilized during construction.

Surface outcrops of the bedrock are rare in and around the power house area. Greg, fine grained bedded quartzite, intricately folded, is exposed on the left bank of Piping River at its confluence with Wangchu. The quartzite is intercalated with thin phyllitic bands and permeated with thin quartz veins in criss-cross fashion. The general foliation trend varies from E-1/25° N to N70^{O}E – S70^{O}W/30°S 20°E. These quartzites are overlain by purple and green phyllite Interbands and are continuously exposed at the riverbed level along Piping River along its right bank. Barring these two outcrops, the area around the power house site is covered by terrace deposit and some slope wash materials.

In order to ascertain the overburden-bed rock profile and the nature of the bed rock at the Piping surface power house site on the left bank of Wangchu River, 10 drill holes, i.e. PH-1*, PH-2*, PH-3*, PH-4* (drilled earlier by WAPCOS Limited in Year 1993), PH-5 to PH-10 (recent drilling by SJVN Limited) were drilled totaling to 444.74m. The drilling indicate the depth of overburden ranges between 11.6 to 21.8m, consisting mainly of boulders, cobbles and pebbles of quartzite and dolomite along with medium to coarse silt / sand seams. The rock encountered in the drill holes is purple phyllite, white to grey, purple and greenish grey coloured quartzite and dolomite. The rock in general is fractured, shattered and sheared in nature. The core recovery in rock ranges between 47 to 100%. No RQD was recorded in any drill hole.

The Bed Rock Level at the power house bench as inferred from the drill holes are given in **Table-5.39:**

Table-5.39: Bed Rock Level at the power house site inferred from the drill holes.

Drill Hole No.	Ground El. (m)	Bed Rock El. (m)	Rock Type
PH-1*	179.041	164.57	Interbands of thinly bedded quartzite and dolomite.
PH-2*	178.529	166.03	Purple phyllite and thin greenish grey quartzite.
PH-3*	178.445	162.285	Grey and purple/ green quartzite and purple phyllite bands.
PH-4*	187.83	166.18	Thinly bedded greenish grey quartzite.
PH-5	± 179.0	167.0	Light to dark grey coloured quartzite.
PH-6	179.82	160.32	Purplish, greenish grey and grey to light grey coloured quartzite.
PH-7	179	166.0	Purplish, greenish grey and grey to light grey coloured quartzite.

PH-8	179	162.25	Purplish, greenish grey and grey to light grey coloured quartzite.
PH-9	179	163.50	Purplish, greenish grey and grey to light grey coloured quartzite.
PH-10	179	166.0	Purplish, greenish grey and grey to light grey coloured quartzite.

***** *Holes drilled by M/s WAPCOS Limited in the Year, 1993.*

A brief summary of all the drill holes drilled in the power house area is given below:-

PH-1*

Location: Left bank of Wangchu River, along the longer axis of power house.

Ground El.: 179.041m

Co-ordinates*: **N:** 44738, **E:** 49835

Total Depth: 39.92m

Agency M/s WAPCOS Limited, in Year, 1993

Depth (m)	Elevation (m)	Overburden /Rock	Remarks
0 to 14.47	179.04 to 164.57	Overburden	Riverine deposits of boulders, pebbles and shingles with coarse sand. Rolled and stained boulders of white grey and pink quartzite also.
14.47 to 39.92	164.57 to 139.12	Bed rock	Bed rock comprises of alternate bands of white grey coloured quartzite, grey coloured dolomite and black slate. The rock is highly jointed and sheared in nature. The core pieces recovered in rock are < 5 cm in length. The high permeability values indicate open nature of joints.

PH-2*

Location: Left bank of Wangchu River, along the shorter axis of power house on the valley side.

Ground El.: 178.529m

Co-ordinates*: **N:** 44722, **E:** 49935

Total Depth: 39.50m

Agency M/s WAPCOS Limited, in Year, 1993

Depth (m)	Elevation (m)	Overburden /Rock	Remarks
0 to 12.50	178.53 to 166.03	Overburden	Riverine terrace deposits of quartzite, schist, etc. and pebbles, gravels and sand.
12.50 to 39.50	166.03 to 139.03	Bedrock	Bed rock comprising of thinly bedded greenish grey coloured quartzite. The rock is fresh. Core is mostly fragmented. No RQD was recorded in the entire drilled depth in rock. Bedding dips at 50^0 to 55^0 changing to 20^0 to 30^0 to sub-horizontal.

PH-3*

Location: Left bank of Wangchu River, along the longer axis of power house.

Ground El.: 178.445m

Co-ordinates*: **N:** 44761, **E:** 50005

Total depth: 39.42m

Agency M/s WAPCOS Limited, in Year, 1993

Depth (m)	Elevation (m)	Overburden /Rock	Remarks
0 to 16.16	178.445 to 162.285	Overburden	Riverine deposits of boulders and pebbles of quartzite with river sand.
16.16 to 39.42	162.285 to 139.025	Bed rock	Bed rock comprising of grey to dark grey coloured highly fractured and shattered dolomite. A thinly bedded quartzitic-phyllite with dolomite bands was recorded between 18.59 and 30.78 m. The core recovery is very poor (< 20%). The high permeability values indicate open nature of joints.

PH-4*

Location: Left bank of Wangchu River, along the shorter axis of power house on the hill side.

Ground El.: 1 87.83m

Co-ordinates*: **N:** 44772**, E:** 49925

Total Depth: 65.90m

Agency M/s WAPCOS Limited, in Year, 1993

Depth (m)	Elevation (m)	Overburden /Rock	Remarks
0 to 21.65	187.83 to 166.18	Overburden	Slope wash consisting of white quartzite rock fragment encountered up to 18.3 m depth. Thereafter Riverine material encountered up to 21.65 m depth.
21.65 to 65.90	166.18 to 121.93	Bed rock	Bed rock consists of purple phyllite, purple with thin greenish quartzite interbeds and greenish grey quartzite. The rock is intruded by irregular quartz veins. The foliation/bedding dips at 50^0 to 60^0. Poor core recovery is due to the soft nature of the phyllite rock which gets washed off during drilling.

PH-5

Location: Left bank of Wangchu River, centre of surface power house.

Ground El.: 179.0m

Co-ordinates: **N:** 44702.833**, E:** 49926.654

Total depth: 50.0m

Agency SJVN Limited.

Depth (m)	Elevation (m)	Overburden /Rock	Remarks
0 to 12.0	179.0 to 167.0	Overburden	Talus material was encountered in the initial one meter depth and thereafter river borne material (RBM) consisting of boulders, cobbles and gravels of pink, green and white coloured quartzite along with biotite-gneiss. A sand/silt seam was encountered at

			2.0 to 3.0 m depth.
12.0 to 50.0	167.0 to 129.0	Bed rock	Bed rock comprising of fine grained, dark grey to light grey coloured quartzite was encountered. The bed rock is mostly fractured, shattered and jointed in nature. Some shearing is also noticed in the rock between 37.0 – 50.0 m depth. The core pieces recovered in rock are mostly < 6 cm in length. No sign of weathering was observed in the rock. No RQD was recorded in the entire drilled depth in rock. The nature of the bed rock recorded with depth is as follows: 12.0 – 13.50 m (El. 167.0 to 165.5 m) Shattered and fractured rock (< 6 cm pieces of rock) 13.50 – 24.20 m (El. 165.5 to 154.80 m) Major reaches shattered and fractured rock (< 6 cm pieces of rock in majority with some 8 cm core pieces also) 24.20 – 29.50 m (El. 154.80 to 149.50 m) Jointed and fractured rock (< 10 cm pieces of rock) 29.50 – 37.0 m (El. 149.50 to 142.0 m) Shattered and fractured rock (< 5 cm pieces of rock) 37.0 – 50.0 m (El. 142.0 to 129.0 m) Shattered and fractured rock with some sheared rock reaches.

Figure-5.43: Photograph showing the quality of the core of PH-5 (RD. 37 - 42).

PH-6

Location: Left bank of Wangchu River, 100 m upstream of centre of surface power house.

Ground elevation: 179.82 meter

Co-ordinates: **N:** 44677.392**, E:** 49829.944

Total Depth: 50.0 meter

Agency SJVN Limited.

Depth (m)	Elevation (m)	Overburden /Rock	Remarks
0 to 19.5	179.82 to 160.32	Overburden	Boulders, cobbles, pebbles of quartzite and quartzitic-phyllite, etc.

19.5 to 50.0	160.32 to 129.82	Bed rock	Bed rock comprising of purplish, greenish grey and grey coloured quartzite encountered between 19.50 m depth to 36.0 m depth (mostly < 4 cm core pieces). Thereafter, light grey coloured quartzite encountered up to 50.0 m depth (mostly < 5 cm core pieces). The bed rock is fractured, shattered and sheared in nature. The shears have been interpreted on the basis of the washings recovered. Staining is rarely seen in the rock. Core recovery in rock ranged between 4.66 to 14%. No RQD was recorded in the entire drilled depth in rock. The nature of the bed rock recorded with depth is as follows: 19.5– 36.0 m Fractured, shattered (< 3 cm size) and sheared rock (washings only). 36.0 –38.0 m Fractured, shattered (< 3 cm size) and sheared rock (washings only). 38.0 – 39.0 m Shear zone (washings only) 39.0 – 40.0 m Fractured, shattered (< 3 cm size) and sheared rock (washings only). 40.0 - 41.0 m Shear zone (washings only) 41.0 – 43.0 m Fractured, shattered (< 4 cm size) and sheared rock (washings only). 43.0 – 44.0 m Shear zone (washings only) 44.0 - 47.0 m Fractured, shattered (< 10 cm size) and sheared rock (washings only). 47.0 – 48.0 m Shear zone (washings only) 48.0 - 49.0 m Fractured, shattered (< 4 cm size) and sheared rock (washings only). 49.0 – 50.0 m Shear zone (washings only).

Drill logs of PH-5 to PH-6 are enclosed as **Appendix- 14 to 15, Vol-IVA**

Besides drilling, 3 Seismic Lines (A-A', B-B' & D-D') of 355m; 115m; and 115; totaling 585m were surveyed.

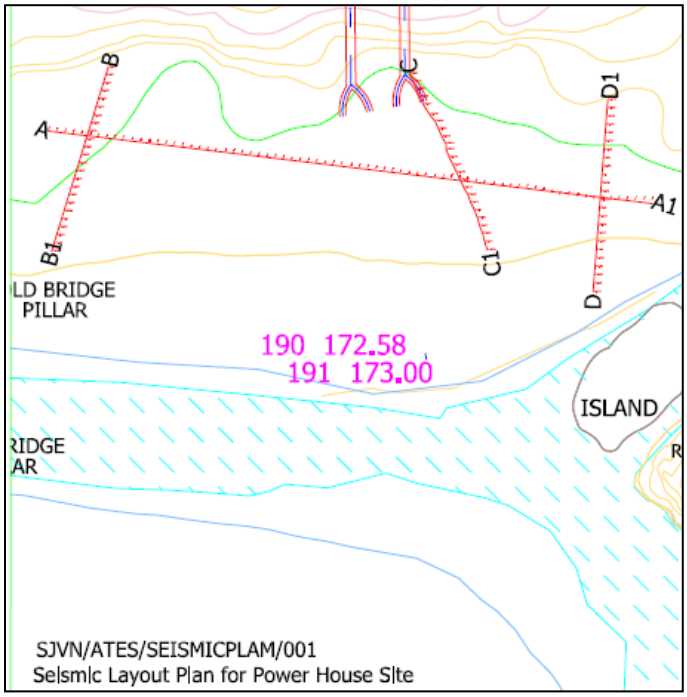
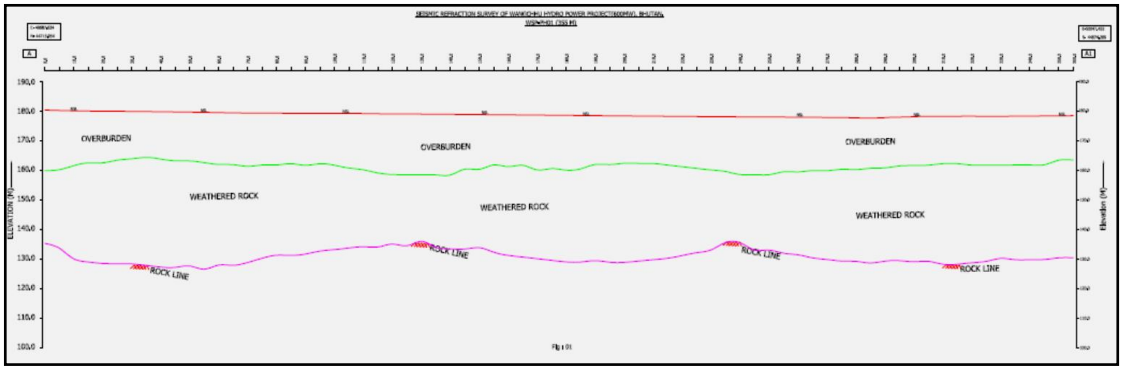


Figure-5.44: Location of the Seismic Lines

Three layers are deciphered in all the seismic lines. The first layer with compression velocities in the range of 400m/s to 1500m/sec could be related to unconsolidated overburden materials as clay, silt and sand. The second layer with recorded P-wave velocity in the range of 1500 m/sec to 3000 m/sec indicates the mixture of fine sand with pieces of rock fragments, weathered boulders of quartzites and phyllites etc. The third layer with recorded velocity in a range of 3000m/s to 4000m/s indicates the presence of sound bed rock, consisting of quartzite, phyllites with various degrees of weathering and fracturing. The Interpreted Rock Line is shown in the following **Figure-5.45:**

Figure-5.45: Interpreted rock line along Seismic Line A-A'



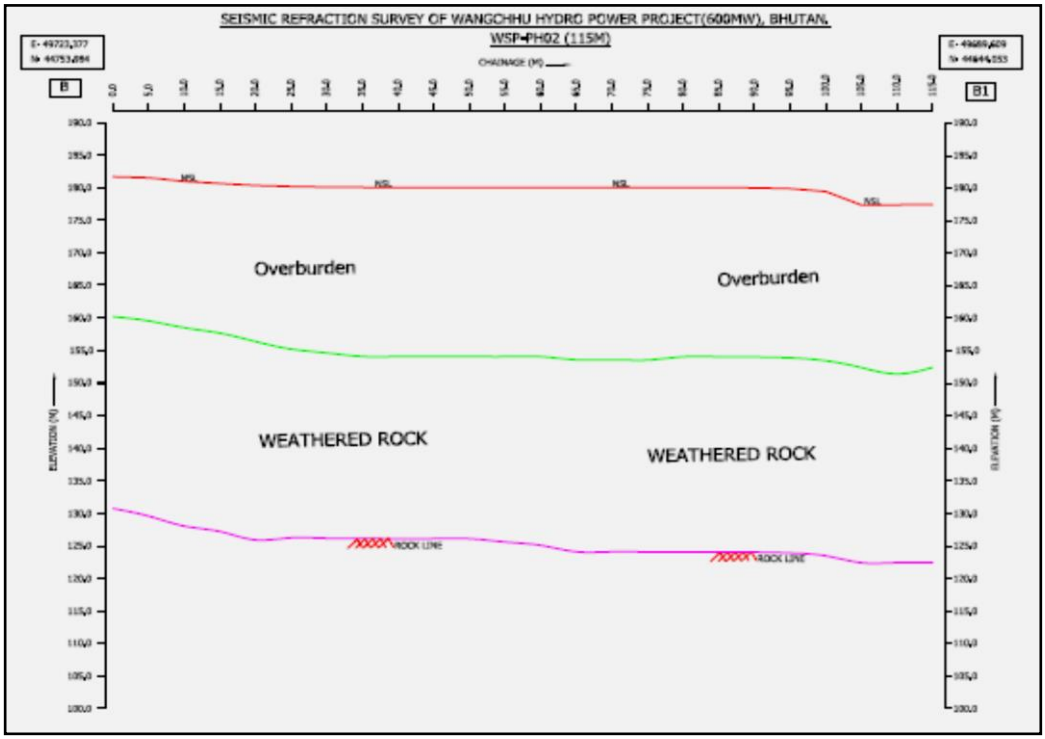


Figure-5.46: Interpreted rock line along Seismic Line B-B'

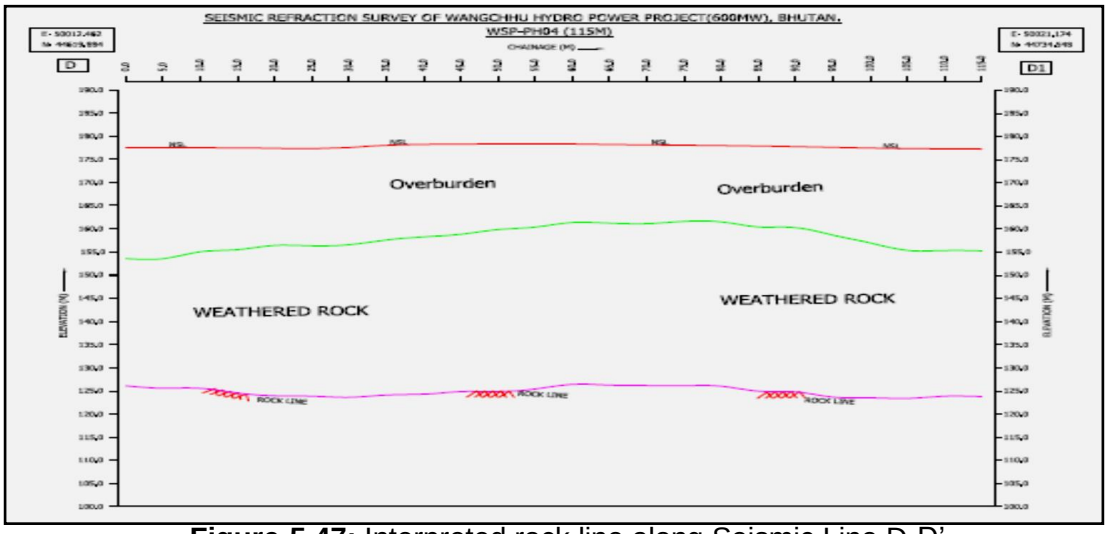


Figure-5.47: Interpreted rock line along Seismic Line D-D'

Geo-technical Appraisal

a) At the central part of the power house, the acceptable foundation grade would be at R.L. 159.00 m (approximately) requiring excavation of 16 to 21m. (NSL El. 179m) interpreted.

b) The water percolation tests conducted in the drill holes have given high permeability values indicating open nature of joints. This may require elaborate foundation treatment in the power house pit and adjoining area including the provision of drainage holes.

c) The power house site is located at the hill toe. The excavation of power house pit may create an imbalance in the stability of the hill mass. Several protective measures may have to be carried out to safeguard power house during and after construction.

d) The presence of fractured, shattered and shear zones will call for in-situ consolidation by means of effective grouting to attain a water tight foundation.

The following measures are expected to improve the stability of the slope behind the power house.

a. Diversion of the major streamlets on the hill slopes far away from the power house area and thus preventing deposited material eroded material coming into the power house.

b. Construction of deeply anchored dwarf wall across the hill slope separating the power house bench and slope above.

c. Construction of concrete pedestals all around deeply seated rock boulders so that they should not roll down in due course of time. Loose big boulder may be manually rolled down and removed at the start of the construction activity.

d. Anchoring of large rock boulders.

e. Construction of deflector walls in the upper reaches of slopes to hold back/arrest the motion of rolling boulders.

In addition, protection wall along the Piping river and Wangchu may be required to protect the power house from flash floods and river erosion.

5.6.2.d. Tail Race Channel

Geology

The water from the power house will pass through Draft Tubes to Tail Race Pool 35m x 25m and then to Tail Race Channel (TRC) 30m x 15m before entering the river. The Maximum and Minimum tail water is 175 & 170.3 respectively. Normal tail water level at El. 174.50m. These structures lie on the left bank of Wangchu river which is primarily formed of four level of river terraces, viz. T0, T1, T2 and T3 consisting mainly of boulders and cobble size material with less of gravel. The sandy layer is confined to the top 1m to 1.5m gravelly layer.

T0 terrace is confined within the channel section and present day flood level and occur at approximately river level. It has been mapped on the left bank of Wangchu river as a linear strip sand witched between the T1 terrace and present day river borne material. T1 terrace occurs at about 1.5 m to 2.0 m above T0 terrace level and has extensive deposit. T1 is quite long, wide and flat and mapped all along the left bank of Wangchu river. T2 terrace occur at about 3.0 m above T1 terrace level and is the next extensively developed terrace close to the foot hill base in the area. The power house is located partially on this terrace. The tail race channel will be excavated through terraces T2 and T1.
One drill hole (TRC-1), drilled along the tail race channel alignment on the river terrace T1. Geological log enclosed as **Appendix- 16, Vol-IVA.**

The brief details of the drill hole are as follows:

TRC-1

Location: Along tail race channel.

Ground El.: 175.03m

Co-ordinates: N: 49947, E: 44630

Total Depth: 30m

Depth (m)	Elevation (m)	Overburden /Rock	Remarks
0 to 12.0	175.0 to 163.0	River borne material	Boulders, cobbles, pebble of quartzite with some dolomite chunks. Sand / silt seam also encountered.
12.0 to 30.0	163.0 to 145.0	Bed rock	Bed rock comprising of dark grey quartzite rock with some light grey quartzite bands was encountered. The rock mass is very closely jointed to fractured and shattered (< 5 cm pieces) in nature. No sign of weathering was observed in the rock. No RQD was recorded in the entire drilled depth in rock. The permeability values range between to lugeon indicating the tight nature of joints. The nature of the bed rock recorded with depth is as follows: 12.0 – 22.20 (El. 163.0 to 152.80 m) Fractured and shattered rock (< 6 cm pieces of rock in majority with some 8 cm core pieces also) with some sheared reaches (Crushed rock only) 22.20-24.70 (El. 152.80 to 150.30 m) Very closely jointed rock with shattered and fractured reaches 24.70-30.0 (El. 150.30 to 145.0 m) Fractured and shattered rock (< 5 cm pieces of rock in majority with some 8 cm core pieces also).

Figure- 5.48: Photograph showing the quality of the core of TRC-1 (RD. 21.5 – 27.7m).

One seismic line of 115m length **(C-C' - Figure-5.49)** was taken at tail race channel location during geophysical survey. Three layers are deciphered in the seismic lines. Interpreted Rock Line is shown below: -

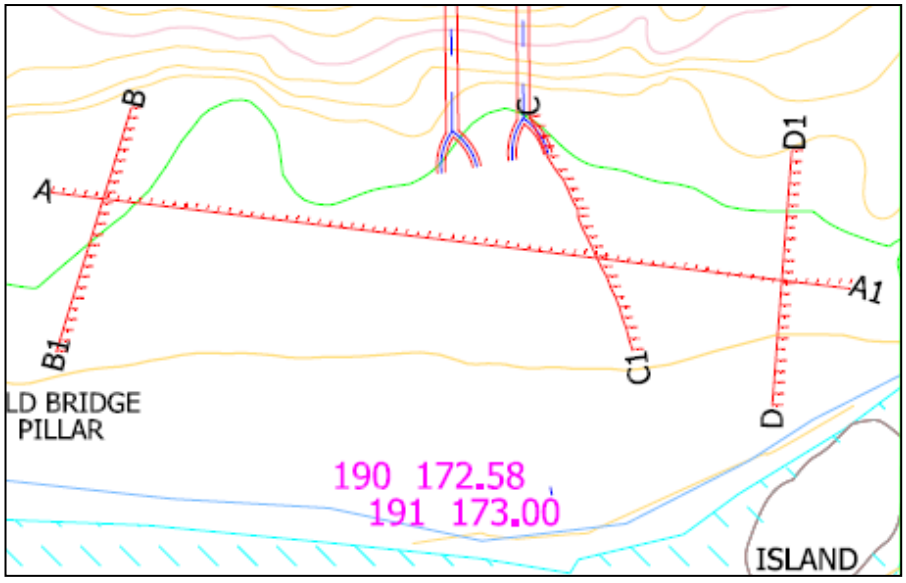


Figure-5.49: Seismic Layout Plan for Power House Site.

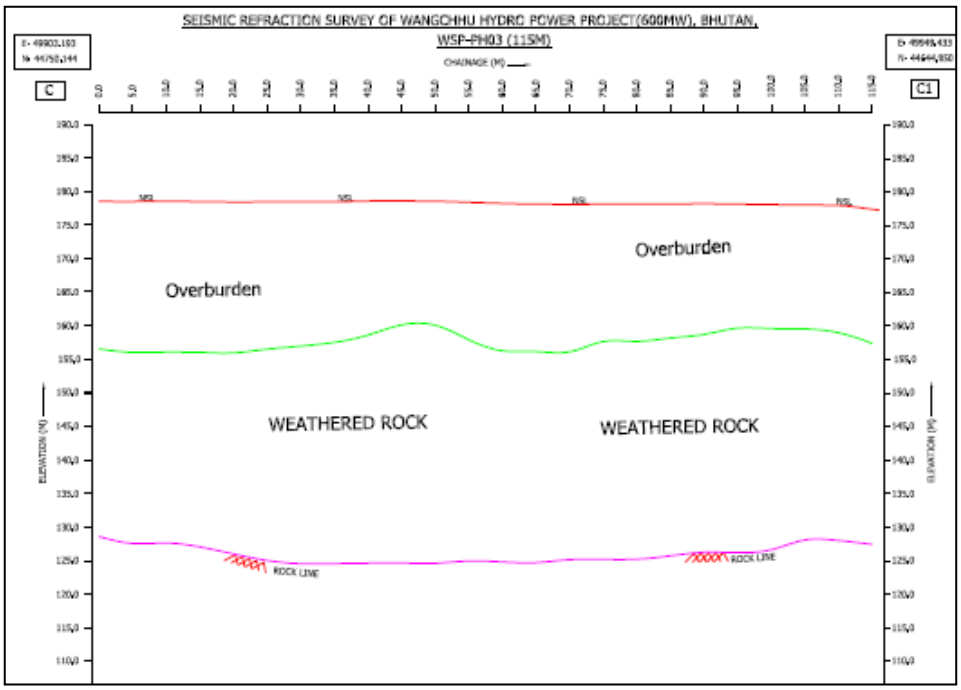


Figure-5.50: Interpreted Rock Line along Seismic Line C-C'.

The detailed report of the field study and conclusions is given as **Annexure-VI; Volume-IV.B.**

Geotechnical Appraisal

The tail race channel will be excavated in terrace deposit material. The one drill hole drilled along the tail race channel alignment has proved bed rock at an elevation of 163.0 m comprising of dark grey quartzite rock with some light grey quartzite bands. The rock mass is jointed and shattered which will require effective treatment for a tight foundation for laying the tail race channel.

5.6.2.e. Switch Yard

The switch yard (220.0m long and 190.0 m wide) lies on the right bank of Wangchu river which is primarily formed of four level of terraces (T0 to T3) consisting mainly of boulders and cobble size material with less of gravel. The sandy layer is confined to the top 1.0 m to 1.5 m gravelly layer. T0 terrace is confined within the channel section and present day flood level and occur at approximately river level. T1 terrace occurs at about 1.5 m to 2.0 m above T0 terrace level. T2 terrace occur at about 3.0 m above T1 terrace level. The switchyard will lie mainly on the T3 terrace with some part located on T2. Presently there has been no geotechnical investigation in the switch yard area:

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6. Seismicity

The project areas lie in the known Himalayan Seismic Belt. Bhutan had experienced a number of shocks in the historical past and their epicentral locations lie within a radius of 1-150 km from the project. Dhurbi earthquake of 1930 (M 7.1) and an earthquake of 21 January, 1941 (M 8.1, which was experienced at 27° 30'E) had seriously affected areas in India and adjoining Bhutan. Between 1929 and 1986 more than 50 shocks of magnitude 4.6 to 6.8 originated in the area bounded by 27° and 28°N latitudes and 89° and 92° longitudes.

Major dislocation features of significance in the project are: Main Boundary Fault (MBF), Main Central Thrust (MCT) and Piping river fault, which are regarded as moderate to steep angle thrust / faults. The MCT and MBF, two closest dislocation features to the project are located about 3 Kms north and 11 Kms south of dam site, respectively. Piping tear fault, as mapped by Geological Survey of India, Bhutan Unit, is considered to be a transverse tectonic plane trending nearly at the foothill near Bhutanghat - Piping Section of Wangchu River which displaces the main Boundary Fault.

In Bhutan Himalaya there are centres of earthquake activity and some of the epicentres are located within a distance of 100-150 km from the project sites. This is corroborated by the fact that more than 50 earthquake events of magnitude ranging between 4.6 and 6.8 mm scale have originated at 27°0':90°0' in Bhutan. On the basis of seismic records, events of M-6 to 7.5 are significant and shocks of M-6 to 6.5 may be expected within a radius of about 100 km from the project sites.

Earthquake may be concentrated in those parts of the faults that either branch out or where two or more fault systems intersect. Hence the location of intersection of N-S and E-W tendering tectonic systems would be area of future seismicity. The project areas fall within the Seismic Zone-IV to V as per Seismic Zoning Map of India (IS: 1893-2002) where shocks of the intensity M-6 to 7 are expected which correspond to the basic horizontal seismic co-efficient of 0.05 to 0.08 g.

Moderately high Seismic activities of north-eastern part of India Sub-continent bordering Assam-Bhutan, doubtdly indicate extension of high ambient tectonic stresses in the lithospheric crust in this region.

An important and very significant observation in this premises is that such phenomena is most probable in geologically recent normal or strike–slip faulting

environment and least likely in thrust faulting environment prevalent in Himalaya region.

Thus, in spite of high stressed nature of the crust in this region, the tectonic probability of impoundment induced seismicity seems to be low. However, in order to monitor any changes in the seismicity levels of this region a suitable array of (5 to 6) independently working seismograph stations, capable of detecting events of M-4 should be set up around the dam site.

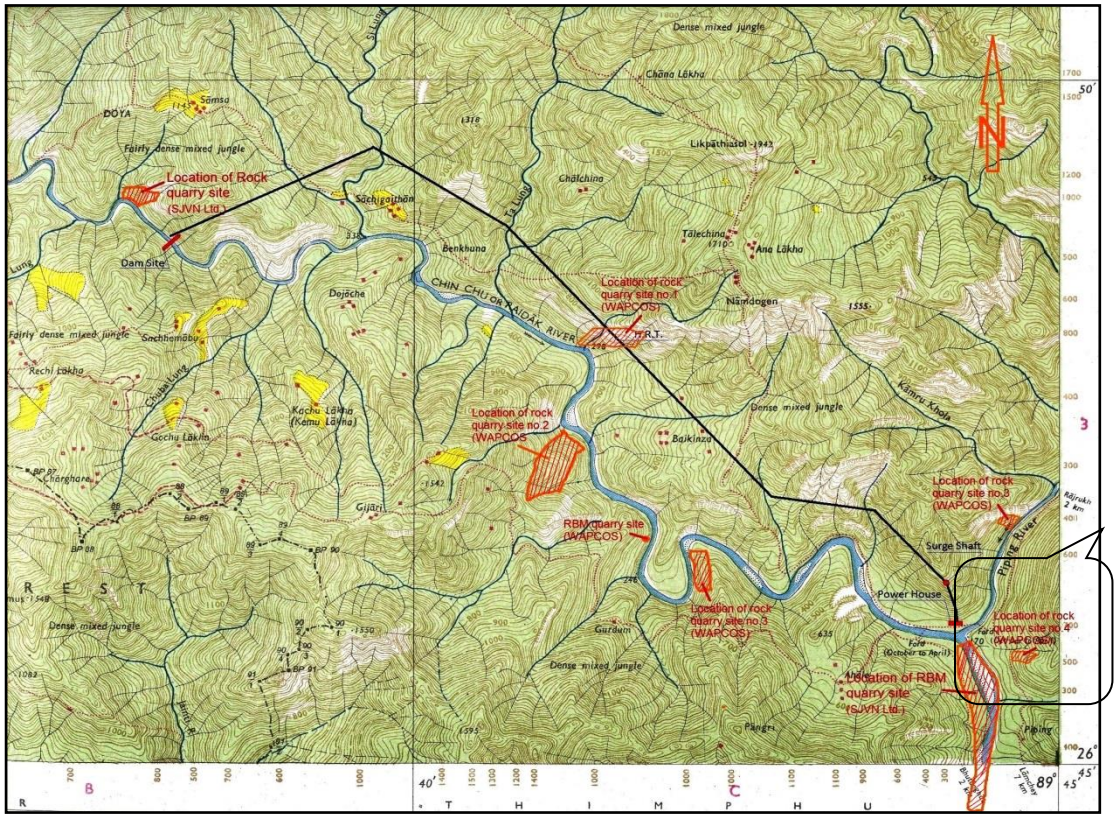
7. CONSTRUCTION MATERIAL SURVEY

7.1. Introduction

The Wangchu HEP envisages construction of a 134 m high concrete gravity dam, 296 m length at crest, 12.3 Km long HRT of 8.5 m finished diameter, a sur0face power house and around 90 m of length of TRT Pool and Channel. The estimated quantity of coarse and fine aggregate required for the construction of the project is 1561251 lac m^3 of coarse aggregate and 794941 m^3 of fine aggregate.

The river borne material of Wangchu river on its right bank just downstream of the Wangchu – Piping Confluence (D/s of the PH Site) and a quarry site 700 m upstream of the dam site on left bank are the potential borrow area for coarse and fine aggregates for the construction of the project. The excavated quartzite muck from the dam, HRT (Upstream part) and diversion tunnels will also be a source of construction material.

The quarry sites identified for the Wangchu Reservoir Scheme by M/s WAPSOC Limited in the Year, 1993 are also being considered. The location of the borrow area of SJVN Limited and M/s WAPCOS Limited is shown in the **Figure-7.51:**



7.2. Earlier Studies for Reservoir Scheme

The construction material survey for the Wangchu Reservoir Scheme was carried out in detail in Year, 1995 and the report titled “Construction material survey and geotechnical studies” is attached as **Annexure-VII, Vol-IVA.**

Five nos. of quarry sites were identified: during the above study, the location and rock type of which are given below:

1. Left bank of Wangchu river, 2.5 Km u/s of dam site (Reservoir Scheme), 7.5 Km D/s of present dam axis - Quartzite rock
2. Right bank of Wangchu river, 1 Km u/s of dam site, (Reservoir Scheme), 9 Km D/s of present dam axis -Quartzite rock
3. Right bank of Wangchu river, 2 Km D/s of dam site (Reservoir scheme) , 12 Km D/s of present dam axis- Dolomite & Quartzite rock
4. Left bank of Wangchu river at about 10Km d/s from the reservoir dam site and around 2 Km from the power house site (Piping) beyond Titritar Village at an attitude ranging from 300 to 400m- Quartzite rock
5. Right bank of piping river, 2 Km from power house - Quartzite rock

In addition River bed material on right bank of Wangchu River, D/s of dam site (Reservoir Scheme), 10 Km D/s of the present dam axis, has also been identified.

Samples were collected from the five quarry site sites detailed above by blasting and, form river bed and sent for laboratory testing. The test results were incorporated in volume VII DPR (January 1995) of the Wangchu Reservoir Scheme. As this volume of the DPR is not available, the test results cannot be looked into in detail, but a brief summary of the results were incorporated in the Volume- 1 (page8-5) of DPR (January 1995) of Wangchu Reservoir Scheme which are summarized below:

a) The rocks from the quarries were found suitable for use as coarse and crushed sand in concrete for wearing and non wearing surfaces.
b) Petrographic testes were done on the coarse and fine aggregates.
c) Suitable concrete mixes can be designed using the available aggregate.
d) Samples were found safe from the view point of alkali – silica reaction.

7.3. Present Studies for ROR Scheme

7.3.1. Estimated Requirement of Construction Material

The estimated quantity of coarse and fine aggregate required for the construction of the dam, diversion tunnel, surge shaft, penstocks, power house and other appurtenant structures of the project is **23,84,853 lac m^3 as** given below in **Table-7.1:**

Table-7.1: Details of the coarse and fine aggregate (m^3) required for the project

Structure	Coarse Aggregate Quantity	Fine Aggregate Quantity
Dam, DT, Coffer Dam Intake	1262871	631436
HRT	199327	99663
PH complex	99053	49527
Dam Wearing Surface	28651	14325
	1589902	**794951**
Total Aggregate (Coarse & Fine):		**23,84,853**

7.3.2. Source of Construction Material

The potential construction material site as already identified and tested for the reservoir scheme could have been utilized for the present ROR Scheme but the for the scattered nature of the quarry sites and their being away from the project structure. Therefore, the study to locate nearby alternate site was undertaken by SJVN Limited. Two potential construction material sites have been identified. Besides these two sites it is proposed to use of muck generated from the excavation of dam, diversion tunnels and u/s part of the HRT as aggregate. The details of the source and the quantity of the material expected is given below in **Table-7.2:**

Table-7.2: Source and Quantity of Construction Material.

Location	Quarry – Shoal Identification	Quantity Expected (lac M^3)	Remarks
Excavated Muck of Dam, DT, and HRT (U/s of Adit-3, 30% of HRT length).	Excavated Muck	2.00	Assuming 70% wastage.
Rock Quarry on the left bank of river Wangchu 700m (U/s of Dam).	Dam Site Quarry.	6.00	-
Shoal Deposits on the R-bank of Wangchu River D/s of Wangchu-	PH Site Shaol	15.00 (3.00 Lac M^3 Every Yr. 5 Yrs.).	-

Piping Confluence.			

7.4. Description of Borrow / Rock Quarries

7.4.1. Excavated Muck from DAM, DT & HRT

The muck from dam, DT, HRT will be generated during their excavation. As this muck will essentially be the of quartzite rock this can be utilized as aggregate. The quantity of muck generated from dam will be around 4.80 lac m^3, from DT 1.10 lac m^3 and from HRT (U/s Portion - 30% of HRT Length) 1.13 lac m^3, totaling to around 7.03 lac m^3. Assuming 30% utilization (70% Wastage), about 2.00 lac m^3 material will be available.

Figure-7.52: Preparation of samples collected from the dam site.

7.4.2. Rock Quarry on the Left Bank (700m U/s of the Dam)

During reconnaissance of the dam site, a rock quarry site was identified on the left bank of the Wangchu River, 700m U/s of the dam site. Hard and compact quartzite rock is exposed at this location which can be utilized as construction material for the dam

complex and initial part of HRT. Survey of this area has already been completed on 1:5000 Scale. An area of 250m length, by 45m width can be mined at an El. 420m to El. 500m. Thus a total of about 9 lac m^3 of aggregate will be available from this quarry **(Figure-7.53).**

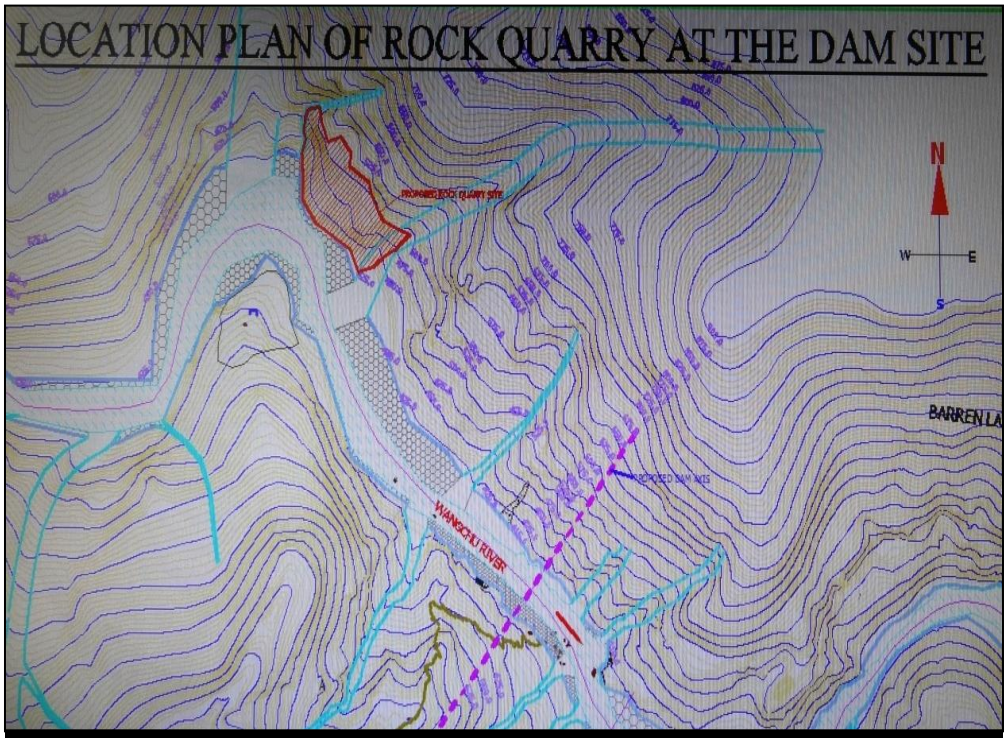


Figure-7.53: Location Plan of Rock Quarry at the Dam Site.

7.4.3. Power House Quarry

A river shoal deposit immediately downstream of the confluence of Piping and Wangchu rivers has been identified as a potential aggregate site extending for around 2 Km downstream.

This shoal is located on the right bank of river Wangchu just D/s of confluence of Wangchu River with the Piping Nallah and extend for 2 Km towards D/s. Although average width of this shoal has been taken as 75m at many places it's width is more than 100m. Further many areas are above the flood planes and can be mined throughout the year to deeper depths.

Considering an average of 2m depth of material extraction each season, the quantity available will be around 3 Lac m^3 every season (2000m x 75m x 2m). Total quantities come out to be 15.00 Lac m^3 in five years considering the river deposits get replenished every year after the monsoon. Further many areas are above the flood plains and can be mined throughout the year to deeper depths.

Figure-7.55: Shoal deposit of the Wangchu River, downstream of Wangchu-Piping Confluence (view looking upstream from the right bank).

Three trial pits were excavated in the shoal deposit and the representative samples (coarse and fine aggregate) were collected in the presence of CSMRS Officials and sent for laboratory testing. Two drill holes, each of 30m depth were also drilled in the shoal deposit to ascertain the aggregate quantity.

Figure-7.56: Excavation of pit (3) in progress in shoal deposit, D/s of Wangchu-Piping river confluence.

Figure-7.57 Walls of the excavated pit (1) in shoal deposit D/s of Wangchu-Piping River Confluence.

7.4.4 Testing of Borrow Areas

Central Soil and Material Research Station (CSMRS), New Delhi was awarded the consultancy work for collection of aggregate samples and laboratory testing of the aggregate samples in the month of May, 2011. CSMRS Officials visited the project site on 09.08.2011 to 15.08.2011 during which the identified quarry sites were shown to them. Samples were collected from these sites and sent for laboratory testing as per BIS/ISO codes for coarse and fine aggregate samples.

Central Soil and Material Research Station (CSMRS) collected samples from these sites for laboratory testing as per BIS / ISO Codes for coarse and fine aggregate samples as given below **(Table-7.3)**:

Table-7.3: Details of the samples sent for testing.

Sample No.	Location	Remarks
WHEP-Right bank	Right bank drift at dam site	As the left bank quarry was not approachable, sample taken from drifts is by construction for quarry site also as the reach is same at both places.
WHEP-Left bank	Left bank drift at dam site	
WHEP-Left bank	Left bank drift at dam site	
WHEP/PH/RBM-1	River deposit at the power house site (coarse aggregate)	-
WHEP/PH/RBM-2	River deposit at the power house site (coarse aggregate)	-
WHEP/PH/RBM-3	River deposit at the power house site (coarse aggregate)	-
WHEP/PH/F-A1,2,3	River deposit at the power house site (fine aggregate)	-

The test results report from CSMRS is appended as Annexure-VIII.

7.4.5. Fine Aggregate

Fine Aggregate will be obtained from RBM by sieving and from Rock Quarry while manufacturing the aggregates. No separate quarry have been earmarked / identified for fine aggregates.

7.4.6. Additional Rock Quarry

As the dam site quarry located 700m u/s of dam on the left bank (refer Table 7.2) could not be tested for want of approach, CWC insisted for locating another quarry. Samples from Quarry no.4, selected by WAPCOS in the year 1995 for the Reservoir scheme, were sent to CSMRS for studying the suitability of the quartzite rock present in this quarry. The test report has indicated that the aggregate from this quarry is suitable for wearing and non-wearing surfaces. (Annexure-IX).

Coarse aggregate quantity required is approx. 21 Lac m^3 inclusive of 38% rejection loss.

Required quantity of Aggregates shall be made available from following:

• Shoal deposite on the Right bank of Wangchu River D/s of Wangchu Piping Confluence.	9.3 Lac Cum (After deducting 38% loss/rejection)
• Rock quarry site (Quarry no. 4) on left bank of Wangchu river , 2 km from Power House site	13.5 Lac Cum
• Excavated Muck of Dam, DT, and HRT (U/s of Adit-3, 30% of HRT length).	2.81 Lac Cum

GEOLOGICAL DRAWINGS TO VOLUMN IV

DETAILED PROJECT REPORT

List of Geological Drawings

S.N	Title of the Drawing	Drawing No.
1	Geological Plan of Dam Area	DAM-WHEP-DPR-GEO-006-02
2	Geological Section along Dam Axis	DAM-WHEP-DPR-GEO-007-03
3	Geological Section along Bucket Area	DAM-WHEP-DPR-GEO-008-01
4	Geological Section along Plunge Pool Area	DAM-WHEP-DPR-GEO-009-00
5	Geological Section along U/S Coffer Dam	DAM-WHEP-DPR-GEO-010-00
6	Geological Section along Diversion Tunnel (DT-1)	DAM-WHEP-DPR-GEO-011-00
7	Geological Section along Diversion Tunnel (DT-2)	DAM-WHEP-DPR-GEO-011A-00
8	Geological Section along Power Intake	DAM-WHEP-DPR-GEO-013-00
9	Geological Plan along HRT Alignment	HRT-WHEP-DPR-GEO-014-02
10	Geological Section along HRT Alignment	HRT-WHEP-DPR-GEO-015-03
11	Geological Plan of Power House Area	PH-WHEP-DPR-GEO-016-01
12	Geological Section from Surge Shaft to TR Channel	PH-WHEP-DPR-GEO-017-01
13	Geological Map of Reservoir Area	WHEP-DPR-GEO-018-02
14	3-D Geological Log of Drift DR-1 (0m to 100m)	DAM-WHEP-DPR-GEO-019-01
15	3-D Geological Log of Drift DL-1 (0 to 70m)	DAM-WHEP-DPR-GEO-020-01
16	3-D Geological Log of Drift DL-2 (0 to 70m)	DAM-WHEP-DPR-GEO-021-01
17	3-D Geological Log of Drift PI -1, Power Tunnel Intake (0 to 50m)	DAM-WHEP-DPR-GEO-022-00
18	Geological section along HRT Adit-1	DRG No-HRT-WHEP-DPR-GEO-023-00
19	Geological section along HRT Adit-2	DRG No-HRT-WHEP-DPR-GEO-024-00
20	Geological section along HRT Adit-3	DRG No-HRT-WHEP-DPR-GEO-026-00

21	Geological section along HRT Adit-4	DRG No-HRT-WHEP-DPR-GEO-027-00
22	Geological Plan at El 155.50m of Power House	DRG No-PH-WHEP-DPR-GEO-028-00
	Geological section along longer axis of Power House pit(Line A-B)	DRG No-PH-WHEP-DPR-GEO-029-00
23	3- D Geological Log of Drift DR-2 Right abutment (Ch 00.00 to 70.00m)	DRG No-HRT-WHEP-DPR-GEO-030-00
24	3- D Geological Log of Drift DR-2(Cross-Cuts) Right abutment (Ch 00.00 to 10.00m on each side of drift)	DRG No-HRT-WHEP-DPR-GEO-031-00
25	3- D Geological Log of Drift DR-1(Cross-Cuts) Right abutment (Ch 00.00 to 10.00m on each side of drift)	DRG No-HRT-WHEP-DPR-GEO-031-00
26	3- D Geological Log of Drift DL-1(Cross-Cuts) Left abutment (Ch 00.00 to 10.00m on each side of drift)	DRG No-HRT-WHEP-DPR-GEO-031-00
27	3- D Geological Log of Drift DL-2(Cross-Cuts) Left abutment (Ch 00.00 to 10.00m on each side of drift)	DRG No-HRT-WHEP-DPR-GEO-033-00

FOR DPR ONLY

LEGEND:

- HILL WASH
- RIVER BORNE MATERIAL
- ALLUVIUM / BOULDER SIZE DEBRIS CONE
- MASSIVE WHITE/GREY QUARTZITE
- PHYLLITIC QUARTZITE
- 45° — DIP AND STRIKE OF FOLIATION
- 10 — DIP AND STRIKE OF BEDDING
- 60° — DIP AND STRIKE OF INCLINED JOINTS
- VERTICAL JOINTS
- SHEAR ZONE
- LANDSLIDE
- DH-04 — DRILL HOLE
- DRIFT
- CROSS CUTS IN DRIFT
- E E' — Geophysical Survey Lines.

SCALE:

-50 m 0 50 100 m

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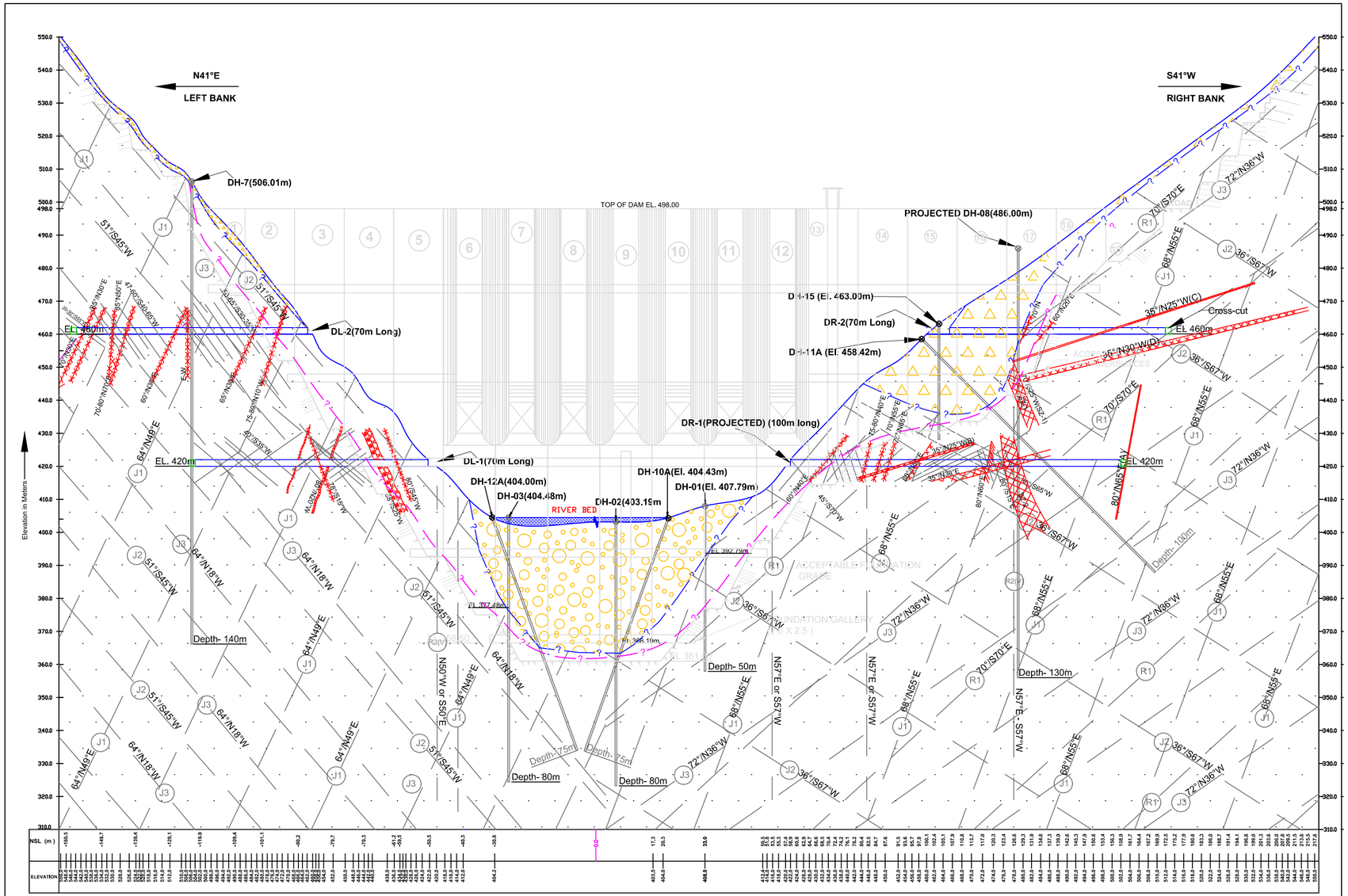
WANGCHU HYDRO ELECTRIC PROJECT.

Geological Plan of Dam Area

अभिकल्पित DSGN.	परीक्षित CHKD.	प्रस्तुत RECM.
रेखांकित DRWN.	पुनरीक्षित SUBM.	

SJVNL GEOLOGY DEPARTMENT

DRG. No. DAM-WHEP-DPR-GEO- 006-02 | Jan., 2013



INDEX

- River Borne Material
- Slope wash Material
- Quartzite
- Trace of Discontinuity with Dip amount/Direction
- Shear seam (<10 cm)
- Fracutred/Shattered Zone (Measured Thickness)
- Shear Zone(Measured Thickness)
- Excavated Drift/Cross cuts
- Drill Hole Completed
- Inferred Lithological Contact
- Stripping Limit from NSL.

FOR DETAILED PROJECT REPORT

Notes:

1. The geological section is based on geological mapping & geotechnical investigations carried out at dam site area. Refer drg. No. DAM-WHEP-DPR-GEO-006-00
2. The foliation/joints and their spacing depicted in the section are schematic.
3. True attitude of discontinuity is shown along the traces and apparent dips are plotted
4. Overburden encountered in drill holes DH-8, DH-11A and Drift DR-2 is 28.5 m , 28.5 m and 28.5m respectively.
5. The low/nil recovery zones encountered in DH-8 from depth 36.5m to 46.5m(SZ-1) and 62.0m to 80.5m(SZ-2) have not been encountered in the Drift DR-1 which may be because of difference in the orientations of Dam Axis and Drift alignment, i.e. N41°E-S41°W and S61°W respectively and drift portal being located 5-6m d/s of dam axis. Part of SZ-1 will get removed during stripping itself & will need dental treatment. The exact location & orientation of SZ-2 needs to be confirmed during pre-construction to firmup the treatment of this zone.
7. Stripping limit marked on both banks is based on the drift data.
8. Shear zone B encountered in the d/s cross cut of drift (DR-1 referred in Drawing No. DAM-WHEP-DPR - GEO-026-00) at El. 460m has not been encountered in the drift , which may be due to pinching behavior and moreover the drift is across the dam axis and the portal of the drift is located 8-10m d/s of dam axis. This needs to established during the construction stage.
9. Shear zone C encountered in the u/s cross cut of drift DR-2 (referred in Drawing No. DAM-WHEP-DPR - GEO-026-00) at El. 463m has not been encountered in the drift , which may be due to pinching behavior and also due to the drift being located about 8-10m d/s of the dam axis. This needs to established during the construction stage.

SCALE 0 5 10 15 20 25 30m

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WANGCHU HYDRO ELECTRIC PROJECT.

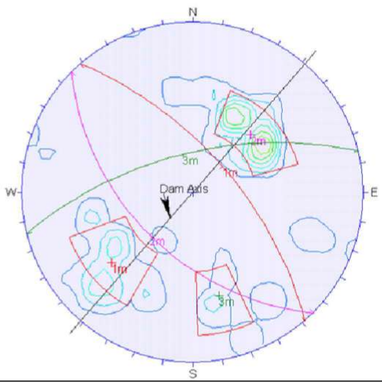
Geological Section along Dam Axis

अभिकल्पित DSGN. Geology Deptt.	समीक्षित CHKD.	संस्तुत RECM.
रेखांकित DRWN.	प्रस्तुत SUBM.	

SJVNL GEOLOGY DEPARTMENT

DRG. No. DAM-WHEP-DPR-GEO-007-03 | MAY, 2013

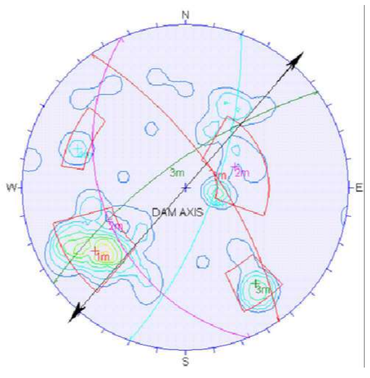
Stereogrphic Projections of Left Bank



Orientations

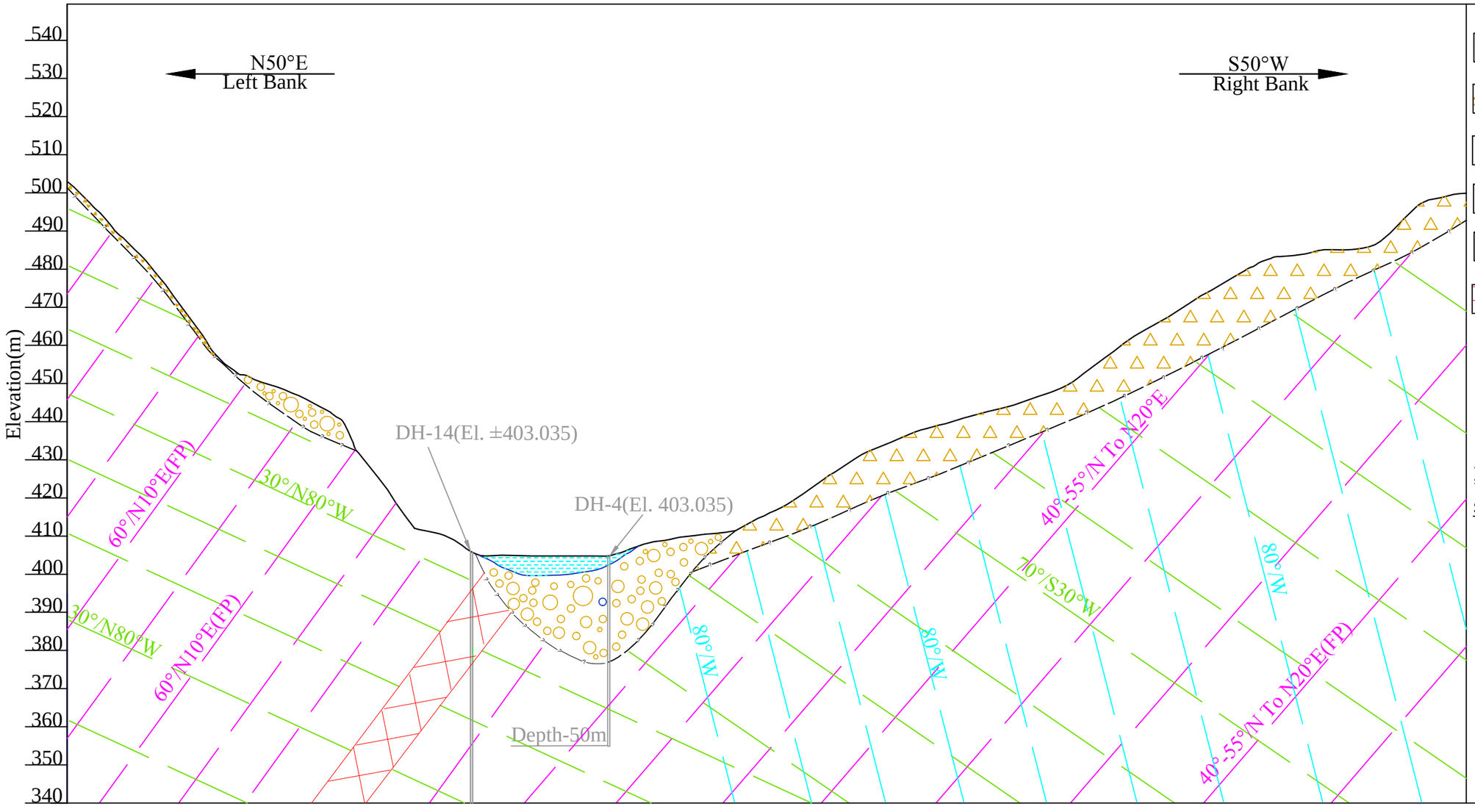
ID	Dip/Direction(Av.)	Range
J1(F)	64°/N49°E	45-75/N30-70°E
J2	51°/S45°W	40°-60°/S25°W-S65%%sW
J3	64°/N18°W	50°-80°/N02°-25°W
R(V)	N50°W/S50°E	

Stereogrphic Projections of Right Bank



Orientations

ID	Dip/Direction(Av.)	Range
J1(F)	68°/N55°E	40°-75°/N50°-80°E
J2	36°/S67°W	22°-54°/S30°W- W
J3	72°/N36°W	50°-80°/N25°-45°W
R1	70°/S70°E	65°-75°/S50°-80°E
R2(Vertical)	N57°E/S57°W	



INDEX

- River Borne Material
- Slope Wash Material
- Quartzite
- Joint Trace
- Inferred Litho Contact
- Shear Zone

Notes:

1. The geological section is based on geological mapping & geotechnical investigations carried out at dam site area. Refer Drg. No.DAM-WHEP-DPR-GEO-006-00
2. The foliation/joints and their spacing depicted in the section are schematic.
3. True attitude of discontinuity is shown along the traces and apparent dips are plotted.
4. Total 56.91m length of Drill Hole DH-14 is shown in this section, for rest of the details please refer to drill hole log.

Scale:

0 10 20 30 40 50m

FOR DETAILED PROJECT REPORT ONLY

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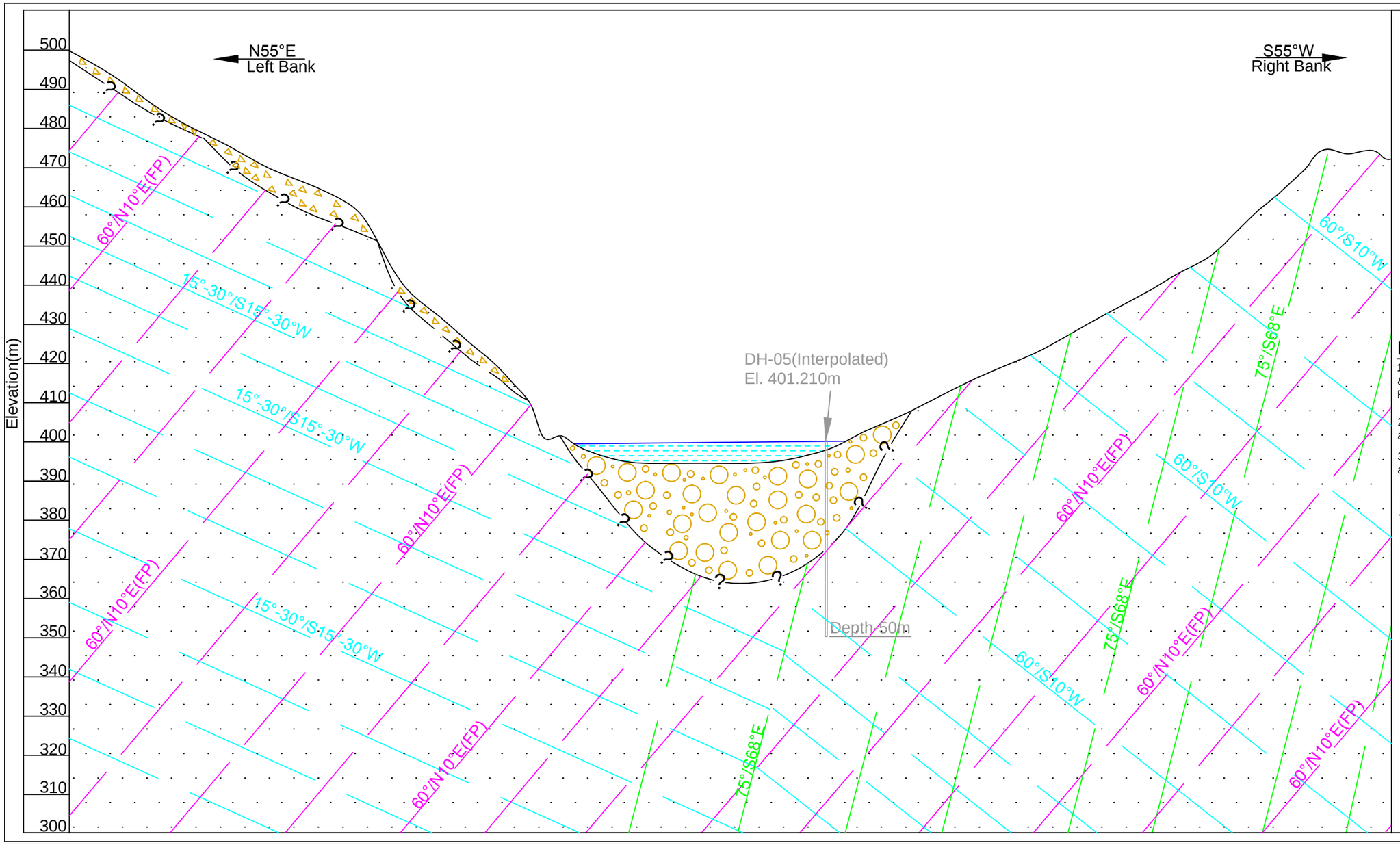
WANGCHU HYDRO ELECTRIC PROJECT(Bhutan).

Geological Section along Bucket Area

अभिकल्पित DSGN.	सर्वेक्षित CHKD.	प्रस्तुत RECM.
रेखांकित DRWN.	प्रस्तुत SUBM.	

SJVNL , Geology Department.

DRG. No. DAM-WHEP-DPR-008 -01 | Dec., 2011



INDEX

- River Borne Material
- Slope Wash Material
- Quartzite
- Joint Trace

Notes:

1. The geological section is based on geological mapping & geotechnical investigations carried out at dam site area. Refer drg. No. DAM-WHEP-DPR-GEO-006-00

2. The foliation/joints and their spacing depicted in the section are schematic.

3. True attitude of discontinuity is shown along the traces and apparent dips are plotted.

Scale:

0 10 20 30 40 50m

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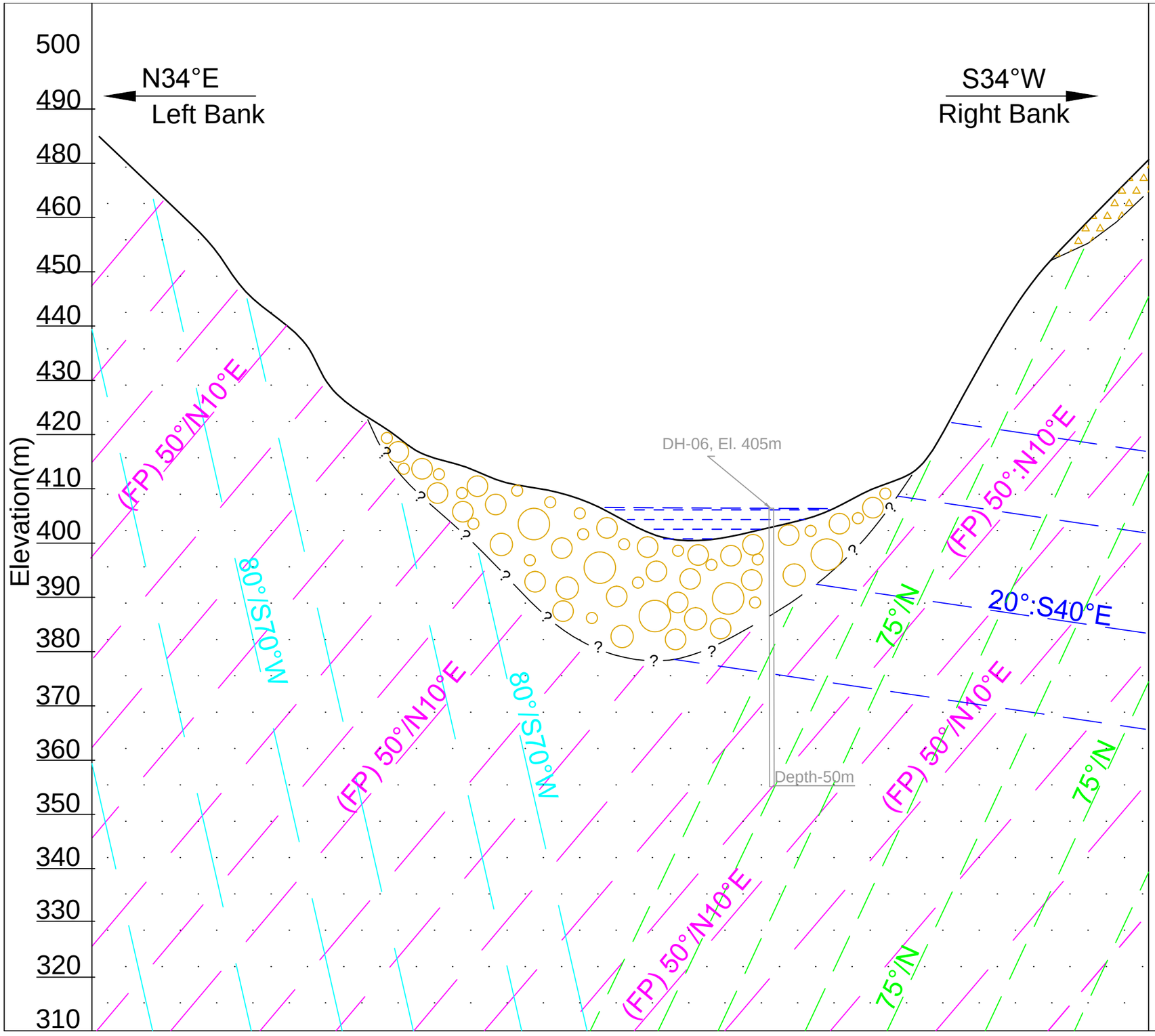
WANGCHU HYDRO ELECTRIC PROJECT(Bhutan).

Geological Section along Plunge Pool Area

अभिकल्पित DSGN.	परीक्षित CHKD.	संस्तुत RECM.
रेखांकित DRWN.	प्रस्तुत SUBM.	

SJVNL , Geology Department.

DRG. No.DAM-WHEP-DPR-GEO-009-00 | **Dec., 2011**



INDEX

- River Borne Material
- Slope Wash Material
- Qaurtzite
- Joint Trace (FP) 50°:N10°E

FOR DPR ONLY

Notes:

1. The geological section is based on geological mapping & geotechnical investigations carried out at dam site area. Refer drg. No. DAM-WHEP-DPR-GEO-006-00
2. The foliation/joints and their spacing depicted in the section are schematic.
3. True attitude of discontinuity is shown along the traces and apparent dips are plotted.

Scale:

0 10 20 30 40 50m

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WANGCHU HYDRO ELECTRIC PROJECT.

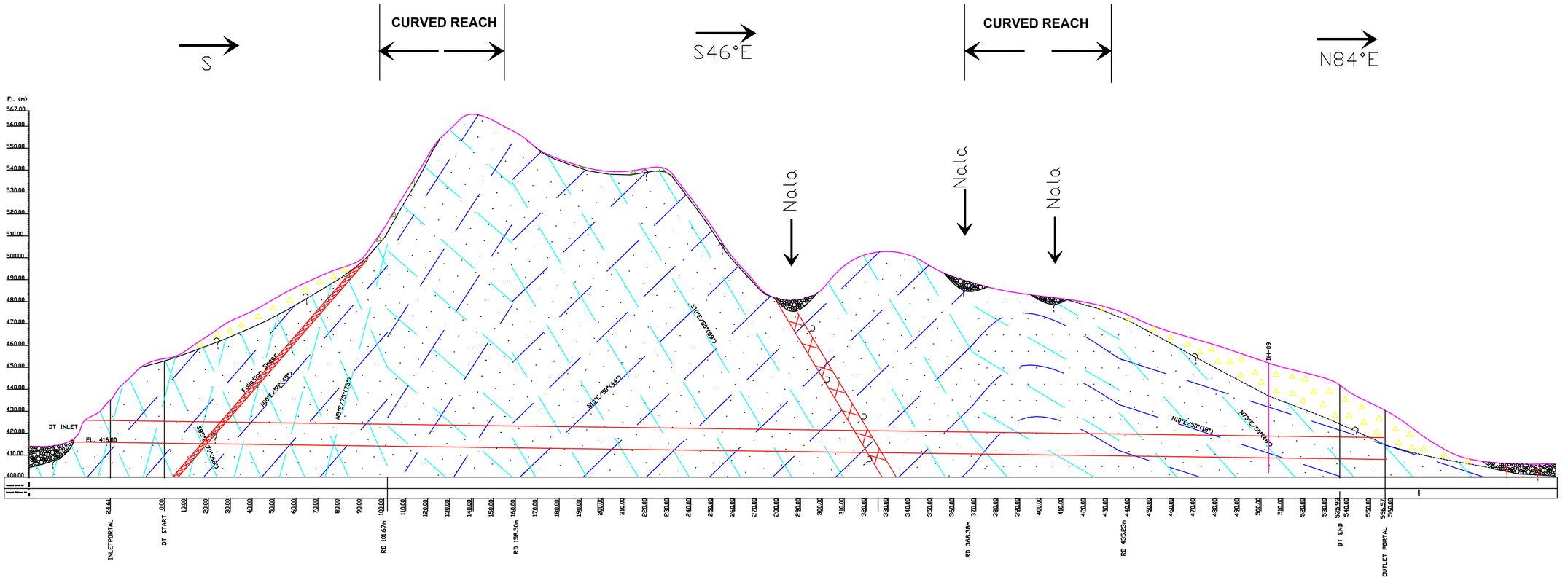
Geological Section along U/S coffer Dam

अभिकल्पित DSGN.	सवीक्षित CHKD.	संस्तुत RECM.
रेखांकित DRWN.	प्रस्तुत SUBM.	

SJVNL GEOLOGY DEPARTMENT

DRG. No. DAM-WHEP- DPR -GEO-010-00 | **Dec., 2011**

GEOLOGICAL SECTION OF DIVERSION TUNNEL (DT-2)



LEGEND

- OVERBURDEN
- QUARTZITE
- SHEAR ZONE

SCALE :

0 10 20 30 40 50M

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SJVN Limited

WANGCHU HYDRO ELECTRIC PROJECT(Bhutan).

Geological Section of Diversion Tunnel (DT-2)

DESIGN.	CHKD.	RECM.
DRWN.	SUBM.	

SJVNL , Geology Department.

DRG. No.DAM-WHEP-DPR-GEO-011A-00 | Sept., 2012

GEOLOGICAL SECTION OF DIVERSION TUNNEL (DT-1)

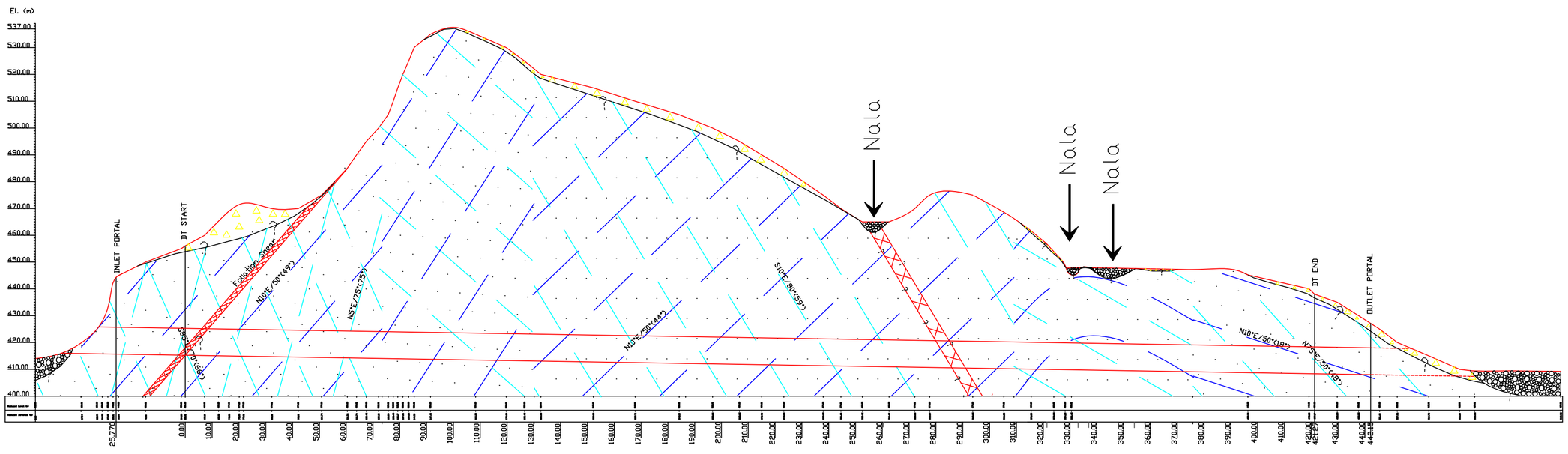
S

CURVE REACH

S46°E

CURVED REACH

N84°E



LEGEND

- OVERBURDEN
- QUARTZITE
- SHEAR ZONE

SCALE :

0 10 20 30 40 50M

FOR DPR ONLY

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SJVN Limited

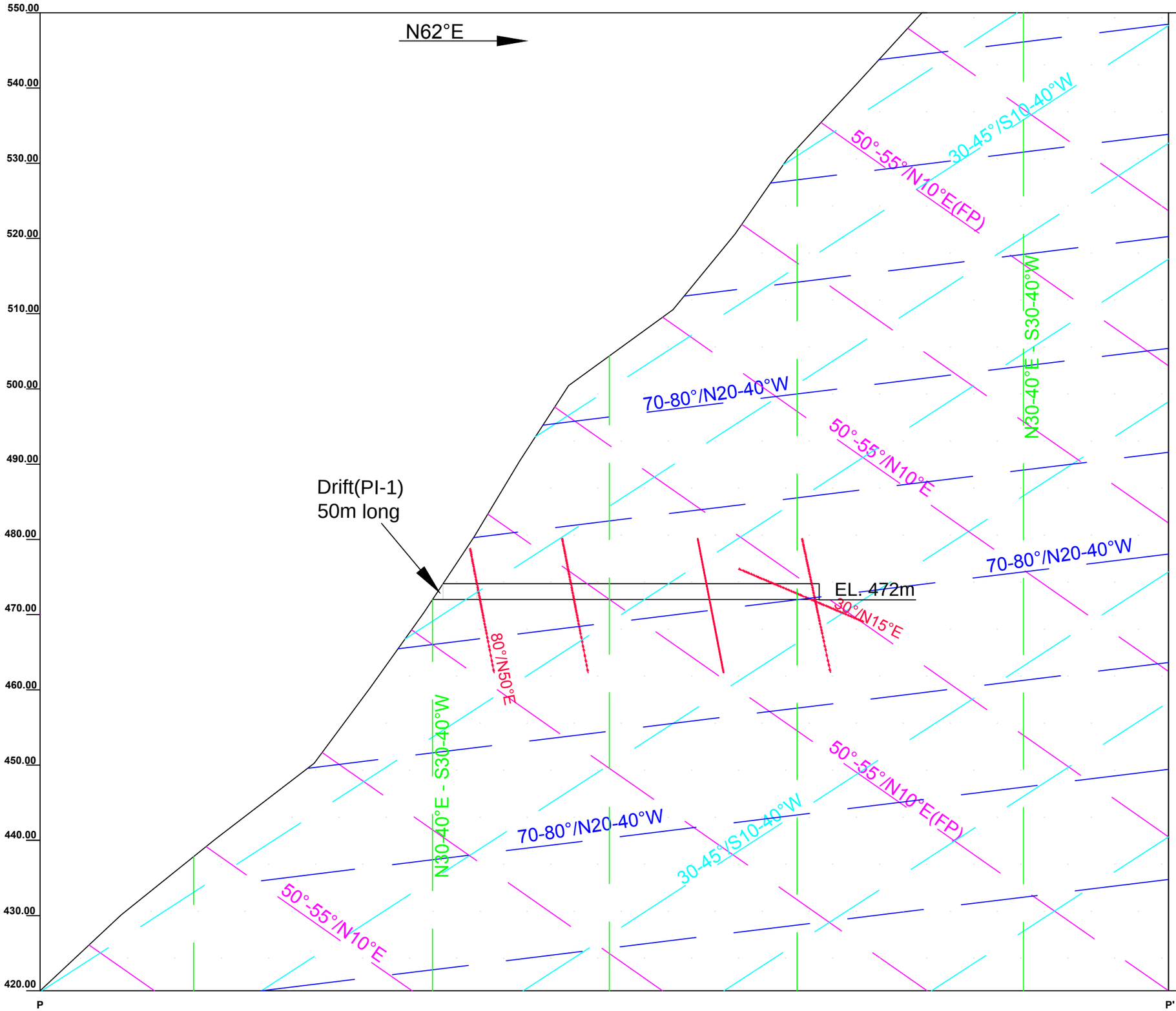
WANGCHU HYDRO ELECTRIC PROJECT(Bhutan).

Geological Section of Diversion Tunnel (DT-1)

अभिकल्पित DSGN.	संशोधित CHKD.	संस्तुत RECM.
रेखांकित DRWN.	प्रस्तुत SUBM.	

SJVNL , Geology Department.

DRG. No.DAM-WHEP-DPR-GEO-011-00	Sep., 2012



INDEX

- River Borne Material
- Slope wash Material
- Quartzite
- Trace of Discontinuity showing Dip amount/Direction
- Shear seam
- Fracutred/Shattered Zone
- Shear Zone

Notes:

1. The geological section is based on geological mapping & geotechnical investigations carried out at dam site area. Refer drg. No. DAM-WHEP-DPR-GEO-006-00
2. The foliation/joints and their spacing depicted in the section are schematic.
3. True attitude of discontinuity is shown along the traces and apparent dips are plotted.

SCALE:

0 10 20 30 40m

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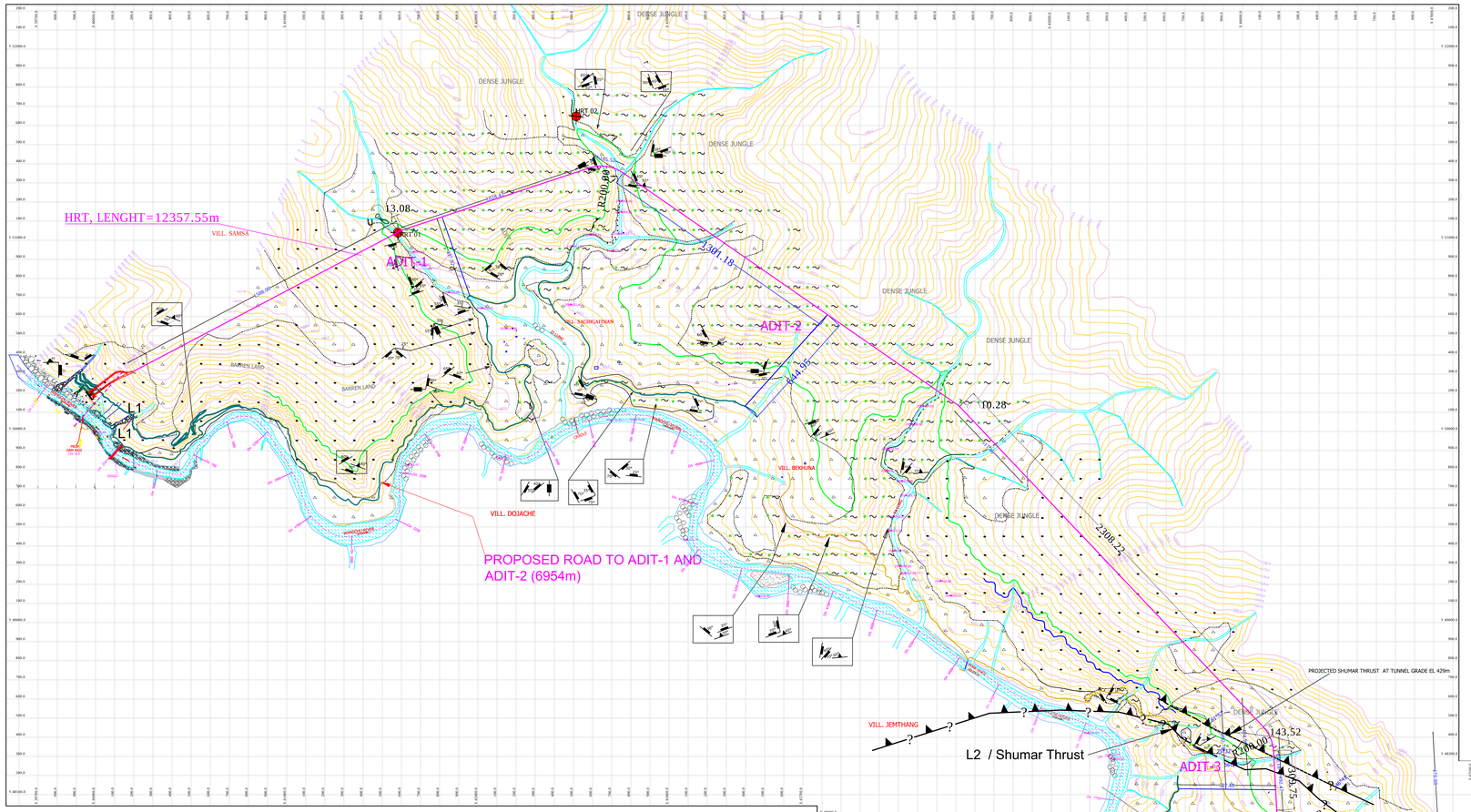
वांगचू जल विद्युत परियोजना (भूटान)
WANGCHU HYDRO ELECTRIC PROJECT.

Geological Section along Power Intake-1

अभिकल्पित DSGN.	सर्वेक्षित CHKD.	संस्तुत RECM.
रेखांकित DRWN.	प्रस्तुत SUBM.	

SJVNL GEOLOGY DEPARTMENT

DRG. No. DAM-WHEP-DPR -GEO-013-00 | **Dec., 2011**



ALIGNMENT NAME	LENGTH OF HRT	LENGTH OF ADITS	TOTAL LENGTH OF ADITS	RD'S OF ADITS
LEFT BANK	12357.55m	ADIT-I=437.92m ADIT-2=644.95m ADIT-3=507.68m ADIT-4=283.67m	1874.22 m	ADIT-I=1811.57m ADIT-2=4109.65m ADIT-3=7603.91m ADIT-4=12322.43m

LEGEND

- RIVER BORNE MATERIAL
- HILLWASH/DEBRIS/SCREE AND SOIL ALLUVIUM
- TERRACE DEPOSITS (T1 T2 T3)
- DOLOMITE
- CARBONACEOUS PHYLLITE
- MASSIVE QUARTZITE
- PHYLLITIC /SCHISTOSE QUARTZITE
- SILTSTONE / SHALE /SLATE / PHYLLITE
- CONGLOMERATE
- STRIKE AND DIP OF BEDDING / FOLIATION (40° / 45°)
- DIP AND STRIKE OF INCLINED / VERTICAL JOINTS (60°)
- FAULT
- THRUST WITH HADE
- THRUST AT TUNNEL GRADE
- AXIS OF SMALL ANTICILINE WITH AMOUNT OF PLUNGE (25)
- LITHOLOGICAL CONTACT: EXPOSED ;INFERRED
- SHEAR ZONE
- LANDSLIDE
- HUTMENTS
- DRILL HOLE (DH)
- BENCH MARK
- LINEAMENT (L L)

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0 50 250 500

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SJVN Limited

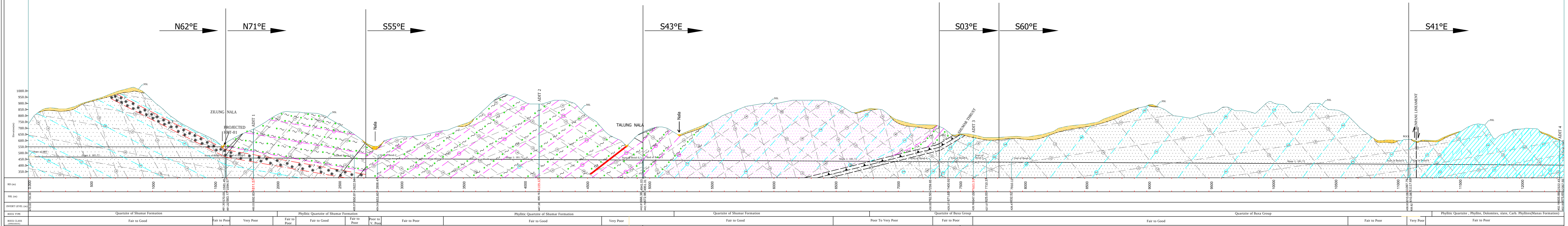
वांगचू जल विद्युत परियोजना(भूटान)
WANGCHU HYDRO ELECTRIC PROJECT(Bhutan).

Geological Plan of Head Race Tunnel

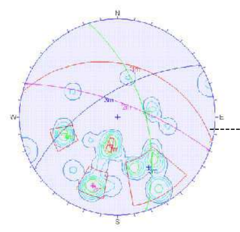
अभिकल्पित DSGN.	संवीक्षित CHKD.	संस्तुत RECM.
रेखांकित DRWN.	प्रस्तुत SUBM.	

SJVNL , Geology Department.

DRG. No.DAM-WHEP-DPR-GEO-014-02	May, 2013



Stereoplots for HRT from Intake to Zilung Nalla

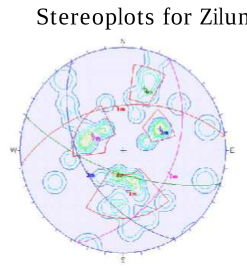


Orientations

ID	Dip/Direction	Range
J1F	33°/015°	25°-40°/010°-020°
J2	73°/020°	60°-80°/010°-030°
J3	62°/328°	50-85°/310-350°
J4	59/073°	50-70°/060-080°

Equal Angle
Lower Hamisphere
32 Poles
32 Entries

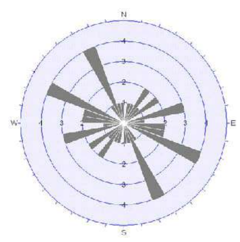
Stereoplots for Zilung Nalla to Talung Nalla HRT Section



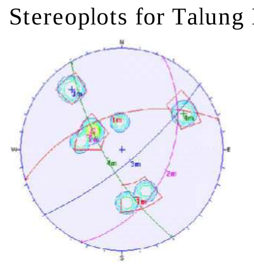
Orientations

ID	Dip/Direction	Range
J1F	43/352	30°-60°/005-340
J2	37/116	30-50/085-145
J3	45/240	40-55/220-260
J4	65/199	55-75/190-208

Equal Angle
Lower Hamisphere
41 Poles
41 Entries



Stereoplots for Talung Nalla to Shumar Thrust HRT Section

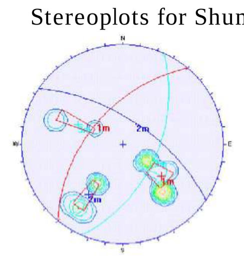


Orientations

ID	Dip/Direction	Range
J1F	52/343	50°-55°/330°-335°
J2	39°/114°	35°-45°/100°-125°
J3	75°/140°	75°/140°
J4	70°/240°	70°/240°

Equal Angle
Lower Hamisphere
08 Poles
08 Entries

Stereoplots for Shumar Thrust to Nunpani Fault HRT Section

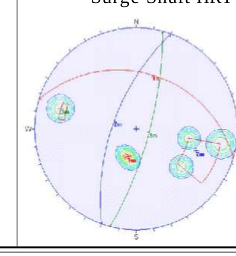


Orientations

ID	Dip/Direction	Range
J1F	53/310	45°-60°/300°-320°
J2	62°/034°	60°-65°/030°-040°
J3	52°/114°	35°-70°/110°-120°

Equal Angle
Lower Hamisphere
08 Poles
08 Entries

Stereoplots for Nunpani Fault to Surge Shaft HRT Section



Orientations

ID	Dip/Direction	Range
J1F	53/310	45°-60°/300°-320°
J2	62°/034°	60°-65°/030°-040°
J3	52°/114°	35°-70°/110°-120°

Equal Angle
Lower Hamisphere
08 Poles
08 Entries

LEGEND

- RIVER/NALLA BORNE MATERIALS
- HILLWASH/ DEBRIS/ SCREE AND SOIL ALLUVIUM
- WHITE GREY QUARTZITE } SHUMAR FORMATION
- PHYLLITIC /SCHISTOSE QUARTZITE } SHUMAR FORMATION
- GRITTY/FELDSPATHIC QUARTZITE — THUNGSING FORMATION } BUXA GROUP
- DOLOMITE WITH THIN INTERBAND OF CARBONACEOUS PHYLLITE — MANAS FORMATION } BUXA GROUP
- LITHOLOGICAL CONTACT: EXPOSED ;INFERRED
- THRUSTS
- SHEAR ZONES
- HIGHLY JOINTED/FRACTURED/SHATTERED WITH SHEAR ZONES
- HRT ALLINGMENT
- FOLIATION/BEDDING JOINTS
- JOINTS

SCALE : 0 50 100 150 200 250m

1.The Foliation/Bedding joints and their spacing depicted in the section are schematic.
3. This section should be read with the text.
4. Chainage/bounderies of rock classes are approximate and calculated from limited field data.

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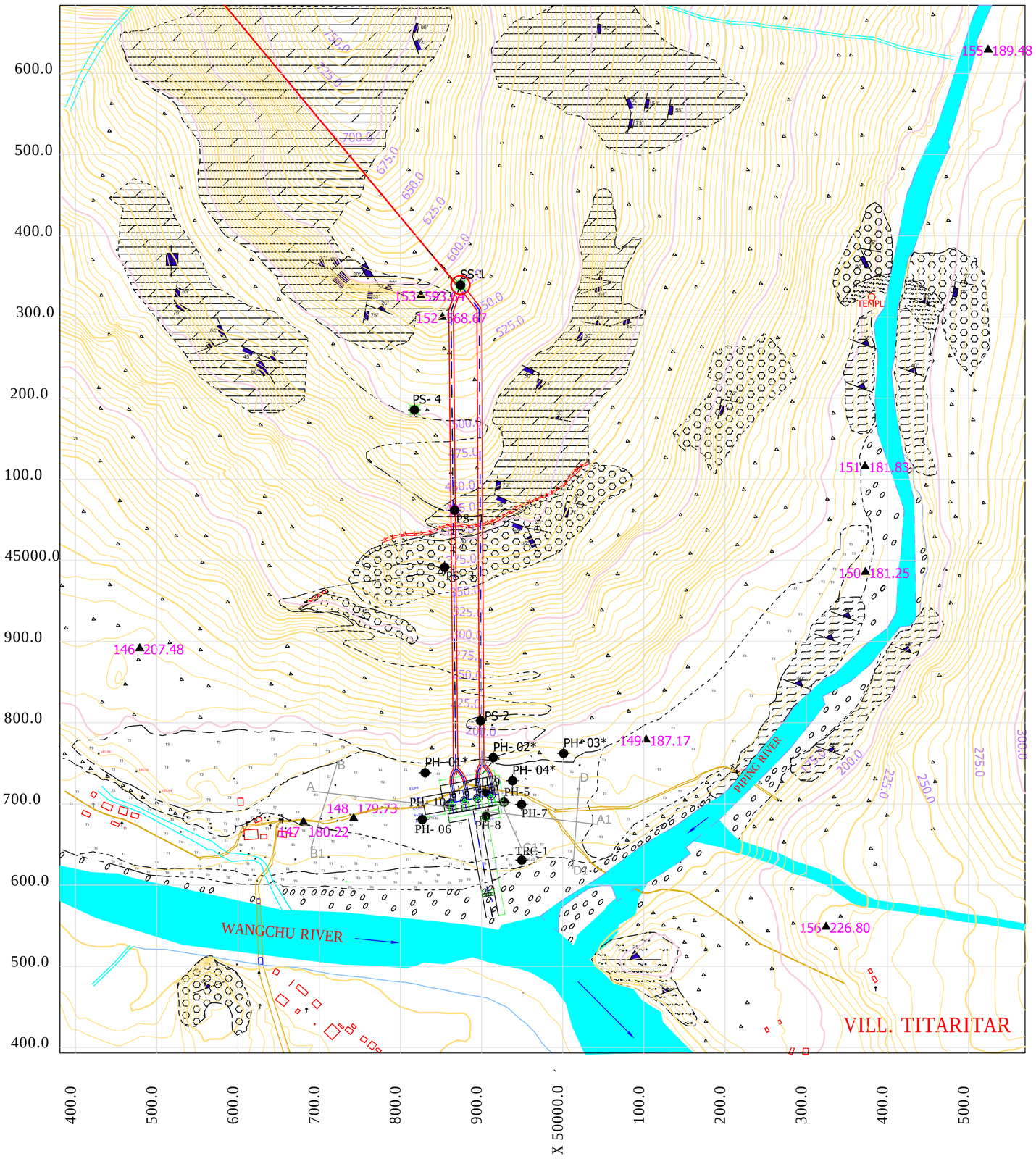
एसजेवीएन लिमिटेड SJVN Limited		
WANGCHU HYDRO ELECTRIC PROJECT(Bhutan).		
Geological Section along Head Race Tunnel Alignment (Ch. 0.00m to 12357.55m)		
DSGN.	CHKD.	RECM.
DRWN.	SUBM.	
SJVNL , Geology Department.		
DRG. No.DAM-WHEP-DPR-GEO-015-03	May., 2013	



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LEGEND

- LOOSE BOULDER, COBBLE, GRAVEL AND SAND MATERIAL
- HILLWASH/ DEBRIS/ SCREE AND SOIL
- TERRACE DEPOSITS (ASSORTED TO INASSORTED COBBLE, PEBBLES, GRAVEL AND SAND AT DIFFERENT LEVELS)
- DOLOMITE
- SHEARED CARBONACEOUS PHYLLITE
- BUFF WHITE/ WHITE AND PINK QUARTZITE
- GREENISH GREY QUARTZITE WITH INTERBANDS OF GREYISH GREEN PHYLLITIC QUARTZITE
- PURPLE- MAROON SILTSTONE / SHALE / PHYLLITE
- STRIKE AND DIP OF BEDDING / FOLIATION
- DIP AND STRIKE OF INCLINED JOINTS
- VERTICAL JOINTS
- AXIS OF OVERTURNED FOLD WITH AMOUNT AND DIRECTION OF PLUNGE
- AXIS OF SMALL ANTICLINE WITH AMOUNT OF PLUNGE
- LITHOLOGICAL CONTACT: EXPOSED ;INFERRED
- SHEAR ZONE
- LANDSLIDE
- HUTMENTS
- PH- 07* DRILL HOLE (by SJVN LTD.)
- PH- 03* DRILL HOLE(by WAPCOS)
- BENCH MARK
- GEOPHYSICAL LINES

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SJVN LIMITED.

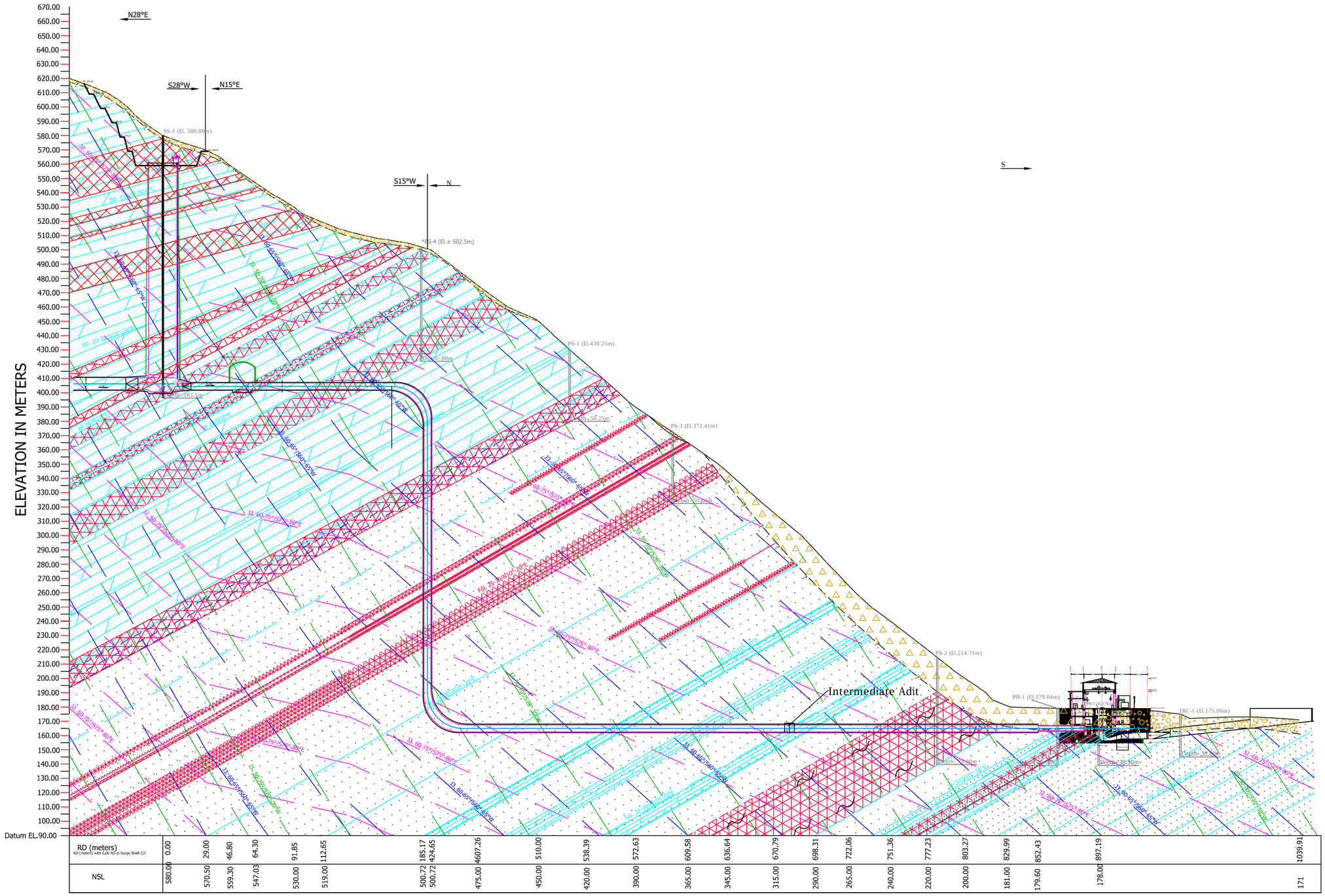
WANGCHU HYDRO ELECTRIC PROJECT.

Geological Map of Power House Area

अभिकल्पित DSGN.	सर्वीक्षित CHKD.	संस्तुत RECM.
रेखांकित DRWN.	प्रस्तुत SUBM.	

SJVNL GEOLOGY DEPARTMENT

DRG. No. PH-WHEP-DPR-GEO- DPR -016-01 | Dec., 2011



INDEX

- River Borne Material
- Slope wash Material
- Quartzite
- Dolomite
- Carbonaceous Phyllites
- Slate
- Trace of Foliation/bedding with Dip amount/Direction (Fol. 25-30/N10°-20°E)
- Trace of Discontinuity with Dip amount/Direction (J1-80/S65°W)
- Shear seam
- Shear Zone
- Drill Hole Completed
- Drill Hole Proposed
- Inferred Lithological Contact

Notes:

1. The geological section is based on geological mapping & geotechnical investigations carried out at dam site area. Refer drg. No. PH-WHEP-DPR-GEO-016-00
2. The foliation/joints and their spacing depicted in the section are schematic.
3. True attitude of discontinuity is shown along the traces and apparent dips are plotted.
4*. Elevation of Drillhole PS-4 may vary and location/depth of Shear encountered in hole will vary accordingly

SCALE 0 10 20 30 40 50m

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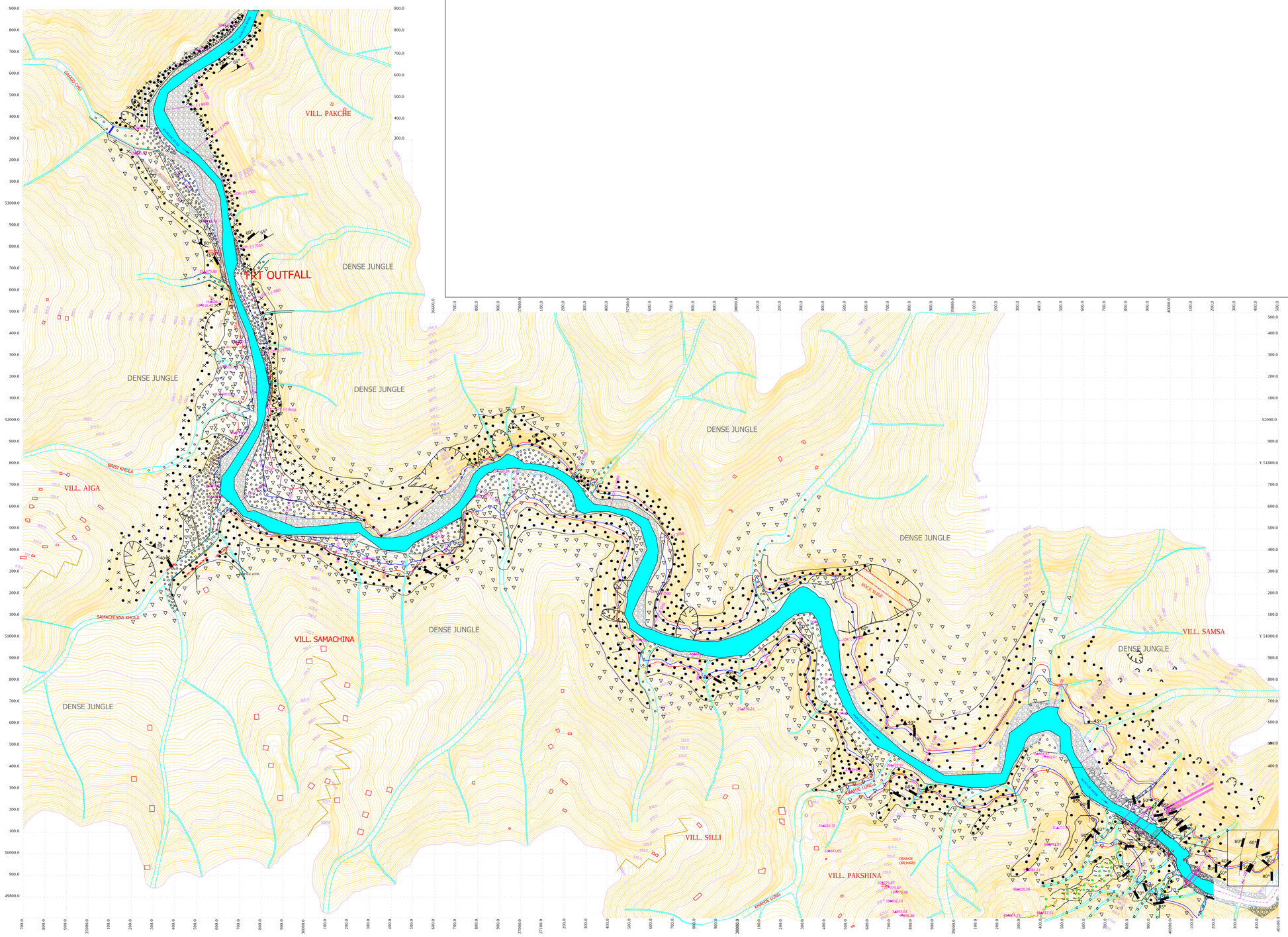
वांगचू जल विद्युत परियोजना(भूटान)
WANGCHU HYDRO ELECTRIC PROJECT.

GEOLOGICAL SECTION FROM SURGE SHAFT TO TR CHANNEL

अभिकल्पन DSGN.	सर्वाधित CHKD.	संशुद्ध RECM.
रेखांकित DRWN. DEVI CHAND	प्रस्तुत SUBM.	

SJVNL GEOLOGY DEPARTMENT

DRG. No. PH-WHEP-DPR -GEO-017-01 | Sept., 2012



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W E
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LEGEND

- RIVER BORNE MATERIALS
- UNDIFFERENTIATED T0/T1/T2 TERRACE DEPOSITS
- HILLWASH/ DEBRIS/ SCREE/TALLUS AND SOIL ALLUVIUM
- WHITE AND GREY QUARTZITE OF SHUMAR FORMATION WITH AUGEN GNEISS SLIVERS OF THIMPHU CRYSTALLINE
- WHITE AND GREY QUARTZITE — SHUMAR FORMATION
- PHYLLITIC QUARTZITE
- SHEARED AND SEEPAGE ZONE
- LITHOLOGICAL CONTACT: EXPOSED ;INFERRED
- ROCK / LAND SLIDE
- FRL (494 m)
- MDDL (484 m)
- METAL ROAD TO TALA TRT OUTFALL

SCALE

500m 0 500m

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SJVN Limited

वांगचू जल विद्युत परियोजना भूटान
WANGCHU HYDRO ELECTRIC PROJECT(Bhutan).

Geological Map of Reservoir Area

अभिकल्पित DSGN.	सर्वीक्षित CHKD.	संस्तुत RECM.
रेखांकित DRWN.	प्रस्तुत SUBM.	

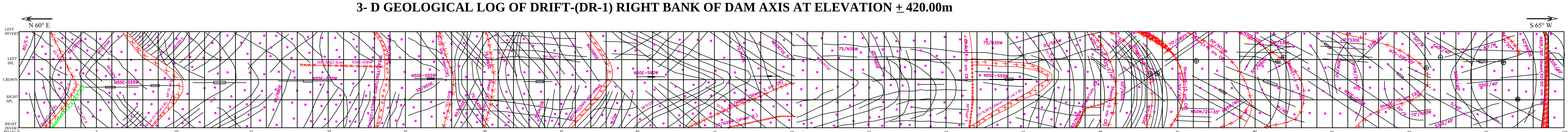
SJVNL , Geology Department.

DRG. No. DAM-WHEP-DPR-018 -02 | **Jan., 2013**

SJVN LIMITED

WANGCHHU HYDROELECTRIC PROJECT, BHUTAN

3- D GEOLOGICAL LOG OF DRIFT-(DR-1) RIGHT BANK OF DAM AXIS AT ELEVATION ± 420.00m



ROCK TYPE	WHITE TO LIGHT GREY COLOURED, FINE GRAINED, CLOSELY TO MODERATELY JOINTED QUARTZITE	WHITE TO LIGHT GREY COLOURED, FINE GRAINED, CLOSELY JOINTED QUARTZITE	WHITE TO LIGHT GREY COLOURED, FINE GRAINED, CLOSELY TO MODERATELY JOINTED QUARTZITE	WHITE TO LIGHT GREY COLOURED, FINE GRAINED, CLOSELY JOINTED QUARTZITE	WHITE TO LIGHT GREY COLOURED, FINE GRAINED, CLOSELY TO MODERATELY JOINTED QUARTZITE								
WEATHERING	W0 - W1												
SEEPAGE	DRY	MOIST TO SLIGHT DRIPPING	DRY	DRY TO SLIGHT DRIPPING									
ROCK CLASSIFICATION	'Q' 5.56 to 6.67 (Fair rock)	'Q' 2.22 to 2.50 (Poor rock)	'Q' 10.0 to 14.44 (Good rock)	'Q' 5.56 to 10.83 (Good to fair rock)	'Q' 1.33 to 1.50 (Poor rock)	'Q' 7.50 to 8.33 (Fair rock)	'Q' 2.50 to 3.70 (Poor rock)	'Q' 4.81 to 7.22 (Fair rock)	'Q' 15.56 to 16.67 (Good rock)	'Q' 5.0 to 7.22 (Fair rock)	'Q' 1.33 to 1.88 (Poor rock)	'Q' 5.0 to 5.19 (Fair rock)	'Q' 2.96 to 3.7 (Poor rock)

SCALE

-1m 0 1 2 3m

NOTE:

The tentative stripping limit has been kept at 12 m, i.e. after the stripping of the 60°/N40°E dipping shear.

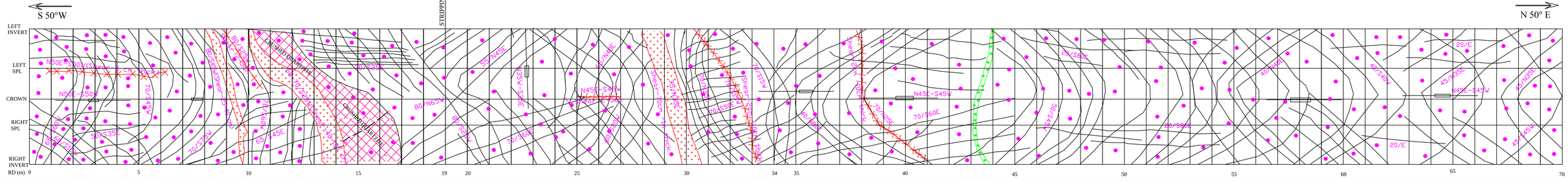
PROMINENT JOINT SETS

SL.No	Strike direction	Dip amount and direction	Continuity
1	N20-45W/S20-45E	40°-70° / S45-70W	>5 m
2	N35W- S35E / N-S	30°-45° / N55E-E	2 to >5 m
3	N55-60E/ S55-60W	Vertical	2 to 4 m
4	N10-45W / S10-45E	60°-70° /N45-80E	2 to >5 m
5	N20-55E / S20-55W	75°/N35-70W	2 to >5 m
6	N70W-S70E	35° /S20W	3- 5 m

INDEX

1.	● ● ●	QUARTZITE
2.	(green box)	QUARTZ VEIN
3.	(curve)	JOINT WITH DIP AMOUNT AND DIRECTION
4.	(box on line)	VERTICALLY DIPPING JOINT
5.	(red hatched)	SHEAR (<1cm) WITH DIP AMOUNT AND DIRECTION
6.	✗ ✗ ✗	SHEAR (1 TO 10cm) WITH DIP AMOUNT AND DIRECTION
7.	(boxed ✗ ✗ ✗)	SHEAR (WITH MEASURED THICKNESS) WITH DIP AMOUNT AND DIRECTION
8.	⊕	DRIPPING CONDITION

एसजेवीएन लिमिटेड SJVN LIMITED.		
WANGCHU HYDRO ELECTRIC PROJECT.		
3-D LOG DRIFT DR-1 (RIGHT BANK OF DAM AXIS EL+ 420m) FROM RD 0m TO 100m		
अभिकल्पित DSGN. / रेखांकित DRWN.	सर्वेक्षित CHKD. / प्रस्तुत SUBM.	संस्तुत RECM.
SJVNL GEOLOGY DEPARTMENT		
DRG. No. DAM-WHEP-DPR-GEO- DPR -019-R1	July., 2012	



ROCK TYPE	WHITE TO LIGHT GREY COLOURED,FINE GRAINED CLOSELY TO MODERATELY JOINTED QUARTZITE					
WEATHERING	W1					
SEEPAGE	MOIST TO DRIPPING CONDITION		DRY	MOIST CONDITION	DRY	DRIPPING
ROCK CLASSIFICATION	GOOD TO FAIR	POOR TO VERY POOR	FAIR	POOR	GOOD TO FAIR	

PROMINENT JOINTS

SL.No	Strike direction	Dip amount and direction	Continuity
1	N15-45W - S15-45E	50°-78° / S45-75W	4 to >5 m
2	N65-75W - S65-75E	60°-80° / S15-25W	2 to >5 m
3	N30-55E - S30-55W	50°-70° / S35-60E	2 to > 5 m
4	N45-55W - S45-55E	40°-70° /N35-45E	>5 m
5	N-S - N10E-S10W	20°/ S80E-E	3 to 5 m
6	N45-50E - S45-50W	Vertical	2 to 4 m
7	N10-W - S10E	40° /N80E	>5 m

INDEX

1.		QUARTZITE
2.		QUARTZ VEIN
3.		JOINT WITH DIP AMOUNT AND DIRECTION
4.		VERTICALLY DIPPING JOINT
5.		SHEAR (<1cm) WITH DIP AMOUNT AND DIRECTION
6.		SHEAR (1 TO 10cm) WITH DIP AMOUNT AND DIRECTION
7.		BLACK SHEAR (WITH MEASURED THICKNESS) WITH DIP AMOUNT AND DIRECTION
8.		CRUSHED QUARTZITE
9.		FAULT

SCALE

-1m 0 1 2 3m

SJVN LIMITED.

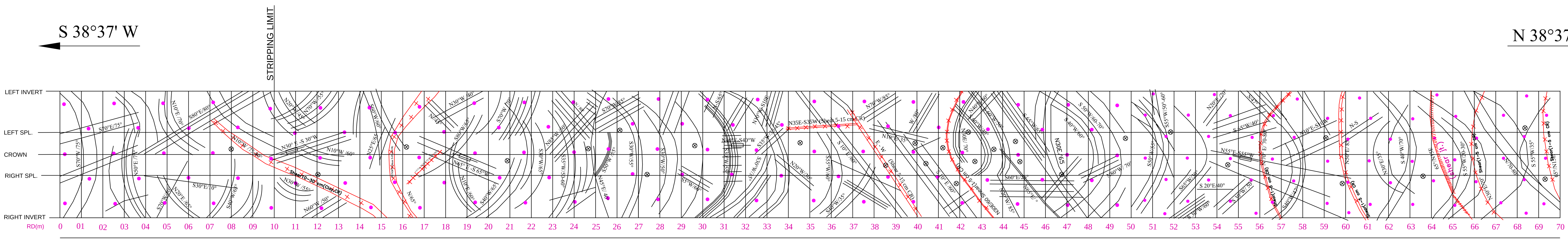
WANGCHU HYDRO ELECTRIC PROJECT.

3-D Geological Log of Drift DL-1(Left Abutment, El 420m),(Ch.0.00m to 70.00m)

अभिकल्पित DSGN.	समीक्षित CHKD.	संगत RECM.
रेखांकित DRWN.	प्रस्तुत SUBM.	

SJVNL GEOLOGY DEPARTMENT

DRG. No. DAM-WHEP-DPR-GEO-020-R1 | Dec., 2011



ROCK TYPE	WHITE TO LIGHT GREY COLOURED, FINE GRAINED, CLOSELY TO MODERATELY JOINTED QUARTZITE					
WEATHERING						
SEEPAGE	DRY	MOIST TO SLIGHT DRIPPING	DRIPPING	HEAVY DRIPPING	DRIPPING	
ROCK CLASSIFICATION	GOOD TO FAIR	POOR	FAIR	POOR	FAIR	POOR TO FAIR

-1m 0 1 2 3m

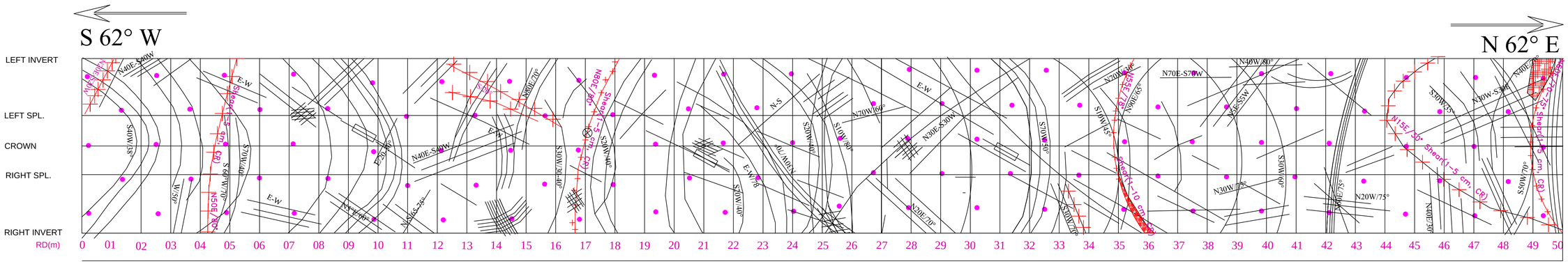
PROMINENT JOINTS

SL.No	Strike direction	Dip amount and direction	Continuity
1	N25-60W - S25-60E	40°-70° / S30-65W	2 to >5 m
2	N60-80W - S60-80E	65°-70° / N10-30E	2 to >5 m
3	N10W-N40E - S10E-S40W	Vertical	1 to 4m
4	N60-80E - S60-80W	30°-60° /N10-30W	2 to 3m
5	N10-30E - S10-30W	50°-85°/ N60-80W	2 to 3 m
6	N35-60W - S35-60E	20°-35°/ S30-55W	2 to >5 m

INDEX

1.	● ● ●	QUARTZITE
2.		JOINT WITH DIP AMOUNT AND DIRECTION
3.		VERTICALLY DIPPING JOINT
4.		SHEAR (<1cm) WITH DIP AMOUNT AND DIRECTION
5.		SHEAR (1 TO 10cm) WITH DIP AMOUNT AND DIRECTION
6.		SHEAR (WITH MEASURED THICKNESS) WITH DIP AMOUNT AND DIRECTION
7.	⊗	DRIPPING LOCATION

SJVN LIMITED.		
WANGCHU HYDRO ELECTRIC PROJECT.		
3-D Geological Log of Drift DL-2(Left Abutment, El. 460m),(Ch.0.00m to 70.00m)		
अभिकल्पित DSGN. / रेखांकित DRWN.	सवीक्षित CHKD. / प्रस्तुत SUBM.	संस्तुत RECM.
SJVNL GEOLOGY DEPARTMENT		
DRG. No. DAM-WHEP-DPR-GEO-021-R1	Dec., 2011	



ROCK TYPE	WHITE TO LIGHT GREY COLOURED, FINE GRAINED, CLOSELY TO MODERATELY JOINTED QUARTZITE
WEATHERING	W1
SEEPAGE	MOSTLY DRY CONDITIONS BUT DRIPPING AND MOIST AT PLACES
ROCK CLASSIFICATION	FAIR / FAIR / POOR / FAIR / POOR

PROMINENT JOINT SETS

SL.No	Strike direction	Dip amount / direction	Continuity
1	N50-70W TO S50-70E	30-45°/S10-40°W	2 to >5 m
2	N50-70E TO S50-70W	70-80°/N20-40°W	
3	N30-40E TO S30-40W	VERTICAL	
4	E-W	VERTICAL	2 to 3 m
5	N20-40W- S20-40E	50-70°/S50-70°W	

INDEX

1.	● ● ●	QUARTZITE
2.		JOINT WITH DIP AMOUNT AND DIRECTION
3.		VERTICALLY DIPPING JOINT
4.		SHEAR (<1cm) WITH DIP AMOUNT AND DIRECTION
5.		SHEAR (1 TO 10cm) WITH DIP AMOUNT AND DIRECTION
6.		SHEAR (WITH MEASURED THICKNESS) WITH DIP AMOUNT AND DIRECTION
7.	⊗	DRIPPING LOCATION

-1m 0 1 2 3m

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SJVN LIMITED.

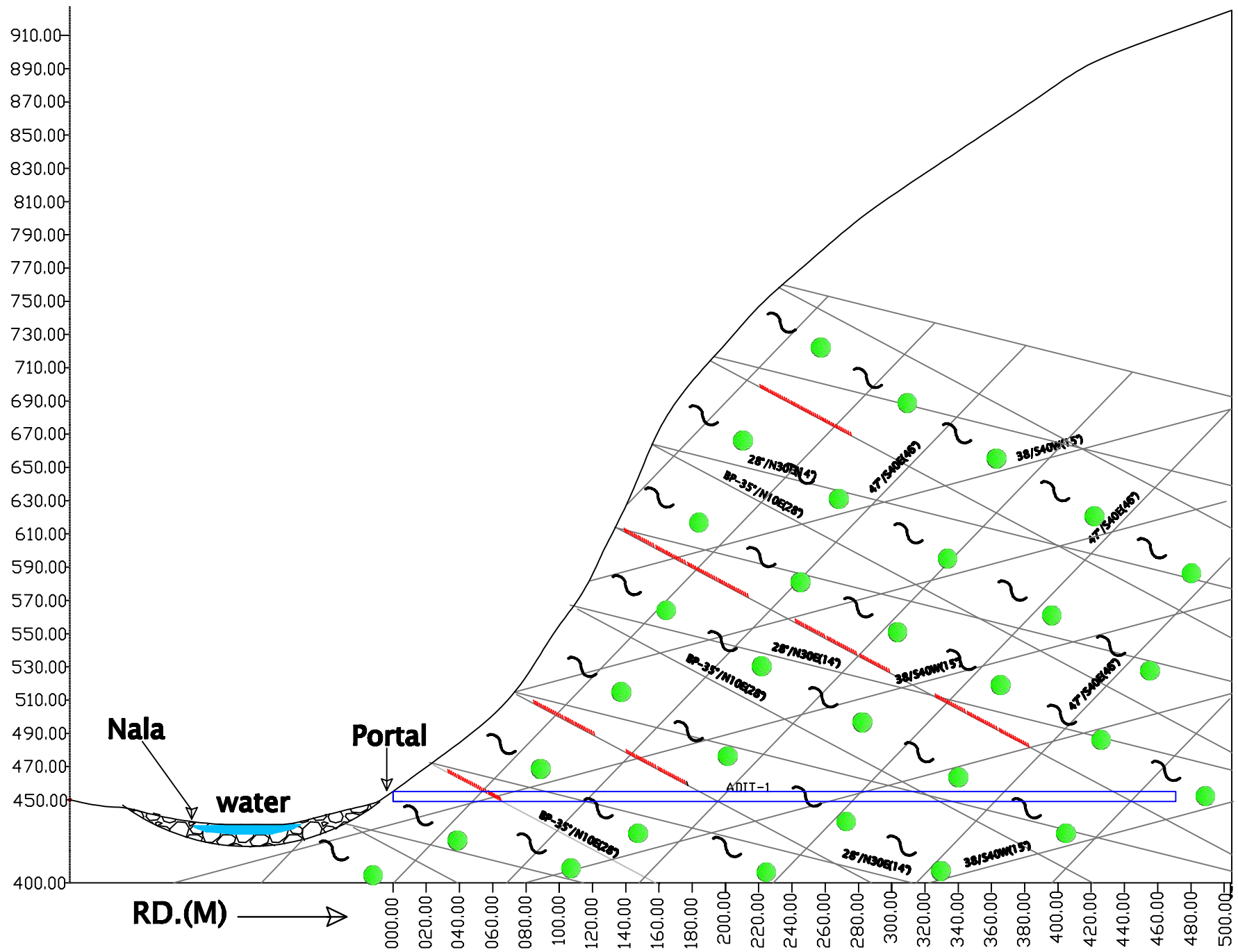
वांगचू जल विद्युत परियोजना (भूटान)
WANGCHU HYDRO ELECTRIC PROJECT.

3-D Geological Log of Drift PI-1(Power Intake on Left bank, El 472m), (Ch.0.00m to 50.00m)

अभिकल्पित DSGN.	सत्यापित CHKD.	संस्तुत REC'M.
रेखांकित DRWN.	प्रस्तुत SUBM.	

SJVNL GEOLOGY DEPARTMENT

DRG. No. DAM-WHEP-DPR-GEO-022-00 | Dec., 2011



INDEX

Phyllitic-Quartzite(Shumar Formation)

Joint trace with Apparent dip in Brackets.

Shear Seam

Remarks-

1. For Plan refer Drg. NO. HRT-WHEP-DPR-GEO-014/R1
2. Rock is Phyllitic-Quartzite(Shumar Formation)
3. Portal area not accessable.
4. Joints taken /interpolated from u/s Zilung nala out-crops.
5. Profile developed from 1:5000 survey sheet.
6. 3 or 3+R Joint sets to be encountered during excavation

Scale: 0 20 40 60 80m

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SJVN Limited

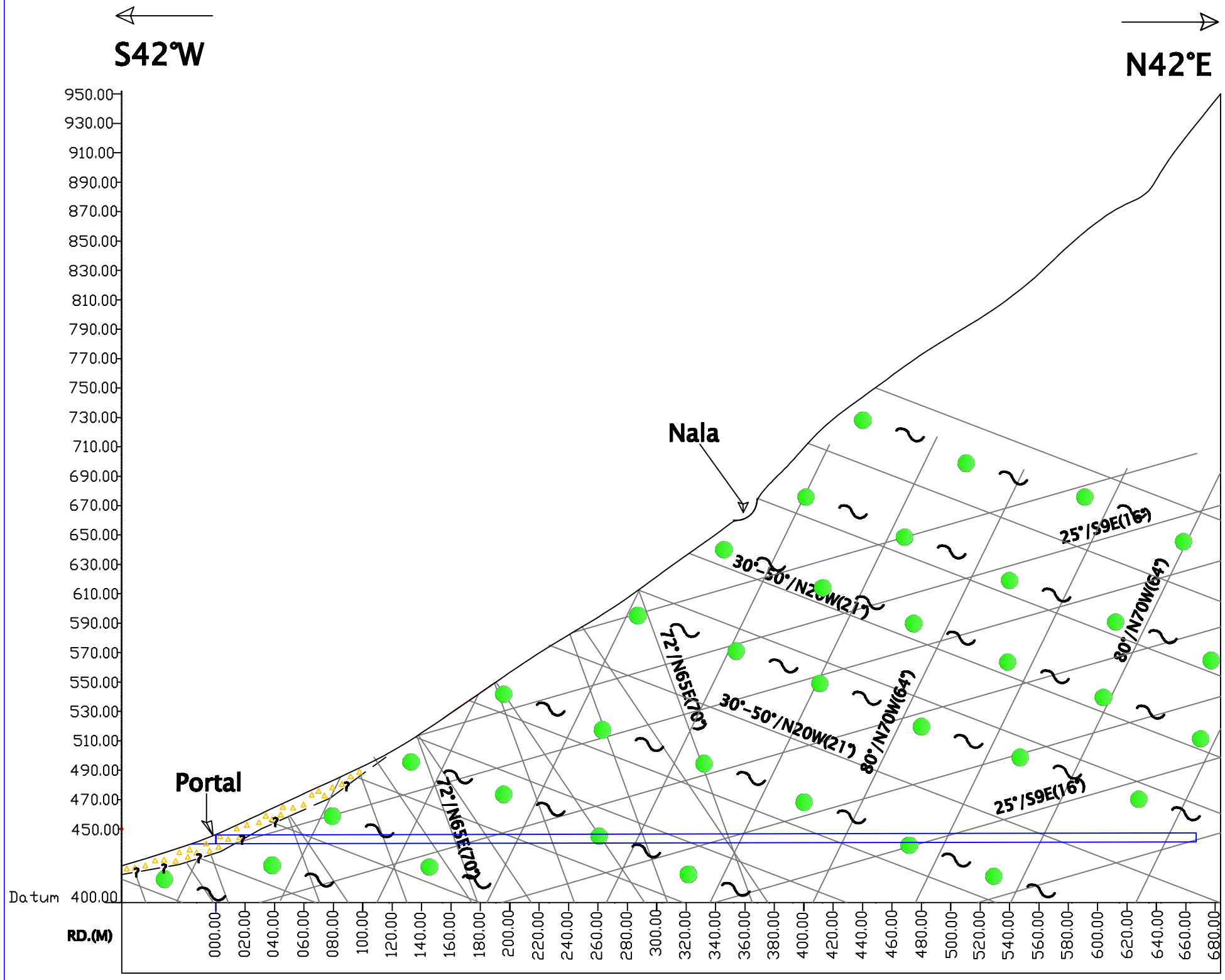
वांगचू जल विद्युत परियोजना(भूटान)
WANGCHU HYDRO ELECTRIC PROJECT(Bhutan).

Geological Section along Adit-1 of HRT

DESIGN.	CHKD.	RECM.
DRAWN.	SUBM.	

SJVNL , Geology Department.

DRG. No.HRT-WHEP-DPR-GEO-023-00	July., 2012



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Slope Wash Material

Phyllitic-Quartzite(Shumar Formation)

47°/S40E(40°)

Joint trace with Apparent dip in Brackets.

Remarks-

1. For Plan refer Drg. NO. HRT-WHEP-DPR-GEO-014/R1
2. Rock is Phyllitic-Quartzite(Shumar Formation)
3. Portal is in overburden.
4. Profile developed from 1:5000 survey sheet.
5. Groundwater seepage likely along the nala along steep dipping joint plane.(80/N70W).
6. 3 or 3+R Joint sets to be encountered during excavation

Scale: 0 20 40 60 80m

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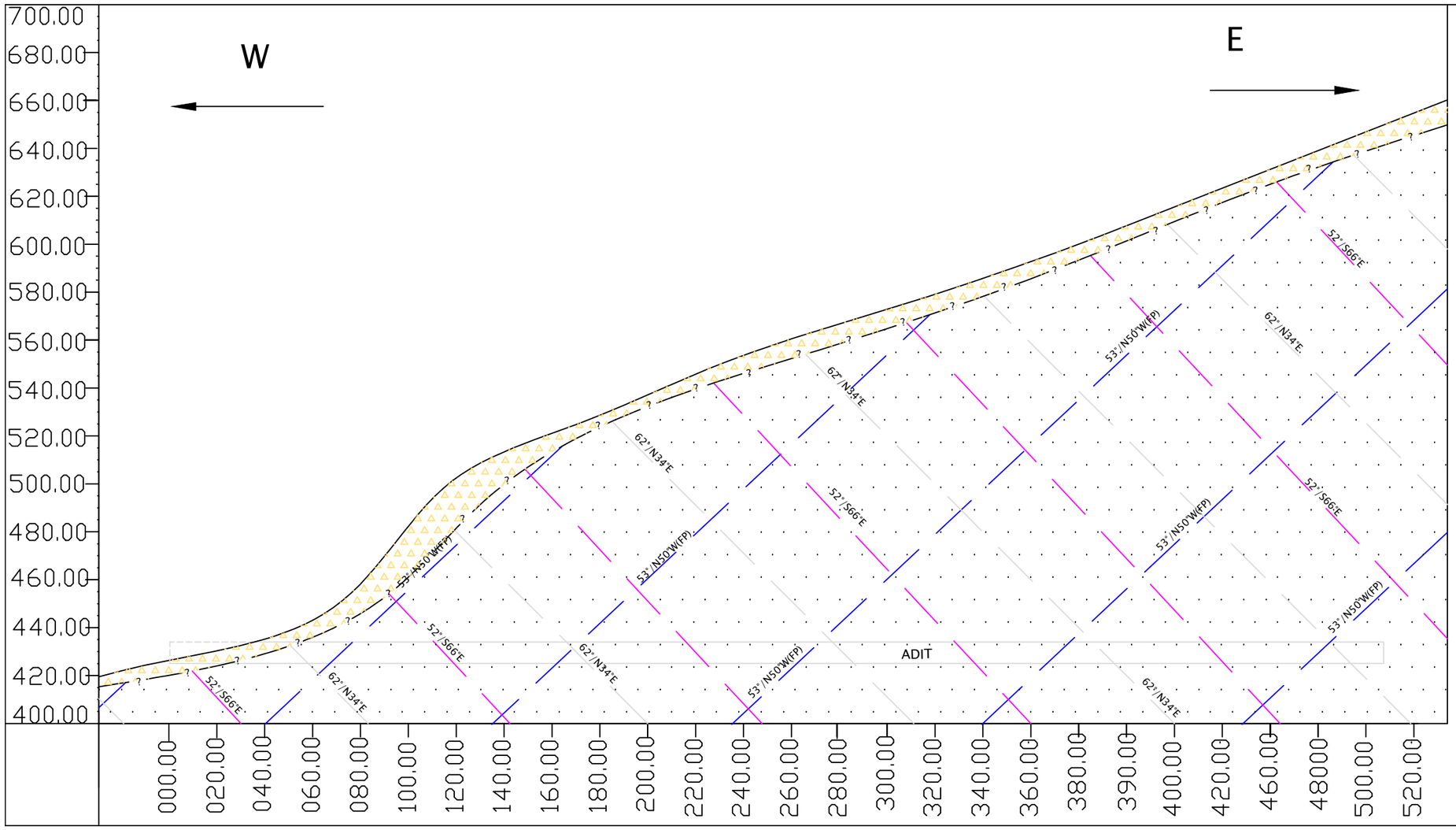
वांगचू जल विद्युत परियोजना (भूटान)
WANGCHU HYDRO ELECTRIC PROJECT(Bhutan).

Geological Section along Adit-2 of HRT

DESIGN.	CHKD.	RECM.
DRAWN.	SUBM.	

SJVNL , Geology Department.

DRG. No.HRT-WHEP-DPR-GEO-024-00 | July., 2012



INDEX

Slope Wash Material

Gritty/feldspathic Quartzite

Joint traces (Dip amount/ dip direction)

Remarks-

1. For Location of Adit refer Drg. No. HRT-WHEP-DPR-GEO-014-03
2. Rock is Gritty/feldspathic Quartzite of Thungsung Formation of Buxa Group.
3. Profile developed from 1:5000 survey sheet.
4. Spacing of joints depicted in the section are schematic.

Scale: 0 20 40 60m

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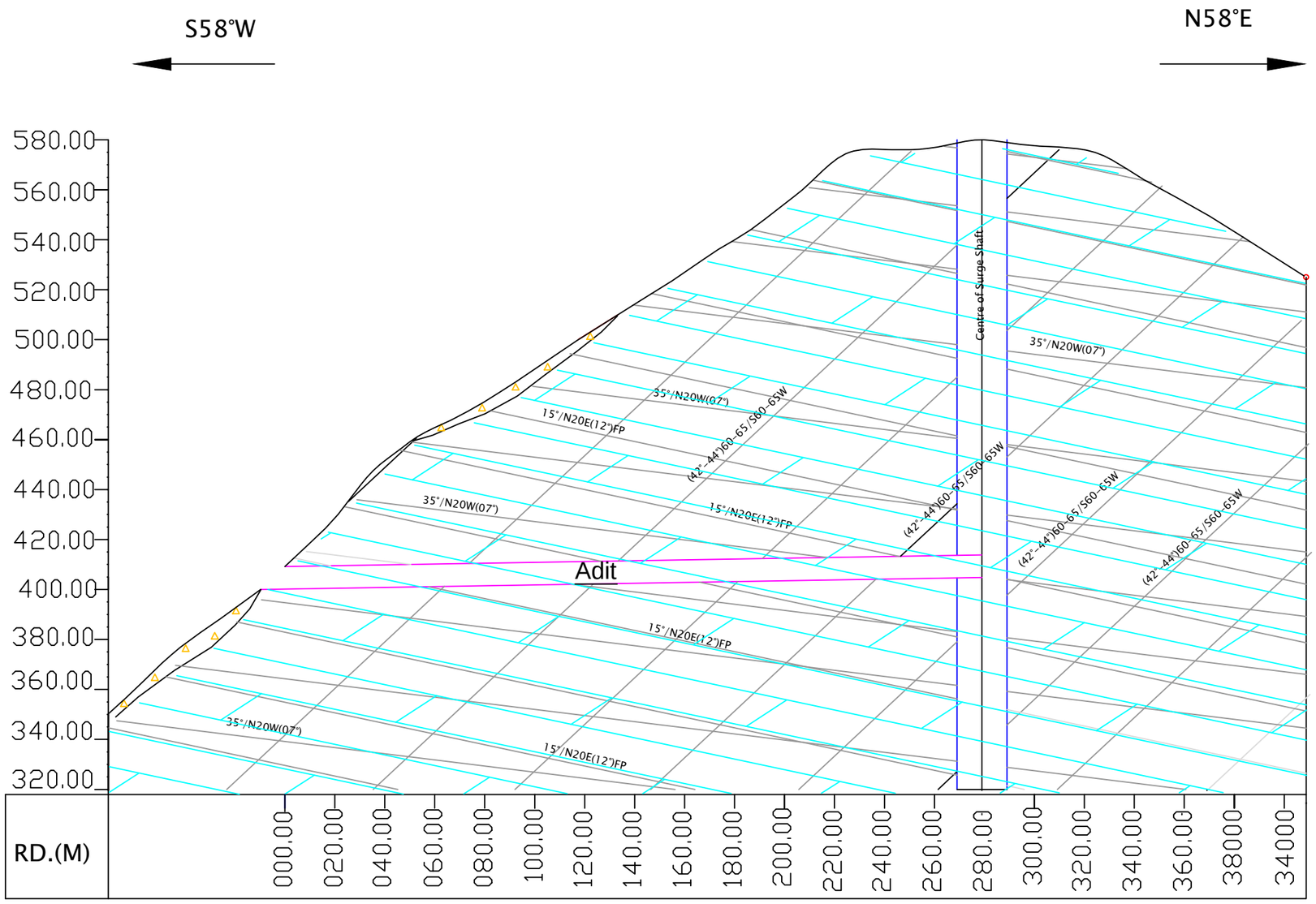
वांगचू जल विद्युत परियोजना (भूटान)
WANGCHU HYDRO ELECTRIC PROJECT(Bhutan).

Geological Section along Adit-3(507.68m) of HRT

अभिकल्पित DSGN.	संवीक्षित CHKD.	संस्तुत RECM.
रेखांकित DRWN.	प्रस्तुत SUBM.	

SJVNL , Geology Department.

DRG. No.HRT-WHEP-DPR-GEO-025-01 | April., 2014



INDEX

- Slope Wash Material
- Dolomite
- Joint trace with apparent dip in Bracket (47°/S40E46°)

Remarks-

1. For Location of Adit refer Drg. No. HRT-WHEP-DPR-GEO-014-03
2. Rock is Dolomite(Buxa Group)
3. Profile developed from 1:5000 survey sheet.
4. Spacing of joints depicted in the section are schematic.

Scale: 0 20 40m

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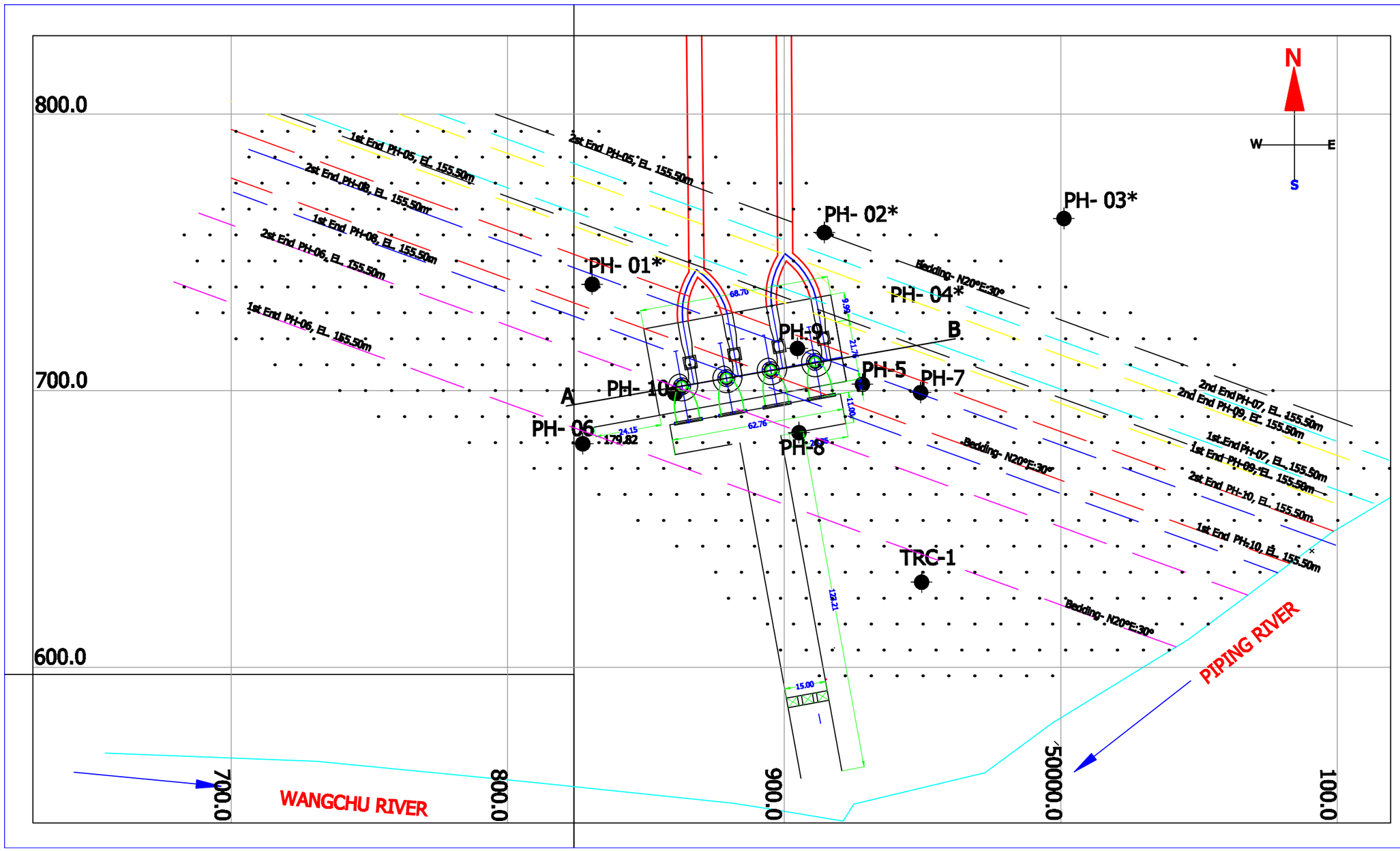
वांगचू जल विद्युत परियोजना (भूटान)
WANGCHU HYDRO ELECTRIC PROJECT(Bhutan).

Geological Section along Adit-4 of HRT

अभिकल्पन DSGN.	परीक्षित CHKD.	संस्तुत RECM.
रेखांकित DRWN.	प्रस्तुत SUBM.	

SJVNL , Geology Department.

DRG. No.HRT-WHEP-DPR-GEO-027-00 | April., 2014



INDEX

- Overburden/RBM
- Quartzite
- PH- 08 Drill Holes Drilled by SJVNL
- PH- 03* Drill Holes Drilled by WAPCOS

Remarks

1. For section along AB refer Drg. No. PH-WHEP-DPR-GEO- 029/00
2. Drill Holes PH-6 to PH-10 done by SJVN are projected, whereas drill holes by GSI are quite away from line and hence not considered.
3. All drill holes (PH-6 to PH-10) are drilled from El. ± 179m

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SJVN LIMITED.

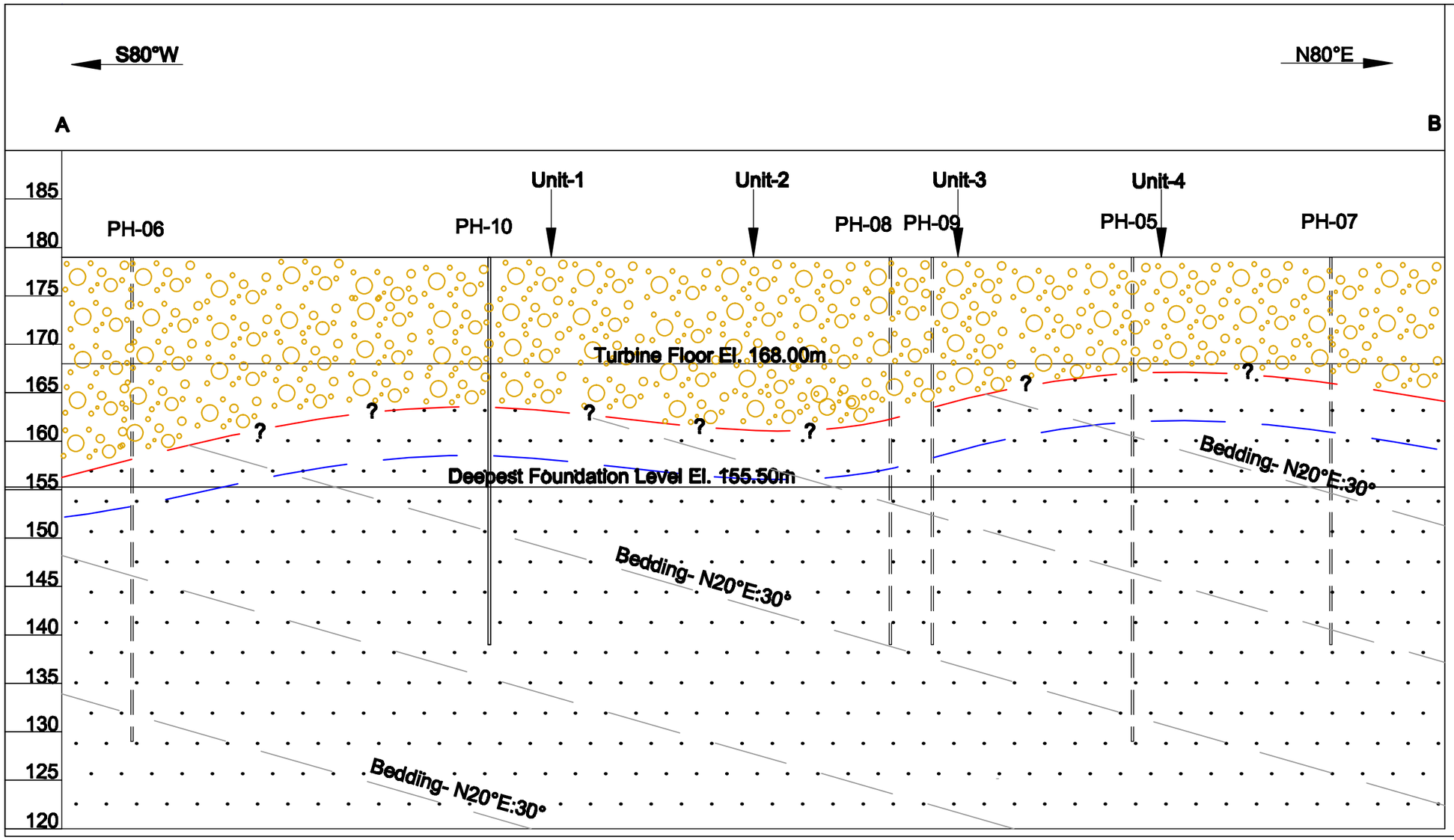
WANGCHU HYDRO ELECTRIC PROJECT.

Geological Plan at Deepest Foundation Level (155.50m)

अभिकल्पित DSGN.	समीक्षित CHKD.	संस्तुत RECM.
रेखांकित DRWN.	SUBM. प्रस्तुत	

SJVNL GEOLOGY DEPARTMENT

DRG. No. PH-WHEP-DPR-GEO- DPR -028-00 | July., 2012



INDEX

RBM

Quartzite

PH-07 — Projected Drill Hole

Foundation Grade Rock Line

Remarks-

1. For Plan refer Drg. NO. PH-WHEP-DPR-GEO-016/R1
2. Drill Holes are projected. Holes PH-06 to PH-10 are projected where as Holes done by GSI are quite away from longer axis and are not considered.

Scale:

0 5 10 15 20m

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वांगचू जल विद्युत परियोजना(भूटान)
WANGCHU HYDRO ELECTRIC PROJECT(Bhutan).

Geological Section along longer Axis of PH (Line A-B)

SJVNL , Geology Department.

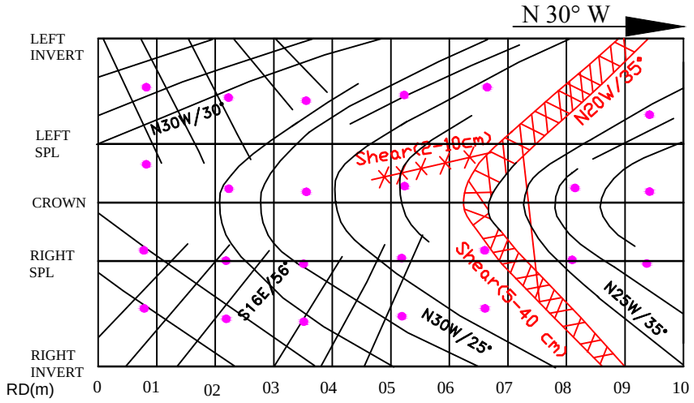
DRG. No.DAM-WHEP-DPR-GEO-029-00	July., 2012

S.J.V.N. LIMITED

WANGCHHU HYDROELECTRIC PROJECT, BHUTAN

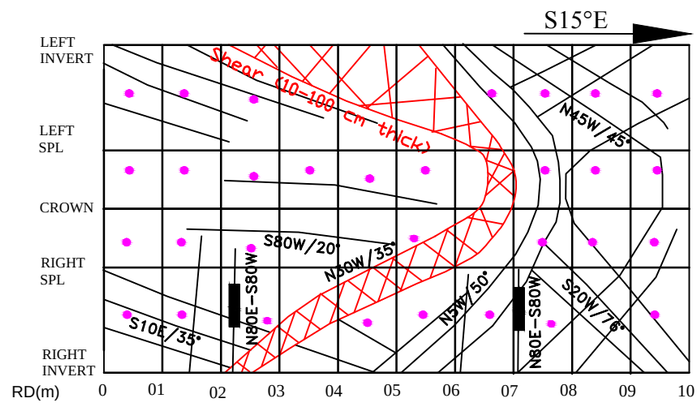
3- D GEOLOGICAL LOG OF CROSS CUTS IN DRIFT DR-2, RIGHT BANK OF DAM AXIS

CROSS-CUT IN UPSTREAM DIRECTION



ROCK TYPE	MODERATELY JOINTED QUARTZITE	CLOSELY TO MODERATELY JOINTED QUARTZITE
WEATHERING	W0 - W1	
SEEPAGE	DRY	
ROCK CLASSIFICATION	GOOD TO FAIR	POOR
Q- VALUE	8.89 to 15.56	1.72 to 2.66

CROSS-CUT IN DOWNSTREAM DIRECTION



ROCK TYPE	CLOSELY TO MODERATELY JOINTED QUARTZITE	MODERATELY JOINTED QUARTZITE
WEATHERING	W0 - W1	
SEEPAGE	DRY	
ROCK CLASSIFICATION	FAIR TO POOR	
Q- VALUE	1.77 to 8.89	

SCALE

-1m 0 1 2 3 4 m

INDEX

1.	● ● ●	WHITE TO LIGHT GREY COLOURED,FINE GRAINED CLOSELY TO MODERATELY JOINTED QUARTZITE
2.	N35E/40°	**JOINT WITH DIP AMOUNT AND DIRECTION**
3.		**VERTICALLY DIPPING JOINT**
4.		**SHEAR (1 TO 10cm) WITH DIP AMOUNT AND DIRECTION**
5.		**SHEAR (WITH MEASURED THICKNESS) WITH DIP AMOUNT AND DIRECTION**

* The previous number of the drawing was DRG. No.DAM-WHEP-DPR-GEO-027-00 (as per 3rd reply to CEA/GSI)

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SJVN Limited

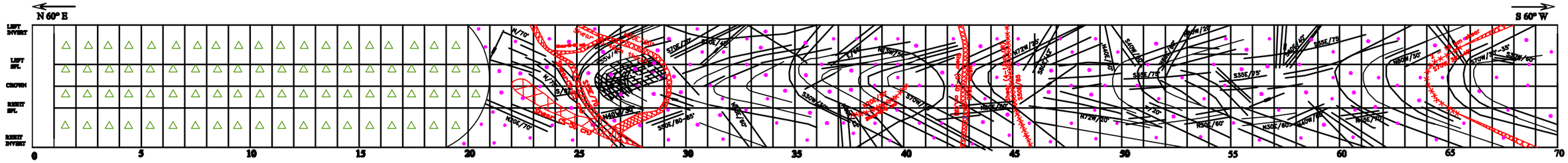
WANGCHU HYDRO ELECTRIC PROJECT(Bhutan).

3-D Geological Log of cross cuts in Drift DR-2
(Right Abutment, El. 463.271m)

अभिकल्पित DSGN.	सर्वीक्षित CHKD.	संस्तुत RECM.
रेखांकित DRWN.	प्रस्तुत SUBM.	

SJVNL , Geology Department.

DRG. No.DAM-WHEP-DPR-GEO-030A-00 | Jan., 2013



ROCK TYPE	FALSE PORTAL	OVERBURDEN COMPRISING OF SLOPE DEBRIS, MAINLY IN THE FORM OF ROCK FRAGMENTS OF QUARTZITES, EMBEDDED IN A SOILY/SANDY MATRIX	CLOSELY JOINTED & FRACTURED QARTZITE	MODERATELY JOINTED QUARTZITE	CLOSELY TO MODERATELY JOINTED QARTZITE	MODERATELY JOINTED QARTZITE
WEATHERING			W0 - W1			W0 - W1
SEEPAGE			DRY			SLIGHT SEEPAGE
ROCK CLASSIFICATION			'Q' value - 4.44 to 14.44 (Good to fair rock)		'Q' value 1.5 to 4.17 (Fair to poor rock)	'Q' value - 5.59 to 15.56 (Good to fair rock)

PROMINENT JOINTS

Sl. no.	Strike direction	Dip amount and direction	Continuity
1	N20-60W - S20-60E	20°-60° / S20-70W	2 to 4 m
2	EW to N40W -S40E	60°-75° / N to N50E	2 to > 5 m
3	NS to N15E- S15W	20°-50° /W to N72W	2 to 4 m
4	N40-75E to S40-75W	70°-85° /S15-50E	2 to 4 m
5	N-S to N20E-S20W	Vertical	2 to 4 m

INDEX

1.	△ △ △	OVERBURDEN
2.	• • •	WHITE TO LIGHT GREY COLOURED,FINE GRAINED CLOSELY TO MODERATELY JOINTED QUARTZITE
3.		JOINT WITH DIP AMOUNT AND DIRECTION
4.		VERTICALLY DIPPING JOINT
5.		SHEAR (<4cm) WITH DIP AMOUNT AND DIRECTION
6.		SHEAR (1 TO 10cm) WITH DIP AMOUNT AND DIRECTION
7.		SHEAR (WITH MEASURED THICKNESS) WITH DIP AMOUNT AND DIRECTION

NOTES:

1. ROCK HAS BEEN ENCOUNTERED AT RD 19.0m ON THE RIGHT INVERT.
2. STEEL RIBS HAVE BEEN PROVIDED BETWEEN RD 0 TO 22.50 m WHERE OVERBURDEN HAS BEEN ENCOUNTERED .
3. RIBS ARE ERECTED AT AN INTERVAL OF 1m C-C.

NOTE:

The tentative stripping limit has been kept at 31m, i.e. after the stripping of the multiple shears between RD 22 to 29.50 m.

SCALE

-1m 0 1 2 3 4m

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SJVN LIMITED.

WANGCHU HYDRO ELECTRIC PROJECT.

3-D LOG DRIFT DR-2 (RIGHT BANK OF DAM AXIS EL.+ 460m)
FROM RD 0m TO 70m

अभियन्ता DSGN.	चेकिंग CHKD.	प्रोजेक्ट PROJ.
ड्राफ्टिंग DRAFT.	स्वीकृत APPD.	

SJVNL GEOLOGY DEPARTMENT

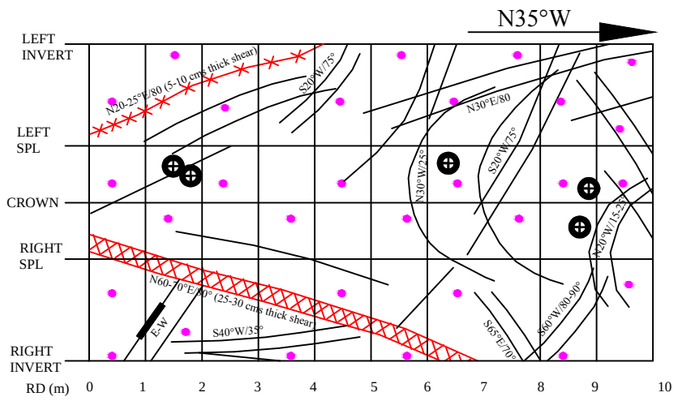
DRG. No. DAM-WHEP-DPR-GEO- DPR -030-00 | July., 2012

SJVN LIMITED

WANGCHHU HYDROELECTRIC PROJECT, BHUTAN

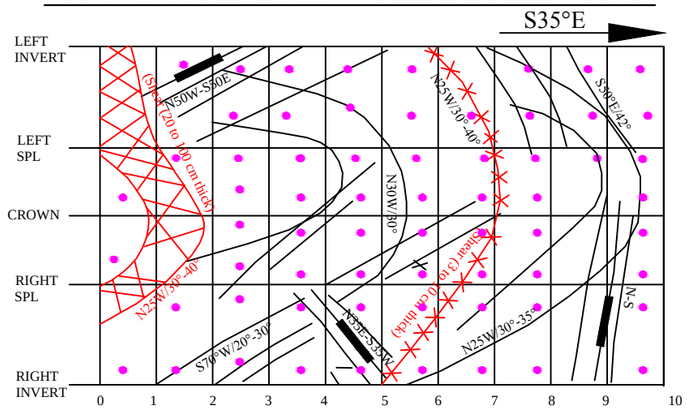
3- D GEOLOGICAL LOG OF DRIFT-(DR-1) RIGHT BANK OF DAM AXIS AT ELEVATION +- 420.0 m

CROSS-CUT IN UPSTREAM DIRECTION



ROCK TYPE	WHITE TO LIGHT GREY COLOURED, FINE GRAINED, CLOSELY TO MODERATELY JOINTED QUARTZITE	
WEATHERING	W1	
SEEPAGE	DRY TO SLIGHT DRIPPING AT PLACES	
ROCK CLASSIFICATION	POOR	FAIR
Q- VALUE RANGES	2.67 to 4.00	4.67 to 5.67

CROSS-CUT IN DOWNSTREAM DIRECTION



ROCK TYPE	WHITE TO LIGHT GREY COLOURED, FINE GRAINED, CLOSELY TO MODERATELY JOINTED QUARTZITE	
WEATHERING	W1	
SEEPAGE	DRY TO SLIGHT DRIPPING AT PLACES	
ROCK CLASSIFICATION	POOR	FAIR TO POOR
Q- VALUE RANGES	1.77 to 2.22	3.70 to 5.19

SCALE

-1m 0 1 2 3 4 m

INDEX

1.	● ● ●	QUARTZITE
2.	N35E/40°	JOINT WITH DIP AMOUNT AND DIRECTION
3.	▬	VERTICALLY DIPPING JOINT
4.	✕ ✕ ✕	SHEAR (1 TO 10cm) WITH DIP AMOUNT AND DIRECTION
5.	✕ ✕ ✕	SHEAR (WITH MEASURED THICKNESS) WITH DIP AMOUNT AND DIRECTION
6.	⊕	DRIPPING CONDITION

* The previous number of the drawing was DRG. No.DAM-WHEP-DPR-GEO-026-00 (as per 3rd reply to CEA/GSI)

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SJVN Limited

WANGCHU HYDRO ELECTRIC PROJECT(Bhutan).

3-D Geological Log of cross cuts in Drift DR-1 (Right Abutment, El. ± 420.0 m)

अभिकल्पित DSGN.	सर्वीक्षित CHKD.	संस्तुत RECM.
रेखांकित DRWN.	प्रस्तुत SUBM.	

SJVNL , Geology Department.

DRG. No.DAM-WHEP-DPR-GEO-031-00 | Jan., 2013

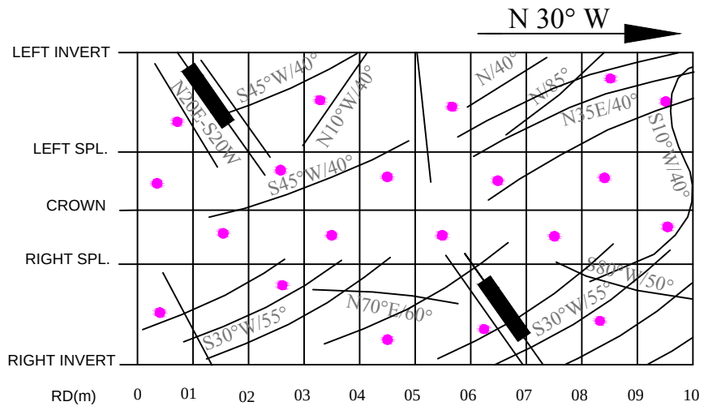
BOREHOLE LOG DATA

SJVN LIMITED

WANGCHU HYDROELECTRIC PROJECT, BHUTAN

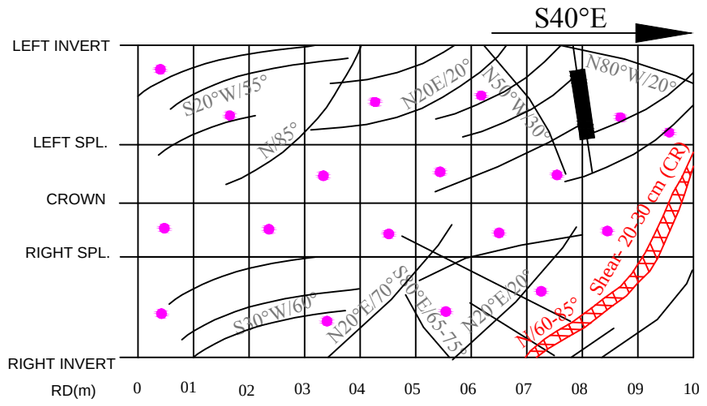
3- D GEOLOGICAL LOG OF DRIFT-DL-1, RIGHT BANK OF DAM AXIS AT ELEVATION ± 420.00 m

CROSS-CUT IN UPSTREAM DIRECTION



ROCK TYPE	WHITE TO LIGHT GREY COLOURED,FINE GRAINED, CLOSELY TO MODERATELY JOINTED QUARTZITE
WEATHERING	W1
SEEPAGE	DRY TO SLIGHT DRIPPING AT PLACES
ROCK CLASSIFICATION	FAIR ROCK
Q- VALUE RANGES	4.67 to 5.67

CROSS-CUT IN DOWNSTREAM DIRECTION



RD (m)

ROCK TYPE	WHITE TO LIGHT GREY COLOURED,FINE GRAINED CLOSELY TO MODERATELY JOINTED QUARTZITE	
WEATHERING	W1	
SEEPAGE	DRY TO SLIGHT DRIPPING AT PLACES	
ROCK CLASSIFICATION	FAIR	POOR
Q- VALUE RANGES	2.67 to 5.67	

SCALE

-1m 0 1 2 3 4 m

INDEX

1.		QUARTZITE
2.	N35E/40°	JOINT WITH DIP AMOUNT AND DIRECTION
3.		VERTICALLY DIPPING JOINT
4.		SHEAR (WITH MEASURED THICKNESS) WITH DIP AMOUNT AND DIRECTION

* The previous number of the drawing was DRG. No.DAM-WHEP-DPR-GEO-024-00 (as per 3rd reply to CEA/GSI)

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SJVN Limited

WANGCHU HYDRO ELECTRIC PROJECT(Bhutan).

3-D Geological Log of cross cuts in Drift DL-1
(Left Abutment, El. +- 420.0 m)

अभिकल्पित DSGN.	परीक्षित CHKD.	संस्तुत RECM.
रेखांकित DRWN.	प्रस्तुत SUBM.	

SJVNL , Geology Department.

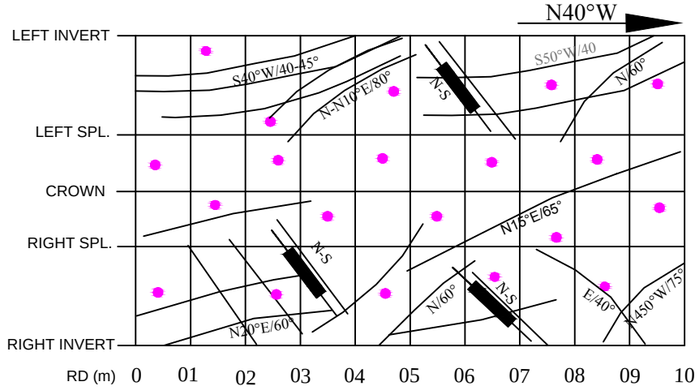
* DRG. No.DAM-WHEP-DPR-GEO-032-00	Jan., 2013

SJVN LIMITED

WANGCHHU HYDROELECTRIC PROJECT, BHUTAN

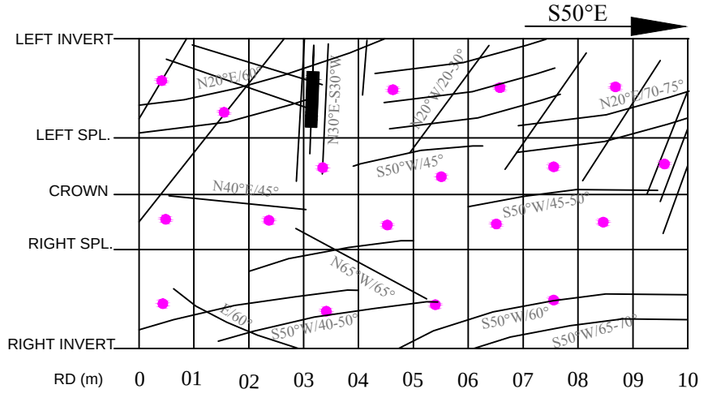
3- D GEOLOGICAL LOG OF DRIFT (DL-2) LEFT BANK OF DAM AXIS AT ELEVATION +- 460.00 m

CROSS-CUT IN UPSTREAM DIRECTION



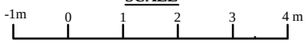
ROCK TYPE	WHITE TO LIGHT GREY COLOURED,FINE GRAINED, CLOSELY TO MODERATELY JOINTED QUARTZITE
WEATHERING	W1
SEEPAGE	DRY TO SLIGHT DRIPPING AT PLACES
ROCK CLASSIFICATION	FAIR
Q- VALUE	5.0 to 5.83

CROSS-CUT IN DOWNSTREAM DIRECTION



ROCK TYPE	WHITE TO LIGHT GREY COLOURED, FINE GRAINED, CLOSELY TO MODERATELY JOINTED QUARTZITE
WEATHERING	W1
SEEPAGE	DRY TO SLIGHT DRIPPING AT PLACES
ROCK CLASSIFICATION	FAIR
Q- VALUE RANGES	4.58 to 5.41

SCALE



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1.	● ● ●	**QUARTZITE**
2.	N35E/40°	**JOINT WITH DIP AMOUNT AND DIRECTION**
3.	▬	**VERTICALLY DIPPING JOINT**

* The previous number of the drawing was DRG. No.DAM-WHEP-DPR-GEO-025-00 (as per 3rd reply to CEA/GSI)

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SJVN Limited

WANGCHU HYDRO ELECTRIC PROJECT(Bhutan).

3-D Geological Log of cross cuts in Drift DL-2 (Left Abutment, El. +- 460.0 m)

अभिकल्पित DSGN.	सर्वेक्षित CHKD.	संस्तुत RECM.
रेखांकित DRWN.	प्रस्तुत SUBM.	

SJVNL , Geology Department.

DRG. No.DAM-WHEP-DPR-GEO-023-00 | Jan., 2013

SJVN LIMITED

Appendix - 1

SHEET NO-1/2

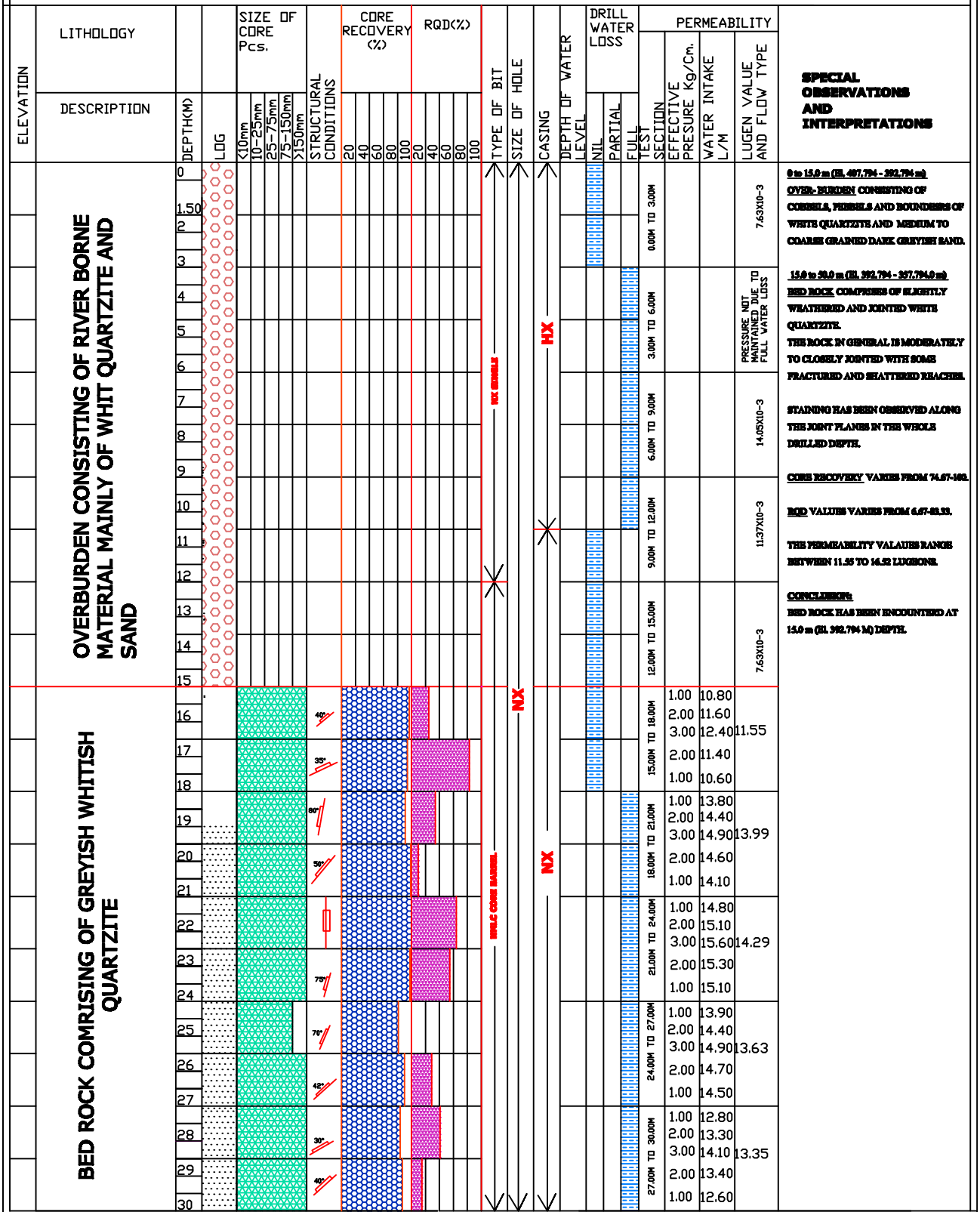
PROJECT: WANGCHU H.E.PROJECT **CO-ORDINATES: N 50060.510 E 39916.111** HOLE NO.DH-1

LOCATION : DAM AXIS (RIGHT BANK)

BEARING OF HOLE : - **ANGLE WITH HORIZANTAL: 90°**

COLLAR ELEVATION : 407.814M **GROUND ELEVATION: 407.794M**

DATE OF START : 02-02-2011 **DATE OF COMPLETION : 22-02-2011** **TOTAL DEPTH :50.00m**



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Appendix - 1

SHEET NO-2/2

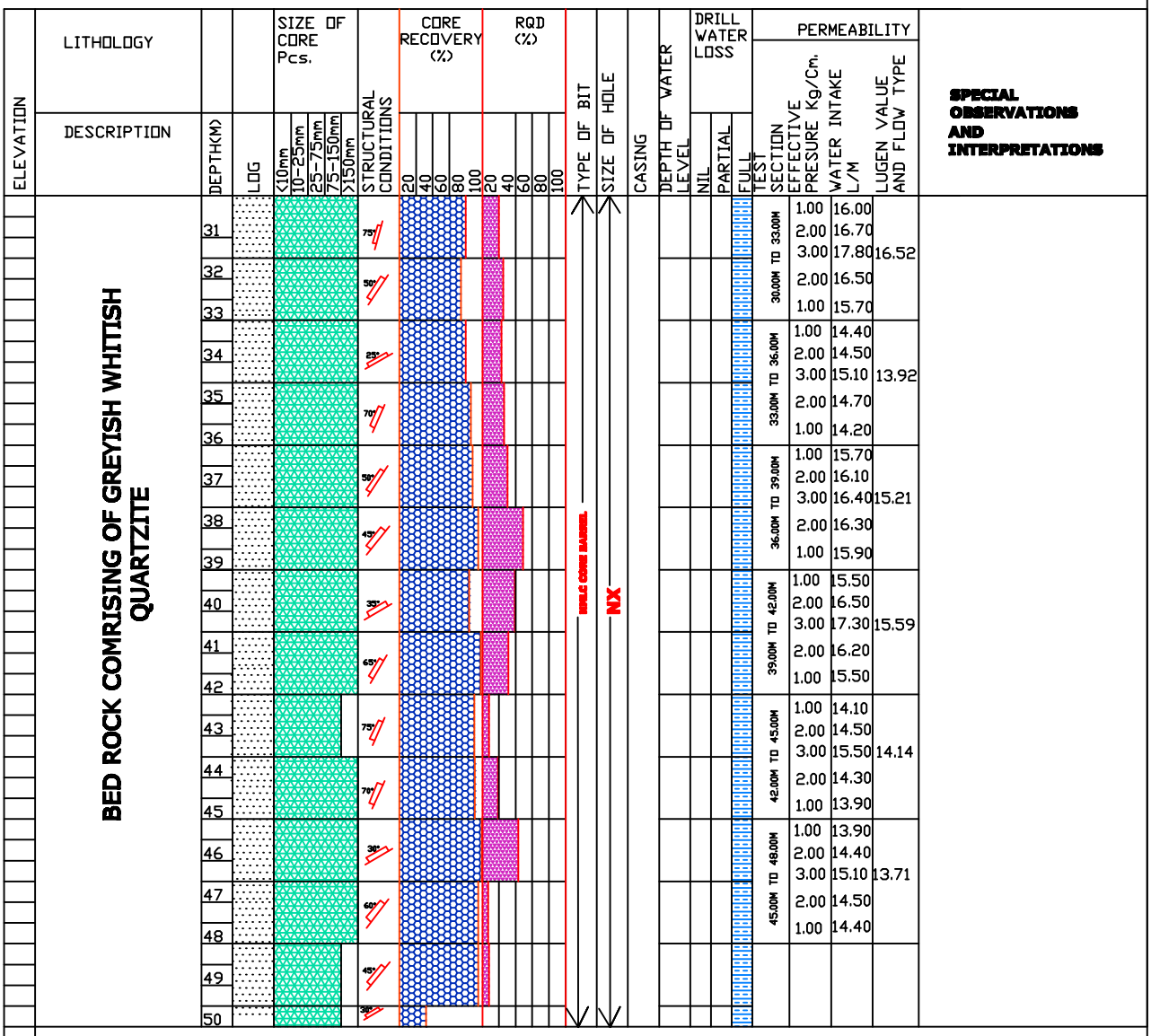
PROJECT: WANGCHU H.E.PROJECT **CO-ORDINATES: N 50060.510 E 39916.111** HOLE NO.DH-1

LOCATION : DAM AXIS (RIGHT BANK)

BEARING OF HOLE : - **ANGLE WITH HORIZANTAL: 90°**

COLLAR ELEVATION : 407.814M **GROUND ELEVATION: 407.794M**

DATE OF START : 02-02-2011 **DATE OF COMPLETION : 22-02-2011** **TOTAL DEPTH :50.00m**



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Appendix - 2
SHEET NO-1/3

PROJECT: **WANGCHU H.E.PROJECT**
CO-ORDINATES: N 50081.80
E 39935.155
HOLE NO. DH-02

LOCATION : DAM SITE
FEATURES: DAM AXIS - CENTRE OF WANGCHU RIVER

BEARING OF HOLE : -
ANGLE WITH HORIZANTAL: 90°

COLLAR ELEVATION : -
GROUND ELEVATION: 403.199 m

DATE OF START :
DATE OF COMPLETION :
TOTAL DEPTH :80.00m

ELEVATION	LITHOLOGY DESCRIPTION	DEPTH(M)	LOG	SIZE OF CORE Pcs. <10mm	10-25mm	25-75mm	75-150mm	>150mm	STRUCTURAL CONDITIONS	CORE RECOVERY (%) 20	40	60	80	100	RQD(%) 20	40	60	80	100	TYPE OF BIT	SIZE OF HOLE	SIZE OF CASING	DEPTH OF WATER LEVEL	DRILL WATER LOSS NIL	PARTIAL	FULL	PERMEABILITY TEST SECTION	EFFECTIVE PRESURE Kg/Cm.	WATER INTAKE L/M	LUGEN VALUE AND FLOW TYPE	SPECIAL OBSERVATIONS AND INTERPRETATIONS
	OVERBURDEN COMPRISING OF BOULDERS, COBBLES, PEBBLES OF QUARTZITE AND BIOTITE GNEISS ALONG WITH A SAND SEAM	0 1.50 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30																				PX NX BX	PX NX BX					0.00M TO 3.00M 3.00M TO 6.00M 6.00M TO 9.00M 9.00M TO 12.00M 12.00M TO 15.00M 15.00M TO 18.00M 18.00M TO 21.00M 21.00M TO 24.00M 24.00M TO 27.00M 27.00M TO 30.00M			161.60X10-3 373.78X10-3 201.37X10-3 269.82X10-3 151.92X10-3 307.43X10-3 290.33X10-3 361.10X10-3 308.30X10-3 300.00X10-3	**0 TO 27.0 m (EL.403.199 TO 366.199 m) OVER BURDEN** COMPRISING OF BOULDERS, COBBELS, PEBBELS OF WHITE AND BIOTITE GNEISS ALONG WITH A SAND SEAM BETWEEN 27.0 TO 27.0 m DEPTH. **27.0 TO 80.0 m (EL.366.199 TO 323.199 m) BED ROCK** COMPRISING OF WHITE TO LIGHT GREY COLOURED, FINE GRAINED QUARTZITE. THE ROCK MASS IN GENERAL IS MODERATELY TO CLOSELY JOINTED WITH SOME SHATTERED AND FRACTURED REACHES. SHEARING IN ROCK OBSERVED BETWEEN 67.0 TO 70.05 m DEPTH. THE JOINTS PLANES GENERALLY DIP BETWEEN 20° TO VERTICAL. SIGNS OF SLIGHT WEATHERING ALONG THE JOINTS PLANES IN ROCK OBSERVED IN THE WHOLE DRILLED DEPTH. **CORE RECOVERY** RANGES BETWEEN 74% TO 98.33%. **RQD** VARIES FROM 0 TO 44%. THE PERMEABILITY VALAUES RANGE BETWEEN 6.11 TO 14.65 LUGEONS. **CONCLUSION:** BED ROCK ENCOUNTERED AT 27.0m (EL.366.199m) DEPTH.

SJVN LIMITED

Appendix - 2

SHEET NO-2/3

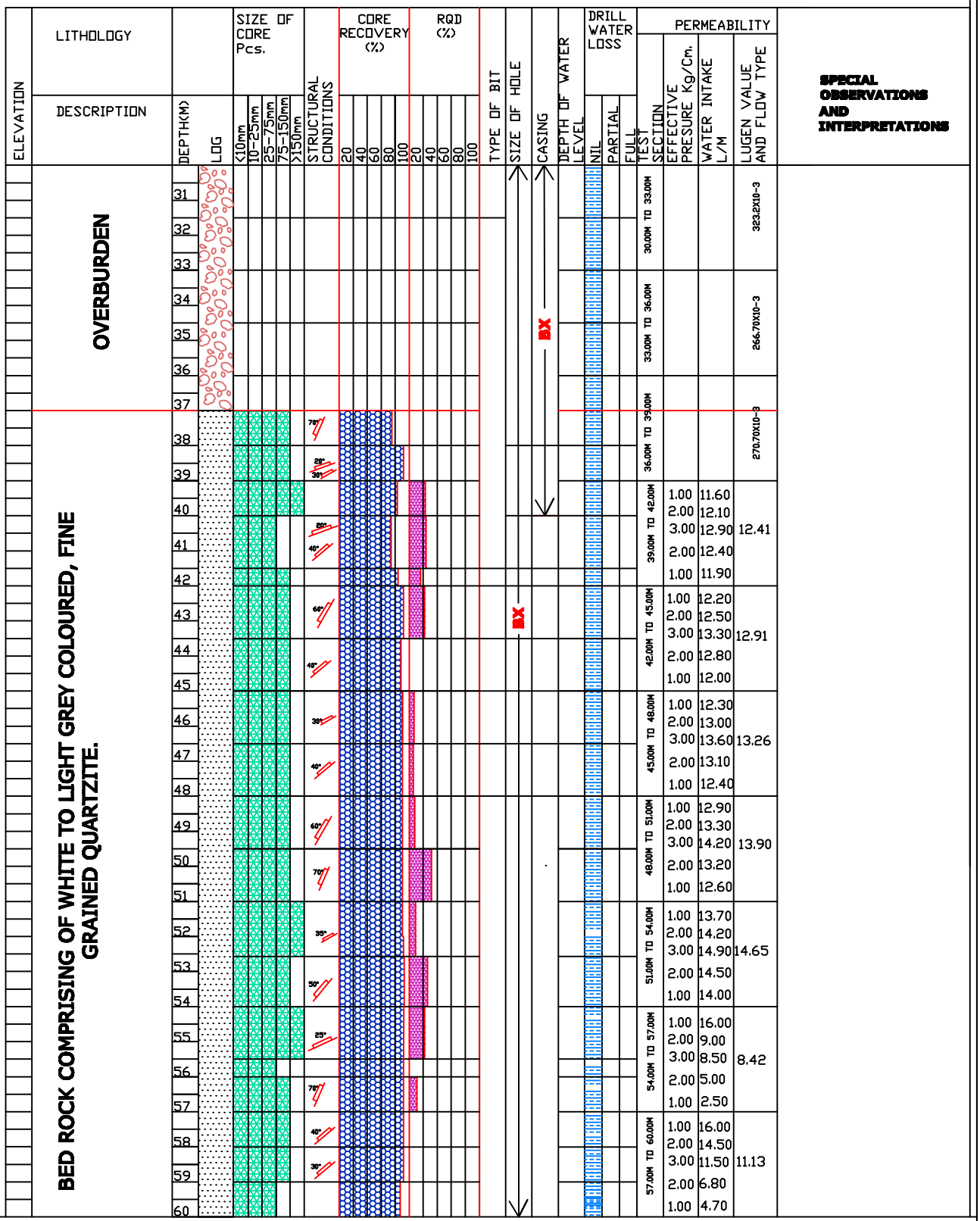
PROJECT: WANGCHU H.E.PROJECT **CO-ORDINATES: N 50081.80 E 39935.155** HOLE NO. DH-02

LOCATION : DAM SITE **FEATURES: DAM AXIS - CENTRE OF WANGCHU RIVER**

BEARING OF HOLE : - **ANGLE WITH HORIZANTAL: 90°**

COLLAR ELEVATION : - **GROUND ELEVATION: 403.199 m**

DATE OF START : **DATE OF COMPLETION :** **TOTAL DEPTH :80.00m**



SJVN LIMITED

Appendix - 2

SHEET NO-3/3

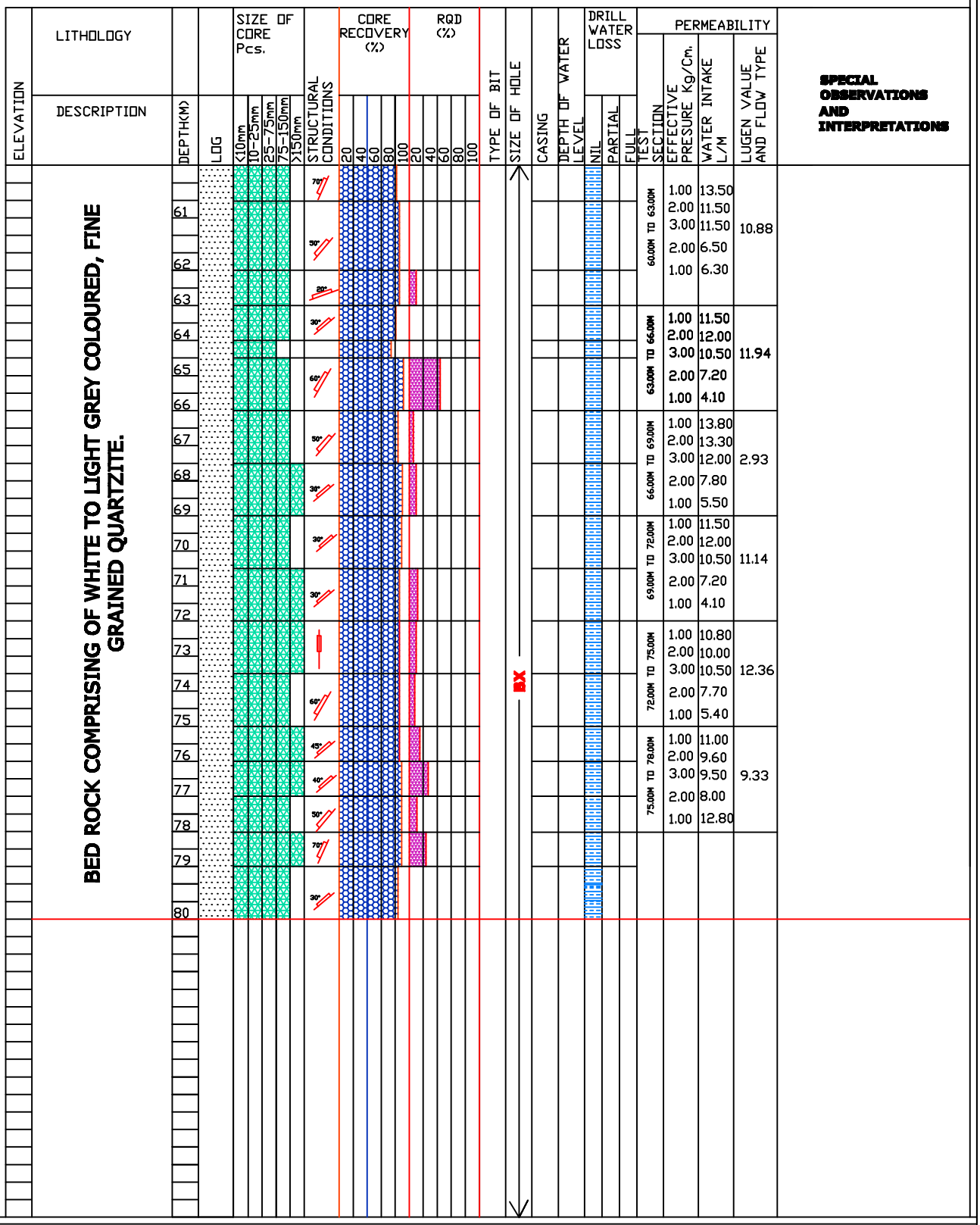
PROJECT: WANGCHU H.E.PROJECT **CO-ORDINATES: N 50081.80 E 39935.155** HOLE NO. DH-02

LOCATION : DAM SITE **FEATURES: DAM AXIS - CENTRE OF WANGCHU RIVER**

BEARING OF HOLE : - **ANGLE WITH HORIZANTAL: 90°**

COLLAR ELEVATION : - **GROUND ELEVATION: 403.199 m**

DATE OF START : **DATE OF COMPLETION :** **TOTAL DEPTH :80.00m**



SJVN LIMITED

Appendix - 3

SHEET NO-1/3

PROJECT: WANGCHU H.E.PROJECT **CO-ORDINATES: N : 50111.841** HOLE NO. DH-3

E : 39957.256

LOCATION : DAM SITE **FEATURES: LEFT BANK OFWANGCHU RIVER, DAM AXIS.**

BEARING OF HOLE :VERTICAL **ANGLE WITH HORIZANTAL: 90°**

COLLAR ELEVATION : **GROUND ELEVATION: 404.483 m**

DATE OF START : **DATE OF COMPLETION :** **TOTAL DEPTH :80.00 m**

ELEVATION	LITHOLOGY DESCRIPTION	DEPTH(M)	LOG	SIZE OF CORE Pcs. <10mm / 10-25mm / 25-75mm / 75-150mm / >150mm	STRUCTURAL CONDITIONS	CORE RECOVERY (%) 20 40 60 80 100	RQD(%) 20 40 60 80 100	TYPE OF BIT	SIZE OF HOLE	SIZE OF CASING	DEPTH OF WATER LEVEL	DRILL WATER LOSS NIL / PARTIAL / FULL	PERMEABILITY TEST SECTION	EFFECTIVE PRESURE Kg/Cm.	WATER INTAKE L/M	LUGEN VALUE AND FLOW TYPE
	OVERBURDEN COMPRISING OF BOULDERS, COBBLES, PEBBLES AND GRAVELS OF QUARTZITE, GRANITE-GNEISS & BIOTITE GNEISS ALONG WITH SAND	0								PX			0.00M TO 3.00M			269.35X10-3
		1.50														
		2														
		3														
		4						HX		HX			3.00M TO 6.00M			300.03X10-3
		5														
		6														
		7											6.00M TO 9.00M			529.95X10-3
		8														
		9														
		10											9.00M TO 12.00M			541.87X10-3
		11														
		12														
		13											12.00M TO 15.00M			612.47X10-3
		14														
		15														
		16						NX		NX			15.00M TO 18.00M			477.00X10-3
		17														
		18														
		19											18.00M TO 21.00M			582.97X10-3
		20														
		21														
		22											21.00M TO 24.00M			412.29X10-3
		23														
		24														
		25											24.00M TO 27.00M			453.39X10-3
		26														
		27														
	BED ROCK	28			70°			EX CORE BARREL			1.00		27.00M TO 30.00M	1.00	10.80	11.53
		29			45°									2.00	10.90	
		30									1.00			3.00	11.50	
														2.00	11.20	
														1.00	10.60	

SPECIAL OBSERVATIONS AND INTERPRETATIONS

0 TO 27.0 m (EL.404.483 TO 377.483 m)
OVER BURDEN COMPRISING OF BOULDERS, COBBLES, PEBBLES AND GRAVELS OF QUARTZITE, GRANITIC-GNEISS & BIOTITE GNEISS ENCOUNTERED ALONG WITH SILT & SAND

27.0 TO 80.0 m (EL 377.483 TO 324.483 m)
BED ROCK COMPRISING OF WHITE TO LIGHT GREY COLOURED, FINE GRAINED QUARTZITE. THE ROCK MASS IN GENERAL IS MODERATELY TO CLOSELY JOINTED WITH SOME SHATTERED AND FRACTURED REACHES.
THE ROCK IS SHEARED BETWEEN 52.50 TO 58.50M DEPTH.
JOINTS PLANES DIPPING 18° TO VERTICAL WERE RECORDED.

SLIGHT SIGNS OF WEATHERING ALONG THE JOINTS PLANES NOTICED IN THE WHOLE DRILLED DEPTH.

CORE RECOVERY IN ROCK RANGES BETWEEN 5.66% TO 100 %.

RQD RANGES FROM 0 TO 69%.

THE PERMEABILITY VALAUES RANGE BETWEEN 2.93 TO 16.92 LUGEONS.

CONCLUSION:
BED ROCK ENCOUNTERD AT 27.0 m (377.483 m) DEPTH.

SJVN LIMITED

Appendix - 3
SHEET NO-2/3

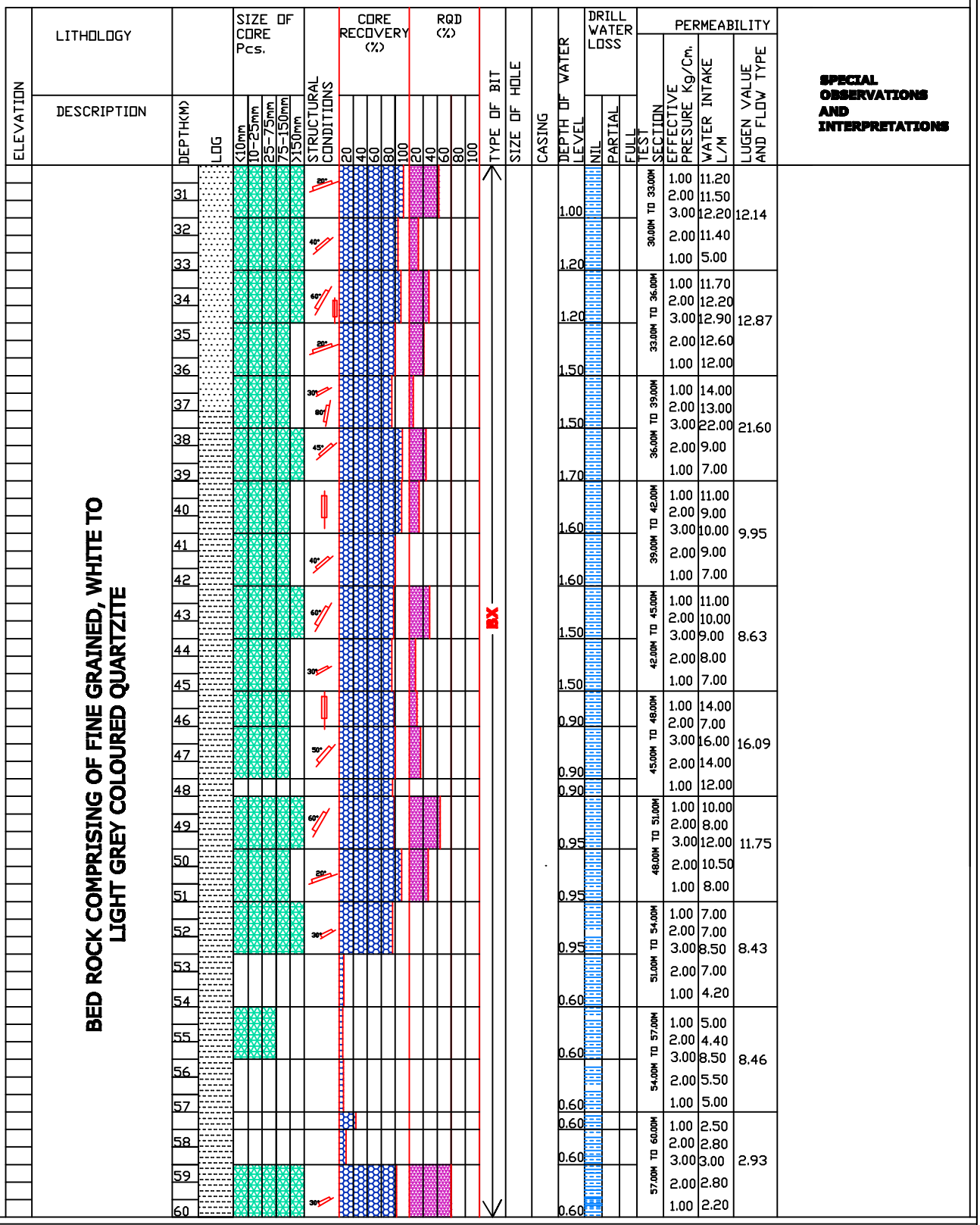
PROJECT: WANGCHU H.E.PROJECT **CO-ORDINATES: N : 50111.841** HOLE NO. DH-3
E : 39957.256

LOCATION : DAM SITE **FEATURES: LEFT BANK OFWANGCHU RIVER, DAM AXIS.**

BEARING OF HOLE :VERTICAL **ANGLE WITH HORIZANTAL: 90°**

COLLAR ELEVATION : **GROUND ELEVATION: 404.483 m**

DATE OF START : **DATE OF COMPLETION :** **TOTAL DEPTH :80.00 m**



SJVN LIMITED

PROJECT: **WANGCHU H.E.PROJECT**

CO-ORDINATES: N : 50111.841
E : 39957.256

HOLE NO. DH-3

LOCATION : DAM SITE

FEATURES: LEFT BANK OFWANGCHU RIVER, DAM AXIS.

BEARING OF HOLE :VERTICAL

ANGLE WITH HORIZANTAL: 90°

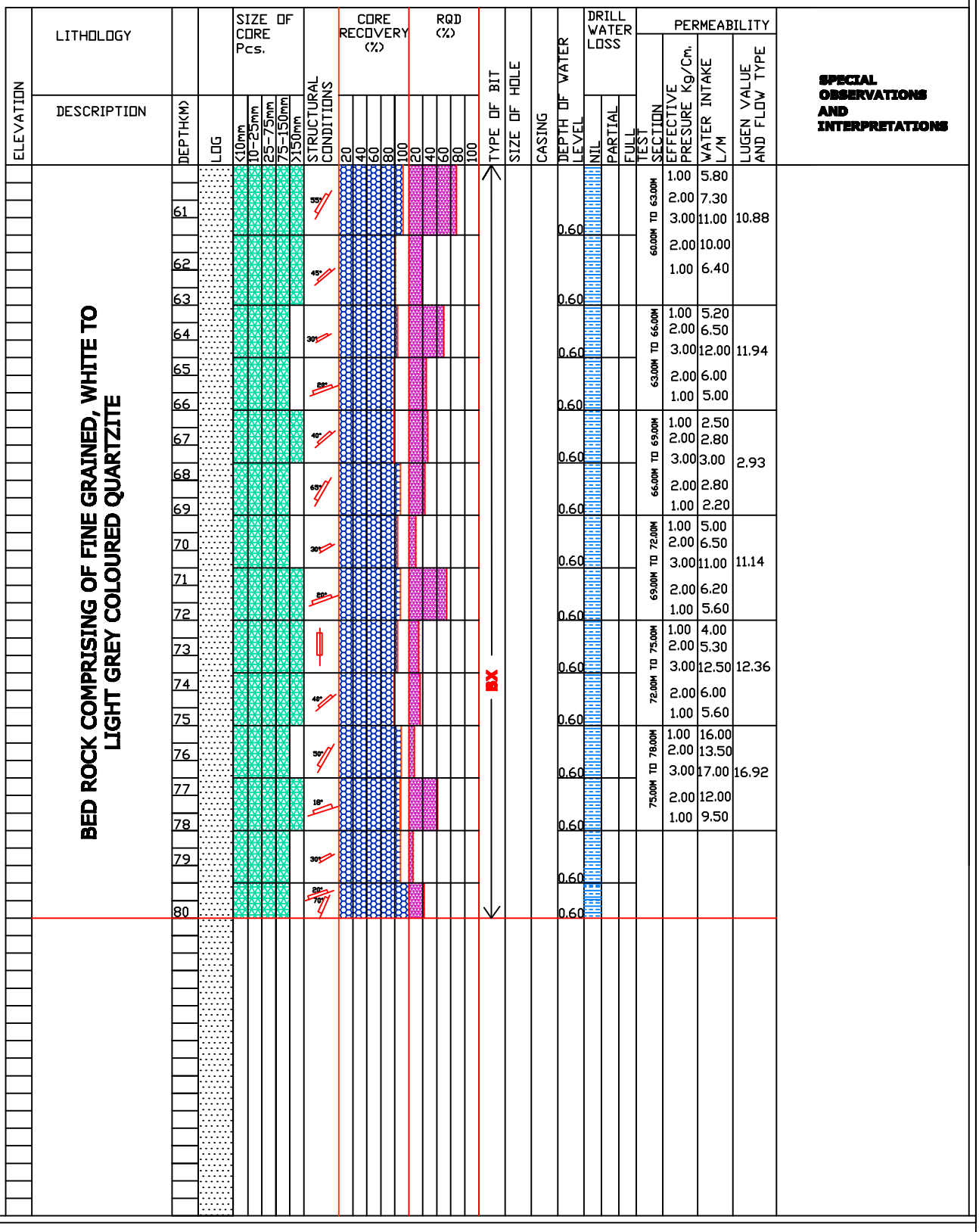
COLLAR ELEVATION :

GROUND ELEVATION: 404.483 m

DATE OF START :

DATE OF COMPLETION :

TOTAL DEPTH :80.00 m



SJVN LIMITED

Appendix - 4

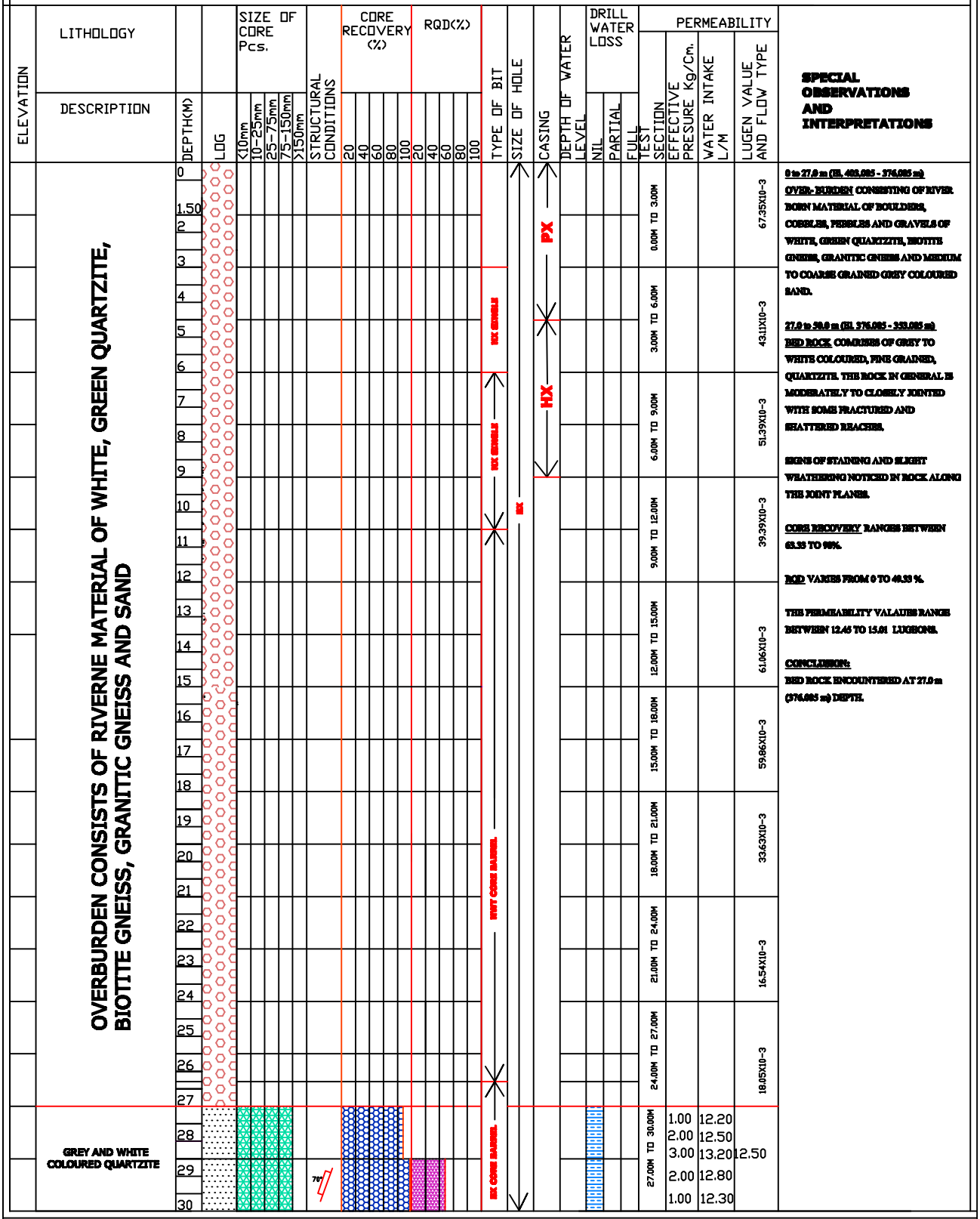
SHEET NO-1/2

PROJECT: WANGCHU H.E.PROJECT | **CO-ORDINATES: N 50022.370 E 40003.320** | HOLE NO. DH-4

LOCATION : 90 M D/S OF DAM AXIS | **ANGLE WITH HORIZANTAL: 90°**

BEARING OF HOLE : - | **GROUND ELEVATION: 403.085m**

DATE OF START : 20-02-2011 | **DATE OF COMPLETION : 16-3-2011** | **TOTAL DEPTH :50.00m**



0 to 27.0 m (El. 403.085 - 376.085 m)
OVER- BURDEN CONSISTING OF RIVER BORN MATERIAL OF BOULDERS, COBBLES, PEBBLES AND GRAVELS OF WHITE, GREEN QUARTZITE, BIOTITE GNEISS, GRANITIC GNEISS AND MEDIUM TO COARSE GRAINED GREY COLOURED SAND.

27.0 to 50.0 m (El. 376.085 - 353.085 m)
BED ROCK COMPRISES OF GREY TO WHITE COLOURED, FINE GRAINED, QUARTZITE. THE ROCK IN GENERAL IS MODERATELY TO CLOSELY JOINTED WITH SOME FRACTURED AND SHATTERED REACHES.

SIGNS OF STAINING AND SLIGHT WEATHERING NOTICED IN ROCK ALONG THE JOINT PLANES.

CORE RECOVERY RANGES BETWEEN 63.33 TO 98%.

RQD VARIES FROM 0 TO 49.33 %.

THE PERMEABILITY VALAUES RANGE BETWEEN 12.45 TO 15.01 LUGEONS.

CONCLUSION:
BED ROCK ENCOUNTERED AT 27.0 m (376.085 m) DEPTH.

SJVN LIMITED

PROJECT: WANGCHU H.E.PROJECT

LOCATION : 90 M D/S OF DAM AXIS

BEARING OF HOLE : -

DATE OF START : 20-02-2011

CO-ORDINATES: N 50022.370
E 40003.320

ANGLE WITH HORIZANTAL: 90°

GROUND ELEVATION: 403.085m

DATE OF COMPLETION : 16-3-2011

HOLE NO. DH-4

TOTAL DEPTH :50.00m

ELEVATION	LITHOLOGY DESCRIPTION	DEPTH(M)	LOG	SIZE OF CORE Pcs. <10mm	10-25mm	25-75mm	75-150mm	>150mm	STRUCTURAL CONDITIONS	CORE RECOVERY (%) 20 40 60 80 100	RQD (%) 20 40 60 80 100	TYPE OF BIT	SIZE OF HOLE	CASING	DEPTH OF WATER LEVEL	DRILL WATER LOSS NIL	PARTIAL	FULL	PERMEABILITY TEST SECTION	EFFECTIVE PRESURE Kg/Cm.	WATER INTAKE L/M	LUGEN VALUE AND FLOW TYPE	SPECIAL OBSERVATIONS AND INTERPRETATIONS
	GREY AND WHITE COLOURED QUARTZITE	31																	30.00M TO 33.00M	1.00	12.90	13.13	
																				2.00	13.40		
																				3.00	14.00		
		32																		2.00	13.10		
		33																		1.00	12.60		
		34							35°										33.00M TO 36.00M	1.00	12.40	12.45	
																				2.00	12.90		
																				3.00	13.50		
		35																		2.00	13.20		
		36							65°											1.00	12.30		
		37																	36.00M TO 39.00M	1.00	13.80	13.63	
																				2.00	14.10		
																				3.00	14.80		
		38																		2.00	14.40		
		39																		1.00	14.00		
		40							45°										39.00M TO 42.00M	1.00	14.20	14.35	
																				2.00	14.50		
																				3.00	15.20		
		41							50°											2.00	14.80		
		42																		1.00	14.30		
		43																	42.00M TO 45.00M	1.00	14.40	14.76	
																				2.00	15.00		
																				3.00	15.70		
		44																		2.00	15.20		
		45																		1.00	14.20		
		46							67°										45.00M TO 48.00M	1.00	14.70	15.01	
																				2.00	15.40		
																				3.00	16.10		
		47																		2.00	15.60		
		48																		1.00	14.40		
		49							74°														
		50																					

SJVN LIMITED

Appendix - 5

SHEET NO-1/2

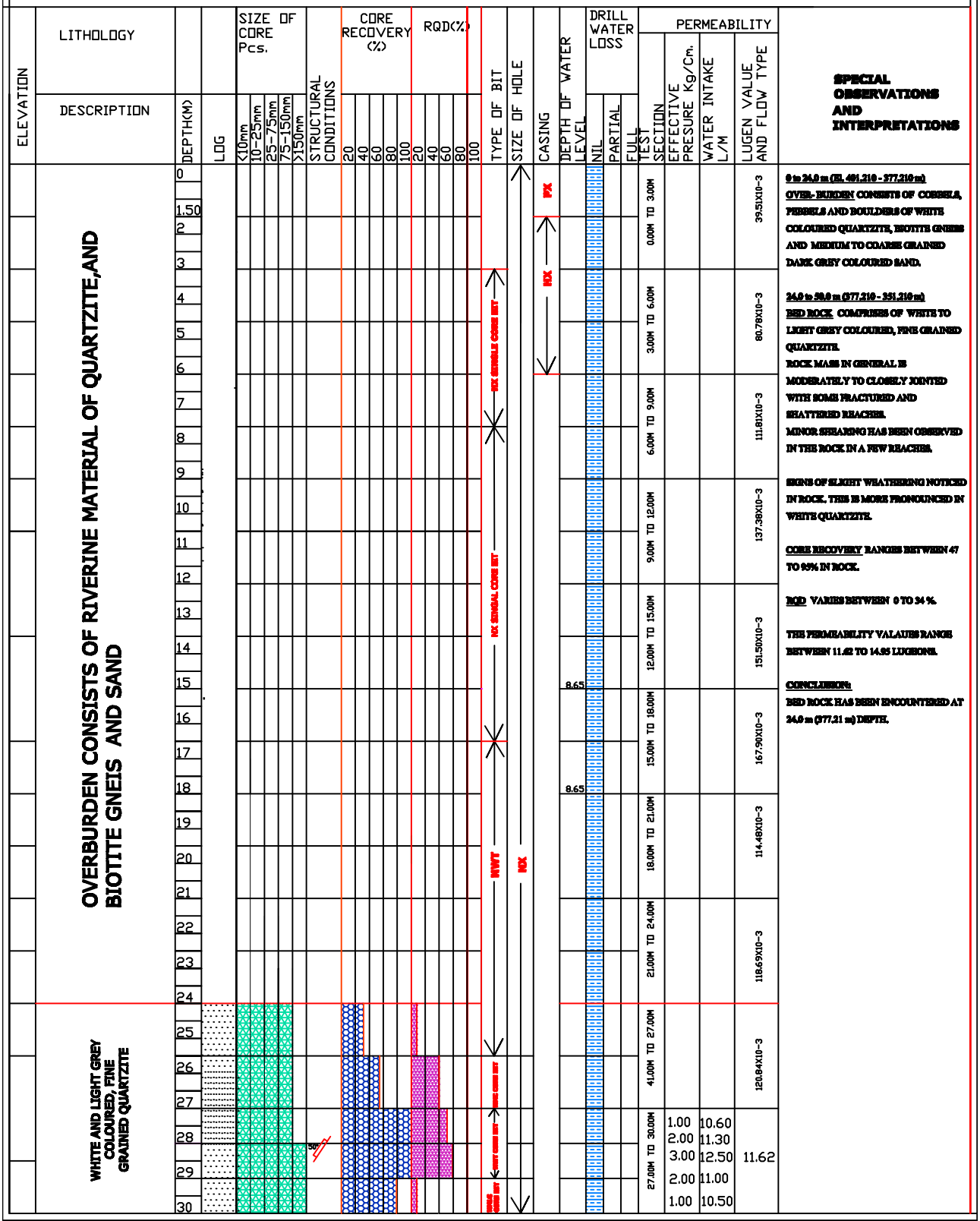
PROJECT: WANGCHU H.E.PROJECT **CO-ORDINATES: N: 49958.11 E: 40033.92** HOLE NO. DH-5

LOCATION : 150 m DOWNSTREAM OF DAM AXIS

BEARING OF HOLE : - ANGLE WITH HORIZANTAL: 90°

COLLAR ELEVATION : 401.230 M **GROUND ELEVATION: 401.210M**

DATE OF START : 27-02-2011 DATE OF COMPLETION : 16-03-2011 TOTAL DEPTH :50.00m



SPECIAL OBSERVATIONS AND INTERPRETATIONS

0 to 24.0 m (El. 401.210 - 377.210 m)
OVER- BURDEN CONSISTS OF COBBELS, PEBBELS AND BOULDERS OF WHITE COLOURED QUARTZITE, BIOTITE GNEISS AND MEDIUM TO COARSE GRAINED DARK GREY COLOURED SAND.

24.0 to 50.0 m (377.210 - 351.210 m)
BED ROCK COMPRISES OF WHITE TO LIGHT GREY COLOURED, FINE GRAINED QUARTZITE.
ROCK MASS IN GENERAL IS MODERATELY TO CLOSELY JOINTED WITH SOME FRACTURED AND SHATTERED REACHES.
MINOR SHEARING HAS BEEN OBSERVED IN THE ROCK IN A FEW REACHES.

SIGNS OF SLIGHT WEATHERING NOTICED IN ROCK. THIS IS MORE PRONOUNCED IN WHITE QUARTZITE.

CORE RECOVERY RANGES BETWEEN 47 TO 95% IN ROCK.

RQD VARIES BETWEEN 0 TO 34 %.

THE PERMEABILITY VALAUES RANGE BETWEEN 11.62 TO 14.95 LUGEONS.

CONCLUSION:
BED ROCK HAS BEEN ENCOUNTERED AT 24.0 m (377.21 m) DEPTH.

SJVN LIMITED

Appendix - 5

SHEET NO-2/2

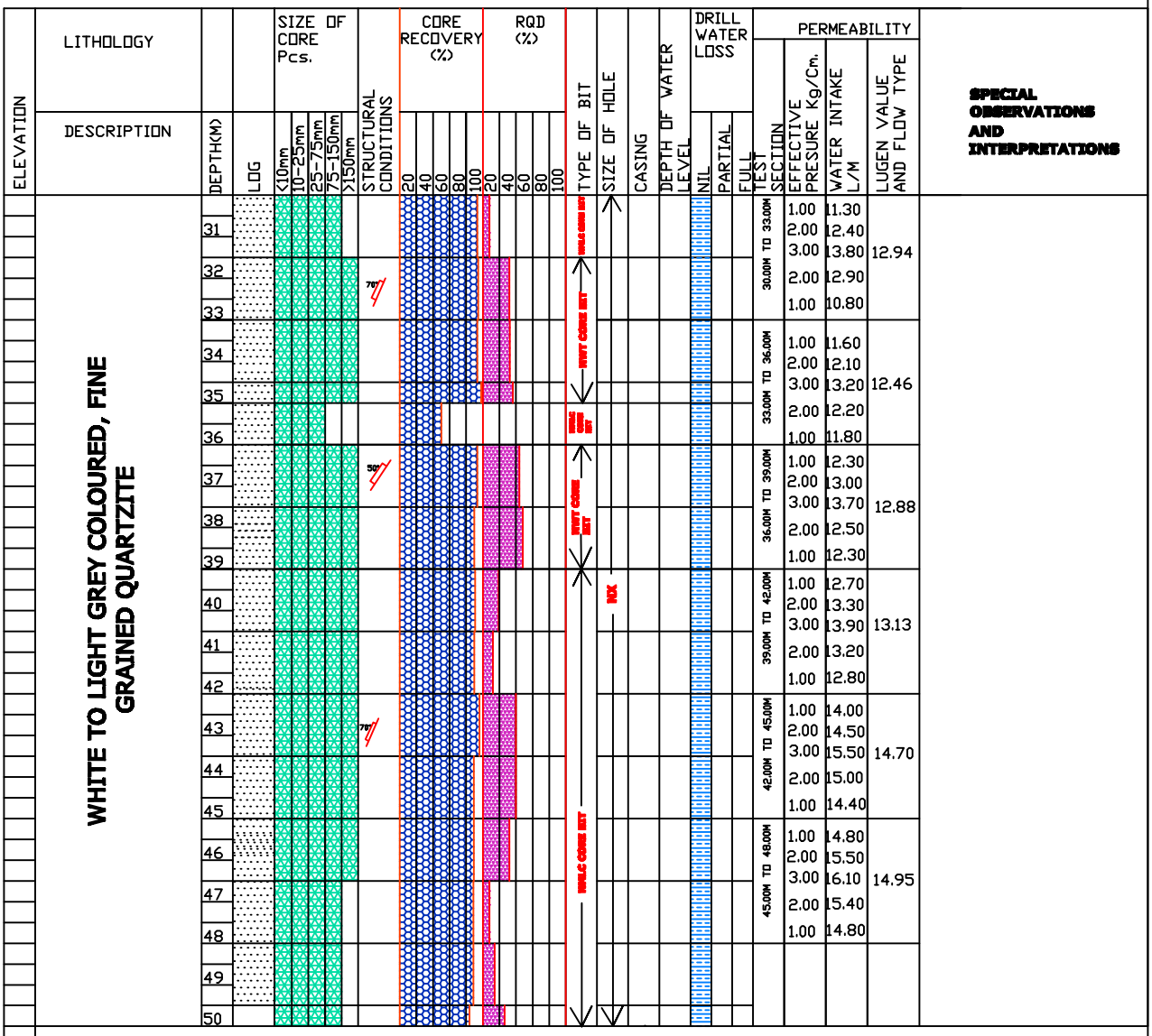
PROJECT: WANGCHU H.E.PROJECT **CO-ORDINATES: N: 49958.11 E: 40033.92** HOLE NO. DH-5

LOCATION : 150 m DOWNSTREAM OF DAM AXIS

BEARING OF HOLE : - **ANGLE WITH HORIZANTAL: 90°**

COLLAR ELEVATION : 401.230 M **GROUND ELEVATION: 401.210M**

DATE OF START : 27-02-2011 **DATE OF COMPLETION : 16-03-2011** **TOTAL DEPTH :50.00m**



SJVN LIMITED

Appendix - 6

SHEET NO-1/2

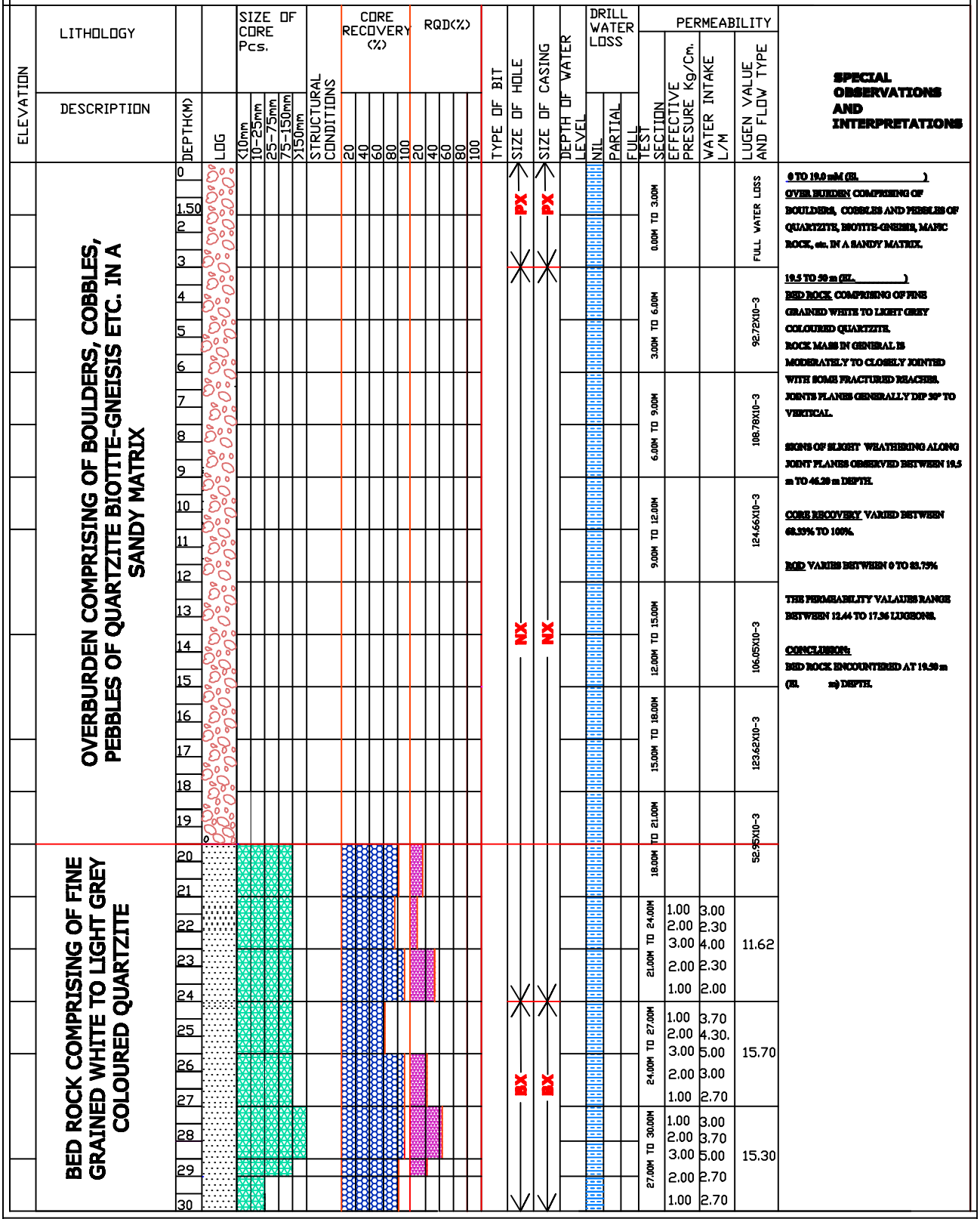
PROJECT: WANGCHU H.E.PROJECT **CO-ORDINATES: N:** **E:** HOLE NO. DH-6

LOCATION : DAM SITE **FEATURES: UPSTREAM COFFER DAM (IN RIVER)**

BEARING OF HOLE : - **ANGLE WITH HORIZANTAL: 90°**

COLLAR ELEVATION : **GROUND ELEVATION:**

DATE OF START : **DATE OF COMPLETION :** **TOTAL DEPTH :50.00m**



SPECIAL OBSERVATIONS AND INTERPRETATIONS

0 TO 19.0 m (El.)

OVER BURDEN COMPRISING OF BOULDERS, COBBLES AND PEBBLES OF QUARTZITE, BIOTITE-GNEISIS, MAFIC ROCK, etc. IN A SANDY MATRIX.

19.5 TO 50 m (El.)

BED ROCK COMPRISING OF FINE GRAINED WHITE TO LIGHT GREY COLOURED QUARTZITE.

ROCK MASS IN GENERAL IS MODERATELY TO CLOSELY JOINTED WITH SOME FRACTURED REACHES.

JOINTS PLANES GENERALLY DIP 30° TO VERTICAL.

SIGNS OF SLIGHT WEATHERING ALONG JOINT PLANES OBSERVED BETWEEN 19.5 m TO 46.20 m DEPTH.

CORE RECOVERY VARIED BETWEEN 68.33% TO 100%.

RQD VARIES BETWEEN 0 TO 83.75%

THE PERMEABILITY VALAUES RANGE BETWEEN 12.44 TO 17.36 LUGEONS.

CONCLUSION:

BED ROCK ENCOUNTERED AT 19.50 m (El. m) DEPTH.

SJVN LIMITED

Appendix - 6

SHEET NO-2/2

PROJECT: WANGCHU H.E.PROJECT **CO-ORDINATES: N:** HOLE NO. DH-6

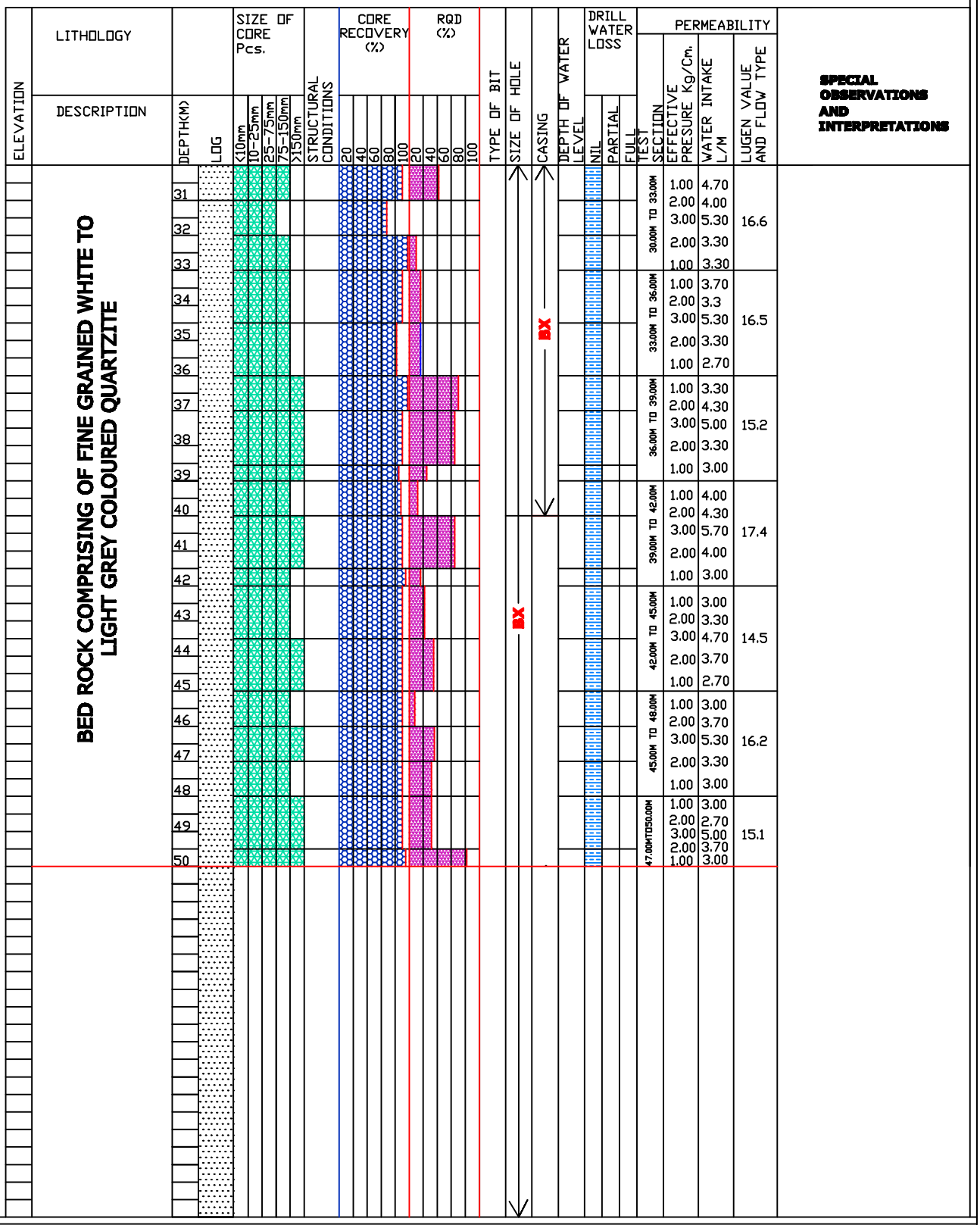
E:

LOCATION : DAM SITE **FEATURES: UPSTREAM COFFER DAM (IN RIVER)**

BEARING OF HOLE : - **ANGLE WITH HORIZANTAL: 90°**

COLLAR ELEVATION : **GROUND ELEVATION:**

DATE OF START : **DATE OF COMPLETION :** **TOTAL DEPTH :50.00m**



SJVN LIMITED

Appendix - 7

SHEET NO-1/5

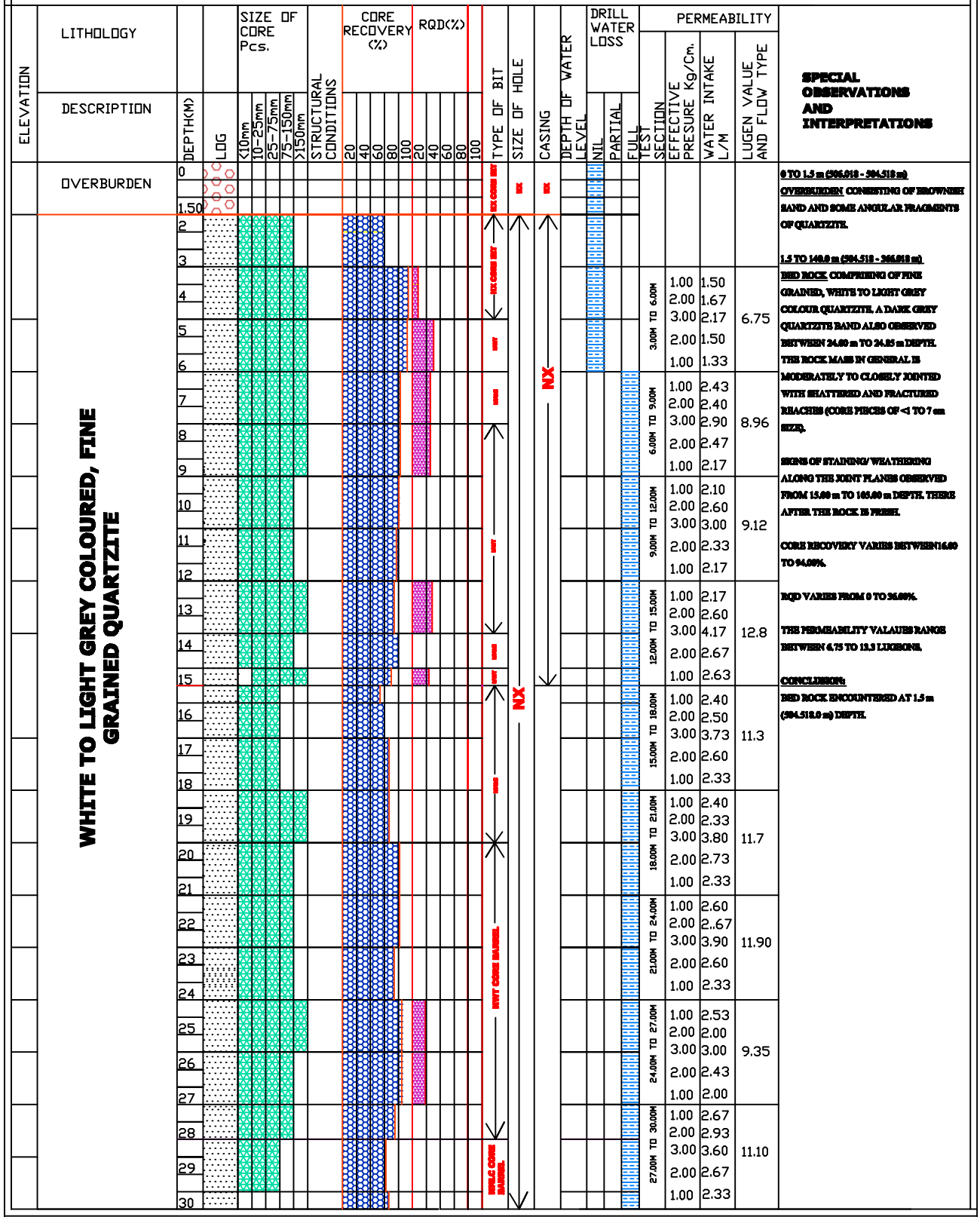
PROJECT: WANGCHU H.E.PROJECT **CO-ORDINATES: N50185.090 E40026.734** HOLE NO.DH-7

LOCATION : DAM AXIS (LEFT BANK)

BEARING OF HOLE : - **ANGLE WITH HORIZANTAL: 90°**

COLLAR ELEVATION :506.218m **GROUND ELEVATION: 506.018m**

DATE OF START : 14-05-2011 **DATE OF COMPLETION :** **TOTAL DEPTH :140.00m**



SPECIAL OBSERVATIONS AND INTERPRETATIONS

0 TO 1.5 m (506.018 - 504.518 m)
OVERBURDEN CONSISTING OF BROWNISH SAND AND SOME ANGULAR FRAGMENTS OF QUARTZITE.

1.5 TO 140.0 m (504.518 - 366.018 m)
BED ROCK COMPRISING OF FINE GRAINED, WHITE TO LIGHT GREY COLOUR QUARTZITE, A DARK GREY QUARTZITE BAND ALSO OBSERVED BETWEEN 24.60 m TO 24.85 m DEPTH. THE ROCK MASS IN GENERAL IS MODERATELY TO CLOSELY JOINTED WITH SHATTERED AND FRACTURED REACHES (CORE PIECES OF <1 TO 7 cm SIZE).

SIGNS OF STAINING/ WEATHERING ALONG THE JOINT PLANES OBSERVED FROM 15.00 m TO 105.00 m DEPTH. THERE AFTER THE ROCK IS FRESH.

CORE RECOVERY VARIES BETWEEN16.00 TO 94.00%.

RQD VARIES FROM 0 TO 36.00%.

THE PERMEABILITY VALAUES RANGE BETWEEN 6.75 TO 13.3 LUGEONS.

CONCLUSION:
BED ROCK ENCOUNTERED AT 1.5 m (504.518.0 m) DEPTH.

SJVN LIMITED

Appendix - 7

SHEET NO-2/5

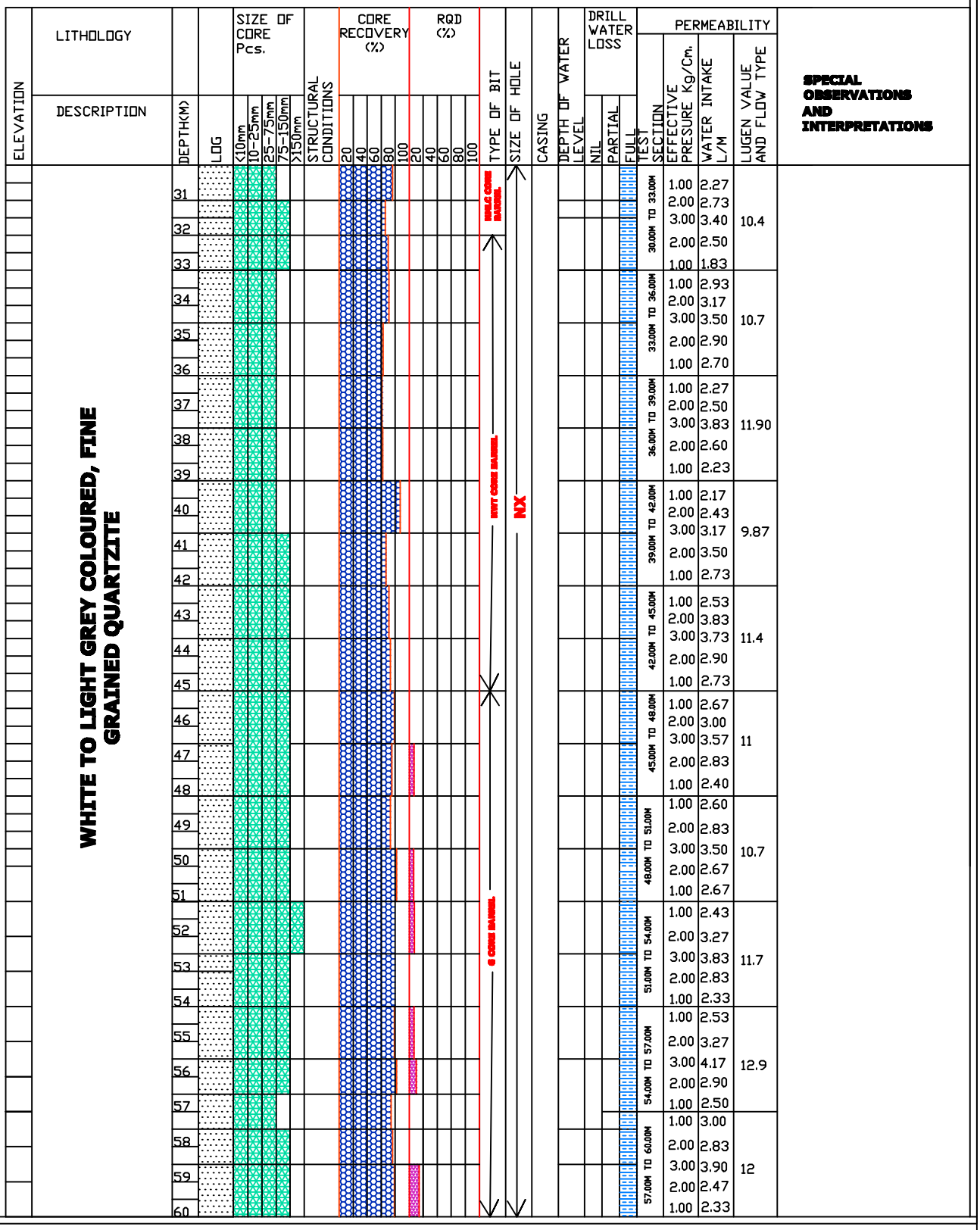
PROJECT: WANGCHU H.E.PROJECT **CO-ORDINATES: N50185.090 E40026.734** HOLE NO.DH-7

LOCATION : DAM AXIS (LEFT BANK)

BEARING OF HOLE : - **ANGLE WITH HORIZANTAL: 90°**

COLLAR ELEVATION :506.218m **GROUND ELEVATION: 506.018m**

DATE OF START : 14-05-2011 **DATE OF COMPLETION :** **TOTAL DEPTH :140.00m**



SJVN LIMITED

Appendix - 7

SHEET NO-3/5

PROJECT: WANGCHU H.E.PROJECT **CO-ORDINATES: N50185.090 E40026.734** HOLE NO.DH-7

LOCATION : DAM AXIS (LEFT BANK)

BEARING OF HOLE : - **ANGLE WITH HORIZANTAL: 90°**

COLLAR ELEVATION :506.218m **GROUND ELEVATION: 506.018m**

DATE OF START : 14-05-2011 **DATE OF COMPLETION :** **TOTAL DEPTH :140.00m**

ELEVATION	LITHOLOGY DESCRIPTION	DEPTH(M)	LOG	SIZE OF CORE Pcs. <10mm / 10-25mm / 25-75mm / 75-150mm / >150mm	STRUCTURAL CONDITIONS	CORE RECOVERY (%)	RQD(%)	TYPE OF BIT	SIZE OF HOLE	CASING	DEPTH OF WATER LEVEL	DRILL WATER LOSS NIL / PARTIAL / FULL	PERMEABILITY TEST SECTION	EFFECTIVE PRESURE Kg/Cm.	WATER INTAKE L/M	LUGEN VALUE AND FLOW TYPE	SPECIAL OBSERVATIONS AND INTERPRETATIONS
	WHITE TO LIGHT GREY COLOURED, FINE GRAINED QUARTZITE	61											60.00M TO 63.00M	1.00	2.50		
		62												2.00	2.90		
		63												3.00	3.83	11.7	
		64											63.00M TO 66.00M	2.00	2.67		
		65												1.00	2.33		
		66												1.00	2.50		
		67												2.00	2.70		
		68												3.00	3.07	9.39	
		69											66.00M TO 69.00M	2.00	3.00		
		70												1.00	2.33		
		71												1.00	2.33		
		72												2.00	2.67		
		73												3.00	3.33	10.3	
		74											69.00M TO 72.00M	2.00	2.50		
		75										8.65		1.00	1.93		
		76												1.00	2.43		
		77												2.00	2.80		
		78												3.00	3.60	11.10	
		79											72.00M TO 75.00M	2.00	2.67		
		80												1.00	2.00		
		81												1.00	2.67		
		82												2.00	3.80		
		83												3.00	3.67	11.2	
		84											75.00M TO 78.00M	2.00	2.60		
		85												1.00	2.33		
		86										8.65		1.00	2.33		
		87												2.00	2.90		
		88												3.00	3.67	11.4	
		89											78.00M TO 81.00M	2.00	2.67		
		90												1.00	2.23		
														1.00	3.27		
														2.00	2.67		
														3.00	4.27	13.3	
													81.00M TO 84.00M	2.00	3.33		
														1.00	2.57		
														1.00	2.67		
														2.00	3.10		
														3.00	4.00	12.3	
													84.00M TO 87.00M	2.00	2.90		
														1.00	2.43		
														1.00	2.53		
														2.00	3.33		
														3.00	3.60	11.2	
														2.00	2.60		
														1.00	2.33		

SJVN LIMITED

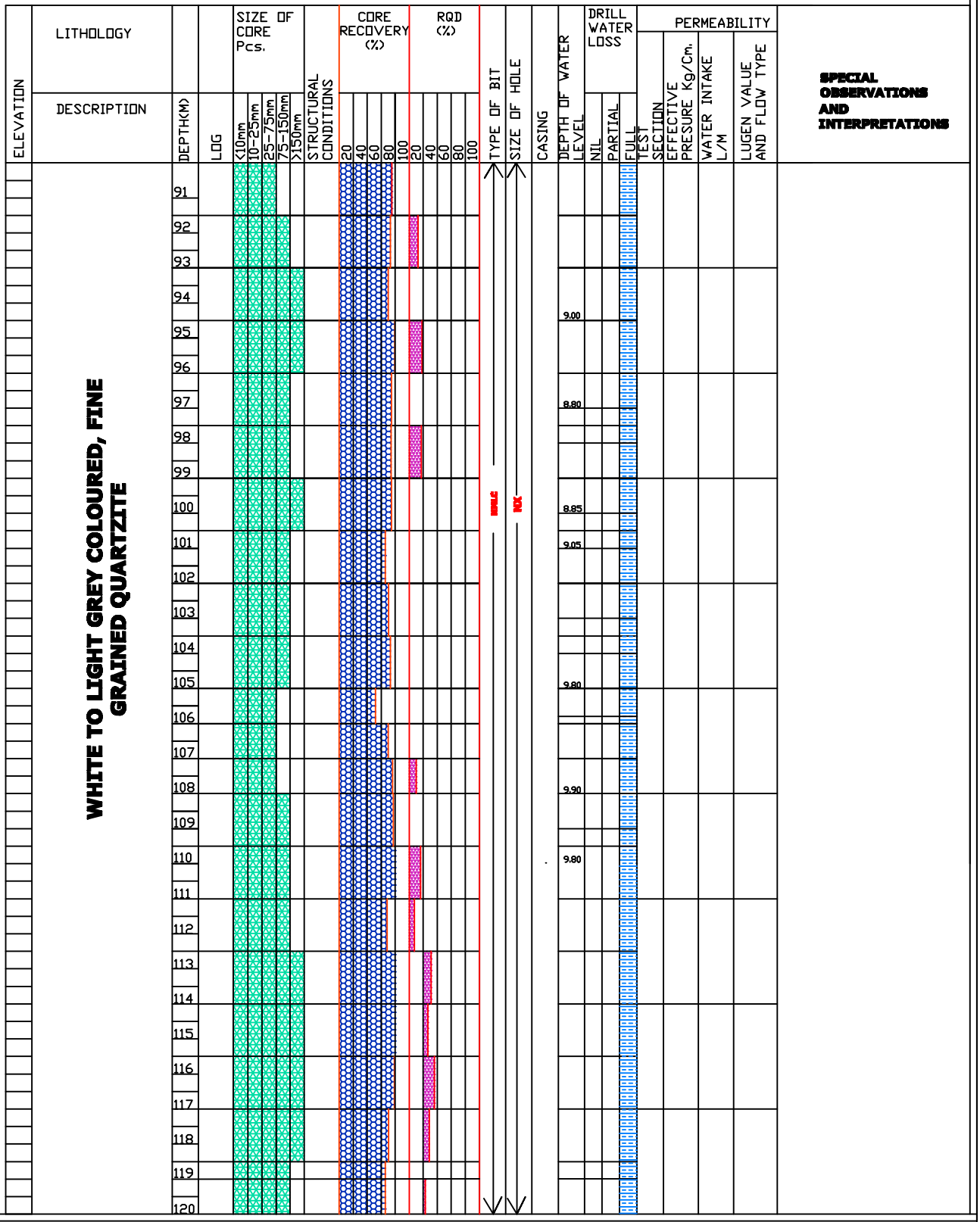
PROJECT: WANGCHU H.E.PROJECT **CO-ORDINATES: N50185.090 E40026.734** HOLE NO.DH-7

LOCATION : DAM AXIS (LEFT BANK)

BEARING OF HOLE : - **ANGLE WITH HORIZANTAL: 90°**

COLLAR ELEVATION :506.218m **GROUND ELEVATION: 506.018m**

DATE OF START : 14-05-2011 **DATE OF COMPLETION :** **TOTAL DEPTH :140.00m**



SJVN LIMITED

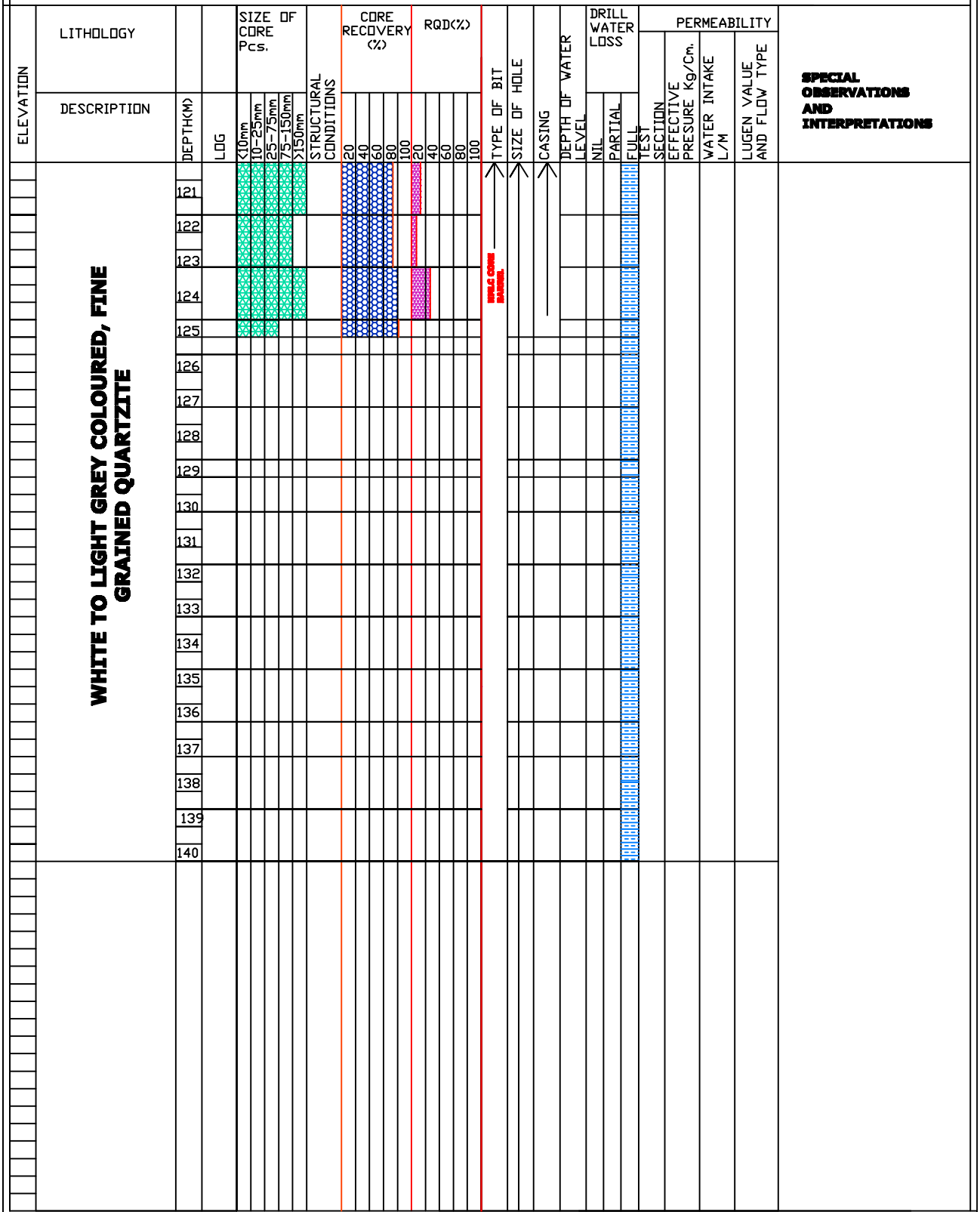
PROJECT: WANGCHU H.E.PROJECT **CO-ORDINATES: N50185.090 E40026.734** HOLE NO.DH-7

LOCATION : DAM AXIS (LEFT BANK)

BEARING OF HOLE : - **ANGLE WITH HORIZANTAL: 90°**

COLLAR ELEVATION :506.218m **GROUND ELEVATION: 506.018m**

DATE OF START : 14-05-2011 **DATE OF COMPLETION :** **TOTAL DEPTH :140.00m**



WAPCOS LIMITED

Appendix - 8

SHEET NO-1/5

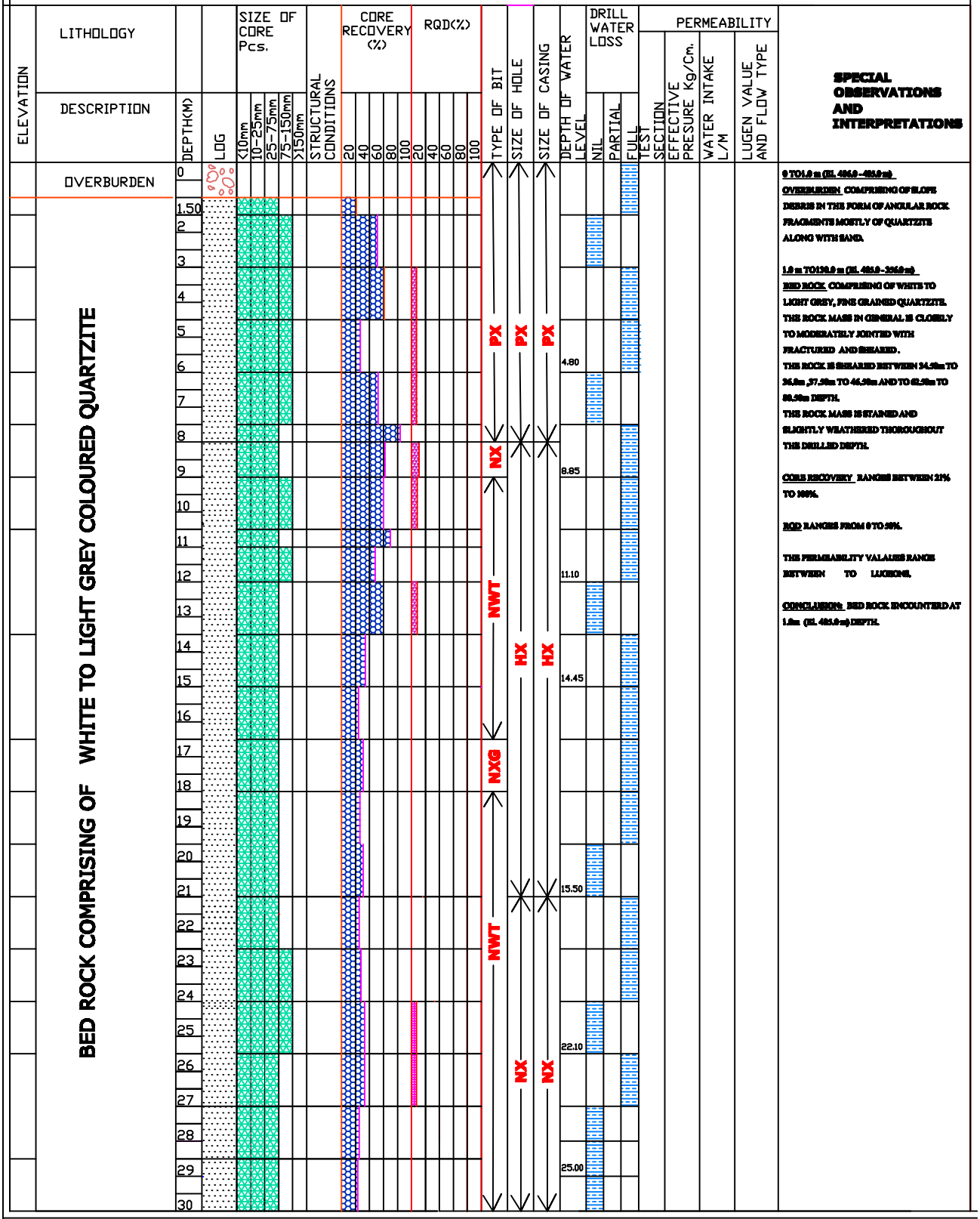
PROJECT: WANGCHU H.E.PROJECT | **CO-ORDINATES: N:** | **E:** | HOLE NO. DH-8

LOCATION : DAM SITE | **FEATURES: DIVERSION TUNNEL OUTLET**

BEARING OF HOLE : -VERTICAL | **ANGLE WITH HORIZONTAL: 90°**

COLLAR ELEVATION : 486.20m | **GROUND ELEVATION: .486.00 m**

DATE OF START : 18.07.2011 | **DATE OF COMPLETION :29.10.2011** | **TOTAL DEPTH : 130.00 m**



0 TO1.5 m (EL 486.0 -484.5 m)
OVERBURDEN COMPRISING OF SLOPE DEBRIS IN THE FORM OF ANGULAR ROCK FRAGMENTS MOSTLY OF QUARTZITE ALONG WITH SAND.

1.5 m TO130.0 m (EL 484.5 - 356.0 m)
BED ROCK COMPRISING OF WHITE TO LIGHT GREY, FINE GRAINED QUARTZITE. THE ROCK MASS IN GENERAL IS CLOSELY TO MODERATELY JOINTED WITH FRACTURED AND SHEARED.
THE ROCK IS SHEARED BETWEEN 54.50m TO 56.0m ,97.50m TO 46.50m AND TO 62.50m TO 88.50m DEPTH.
THE ROCK MASS IS STAINED AND SLIGHTLY WEATHERED THROUGHOUT THE DRILLED DEPTH.

CORE RECOVERY RANGES BETWEEN 21% TO 100%.

RQD RANGES FROM 0 TO 50%.

THE PERMEABILITY VALAUES RANGE BETWEEN TO LUGEONS.

CONCLUSION: BED ROCK ENCOUNTERD AT 1.5m (EL 484.5 m) DEPTH.

WAPCOS LIMITED

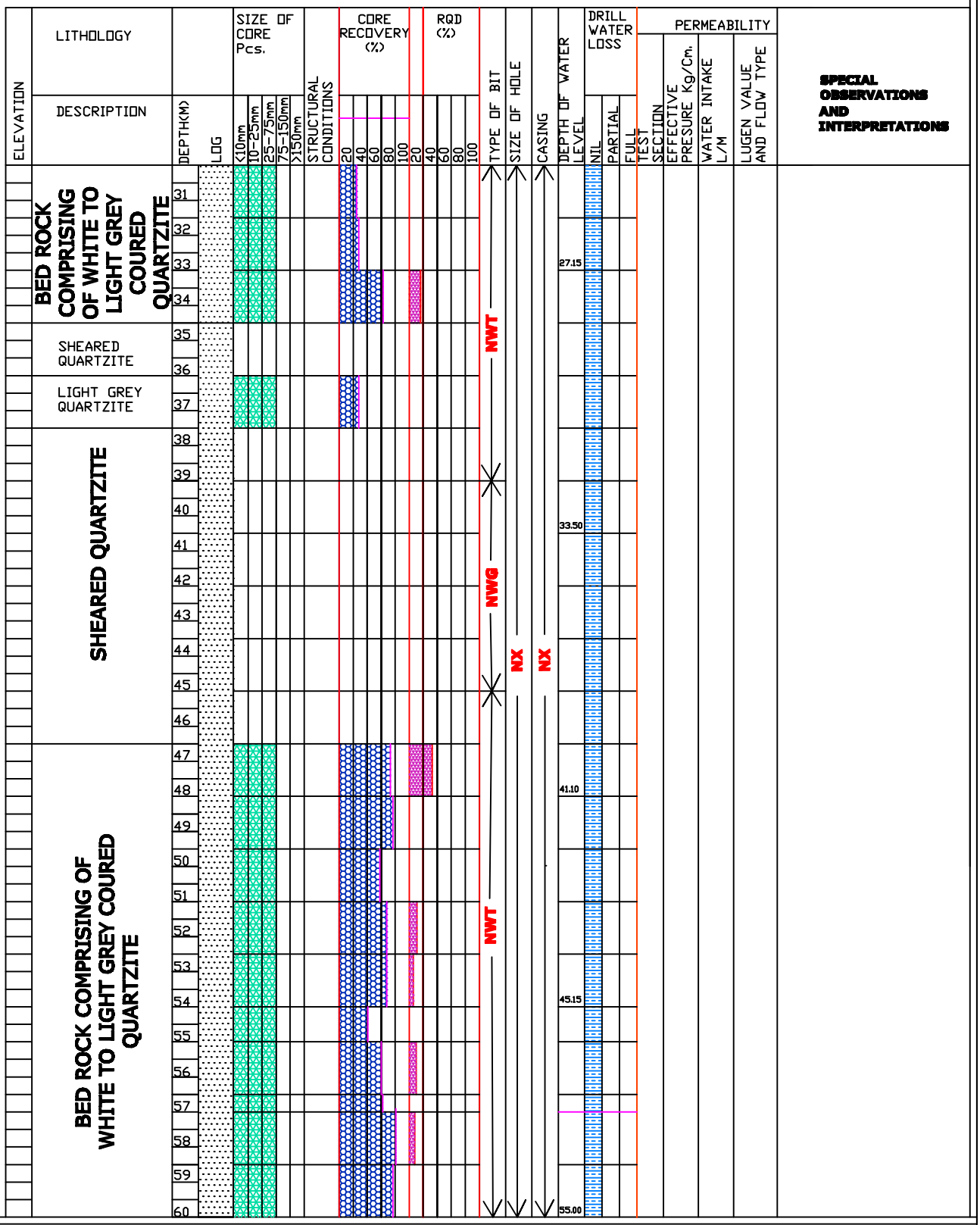
PROJECT: WANGCHU H.E.PROJECT **CO-ORDINATES: N:** HOLE NO. DH-8
E:

LOCATION : DAM SITE **FEATURES: DIVERSION TUNNEL OUTLET**

BEARING OF HOLE : -VERTICAL **ANGLE WITH HORIZONTAL: 90°**

COLLAR ELEVATION : 486.20m **GROUND ELEVATION: .486.00 m**

DATE OF START : 18.07.2011 **DATE OF COMPLETION :29.10.2011** **TOTAL DEPTH : 130.00 m**



WAPCOS LIMITED

Appendix - 8

SHEET NO-3/5

PROJECT: WANGCHU H.E.PROJECT | **CO-ORDINATES: N:** | HOLE NO. DH-8

E:

LOCATION : DAM SITE | **FEATURES: DIVERSION TUNNEL OUTLET**

BEARING OF HOLE : -VERTICAL | **ANGLE WITH HORIZONTAL: 90°**

COLLAR ELEVATION : 486.20m | **GROUND ELEVATION: .486.00 m**

DATE OF START : 18.07.2011 | **DATE OF COMPLETION :29.10.2011** | **TOTAL DEPTH : 130.00 m**

ELEVATION	LITHOLOGY DESCRIPTION	DEPTH(M)	LOG	SIZE OF CORE Pcs. <10mm / 10-25mm / 25-75mm / 75-150mm / >150mm	STRUCTURAL CONDITIONS	CORE RECOVERY (%) 20 40 60 80 100	RQD(%) 20 40 60 80 100	TYPE OF BIT	SIZE OF HOLE	SIZE OF CASING	DEPTH OF WATER LEVEL	DRILL WATER LOSS NIL / PARTIAL / FULL	PERMEABILITY TEST SECTION	EFFECTIVE PRESURE Kg/Cm.	WATER INTAKE L/M	LUGEN VALUE AND FLOW TYPE	SPECIAL OBSERVATIONS AND INTERPRETATIONS
		61															0 TO 21.0 m (EL. 465.0 - 494.0 m) OVERBURDEN COMPRISING OF SLOPE DEBRIS IN THE FORM OF ANGULAR ROCK FRAGMENTS MOSTLY OF QUARTZITE ALONG WITH SAND.
		62															
	SHEARED QUARTZITE	63															21.0 m TO 90.0 m (EL. 494.0 - 465.0 m) BED ROCK COMPRISING OF WHITE TO LIGHT GREY/BLUE COLOURED, FINE GRAINED QUARTZITE. THE ROCK MASS IN GENERAL IS CLOSELY TO MODERATELY JOINTED WITH FRACTURED AND SHATTERED REACHES. BLACK FILLINGS ALONG THE JOINT PLANES OBSERVED.
		64									57.00						
		65															
		66															
		67															
		68															THE ROCK MASS IS STAINED AND SLIGHTLY WEATHERED THOROUGHOUT THE DRILLED DEPTH.
		69															
		70									59.50						CORE RECOVERY RANGES BETWEEN 44% TO 88.6%.
		71															
		72						NWT	NX	NX							RQD RANGES FROM 0 TO 26%.
		73															
		74															THE PERMEABILITY VALAUES RANGE BETWEEN TO LUGEONS.
		75									70.05						
		76															CONCLUSION: BED ROCK ENCOUNTERD AT 21.0 (EL. 494.0 m) DEPTH.
		77															
		78															
		79									75.00						
		80															
	BED ROCK COMPRISING OF WHITE TO LIGHT GREY COLOURED QUARTZITE	81															
		82									76.00		81.00M TO 84.00M	1.00	4.00		
														2.00	4.30		
		83												3.00	4.67	14.20	
														2.00	4.03		
		84												1.00	3.77		
		85											84.00M TO 87.00M	1.00	2.27		
														2.00	3.03		
		86												3.00	3.61	11.10	
														2.00	2.35		
		87						BX	BX	BX				1.00	2.67		
		88											87.00M TO 90.00M	1.00	4.17		
														2.00	4.27		
		89												3.00	5.20	16.00	
														2.00	4.33		
		90												1.00	3.87		

WAPCOS LIMITED

PROJECT: WANGCHU H.E.PROJECT | **CO-ORDINATES: N:** | HOLE NO. DH-8

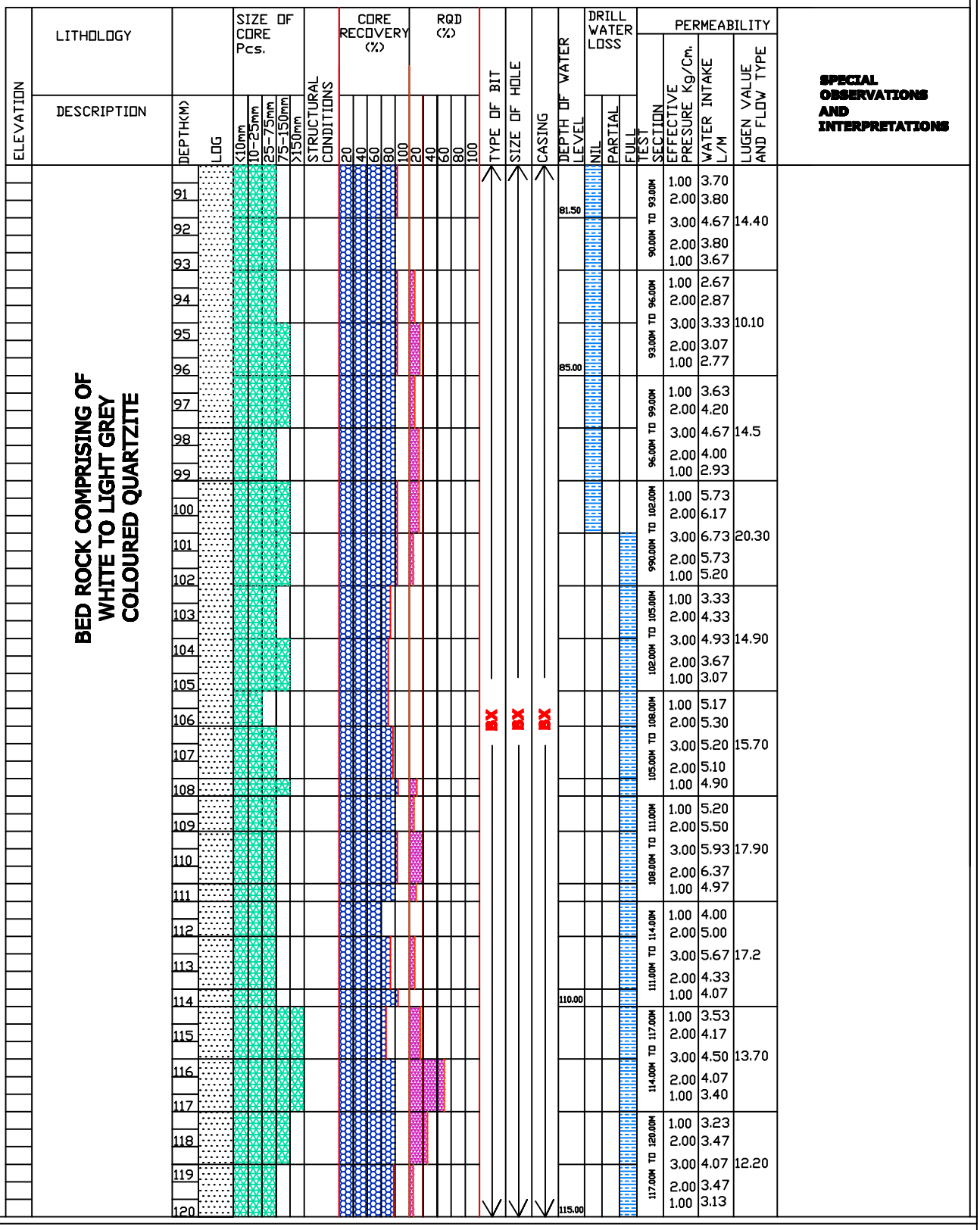
E:

LOCATION : DAM SITE | **FEATURES: DIVERSION TUNNEL OUTLET**

BEARING OF HOLE : -VERTICAL | **ANGLE WITH HORIZONTAL: 90°**

COLLAR ELEVATION : 486.20m | **GROUND ELEVATION: .486.00 m**

DATE OF START : 18.07.2011 | **DATE OF COMPLETION :29.10.2011** | **TOTAL DEPTH : 130.00 m**



WAPCOS LIMITED

Appendix - 8

SHEET NO-5/5

PROJECT: WANGCHU H.E.PROJECT **CO-ORDINATES: N:** HOLE NO. DH-8

E:

LOCATION : DAM SITE **FEATURES: DIVERSION TUNNEL OUTLET**

BEARING OF HOLE : -VERTICAL **ANGLE WITH HORIZONTAL: 90°**

COLLAR ELEVATION : 486.20m **GROUND ELEVATION: .486.00 m**

DATE OF START : 18.07.2011 **DATE OF COMPLETION :29.10.2011** **TOTAL DEPTH : 130.00 m**

ELEVATION	LITHOLOGY DESCRIPTION	DEPTH(M)	LOG	SIZE OF CORE Pcs. <10mm	10-25mm	25-75mm	75-150mm	>150mm	STRUCTURAL CONDITIONS	CORE RECOVERY (%) 20 40 60 80 100	RQD (%) 20 40 60 80 100	TYPE OF BIT	SIZE OF HOLE	CASING	DEPTH OF WATER LEVEL	DRILL WATER LOSS NIL	PARTIAL	FULL	PERMEABILITY TEST SECTION	EFFECTIVE PRESURE Kg/Cm.	WATER INTAKE L/M	LUGEN VALUE AND FLOW TYPE	SPECIAL OBSERVATIONS AND INTERPRETATIONS
	BED ROCK COMPRISING OF WHITE TO LIGHT GREY COLOURED QUARTZITE	121										BX	BX	BX	119.50				120.00M TO 123.00M	1.00	5.00		
																				2.00	5.33		
		122																		3.00	6.07	18.50	
																				2.00	5.63		
		123																		1.00	4.77		
		124																	123.00M TO 126.00M	1.00	3.67		
																				2.00	4.33		
		125																		3.00	5.33	16.10	
																				2.00	4.13		
		126																		1.00	3.53		
		127													125.00				126.00M TO 129.00M	1.00	4.33		
																				2.00	5.00		
		128																		3.00	6.27	19.00	
																				2.00	4.80		
		129																		1.00	4.33		
		130																					

SJVN LIMITED

Appendix - 9

SHEET NO-1/2

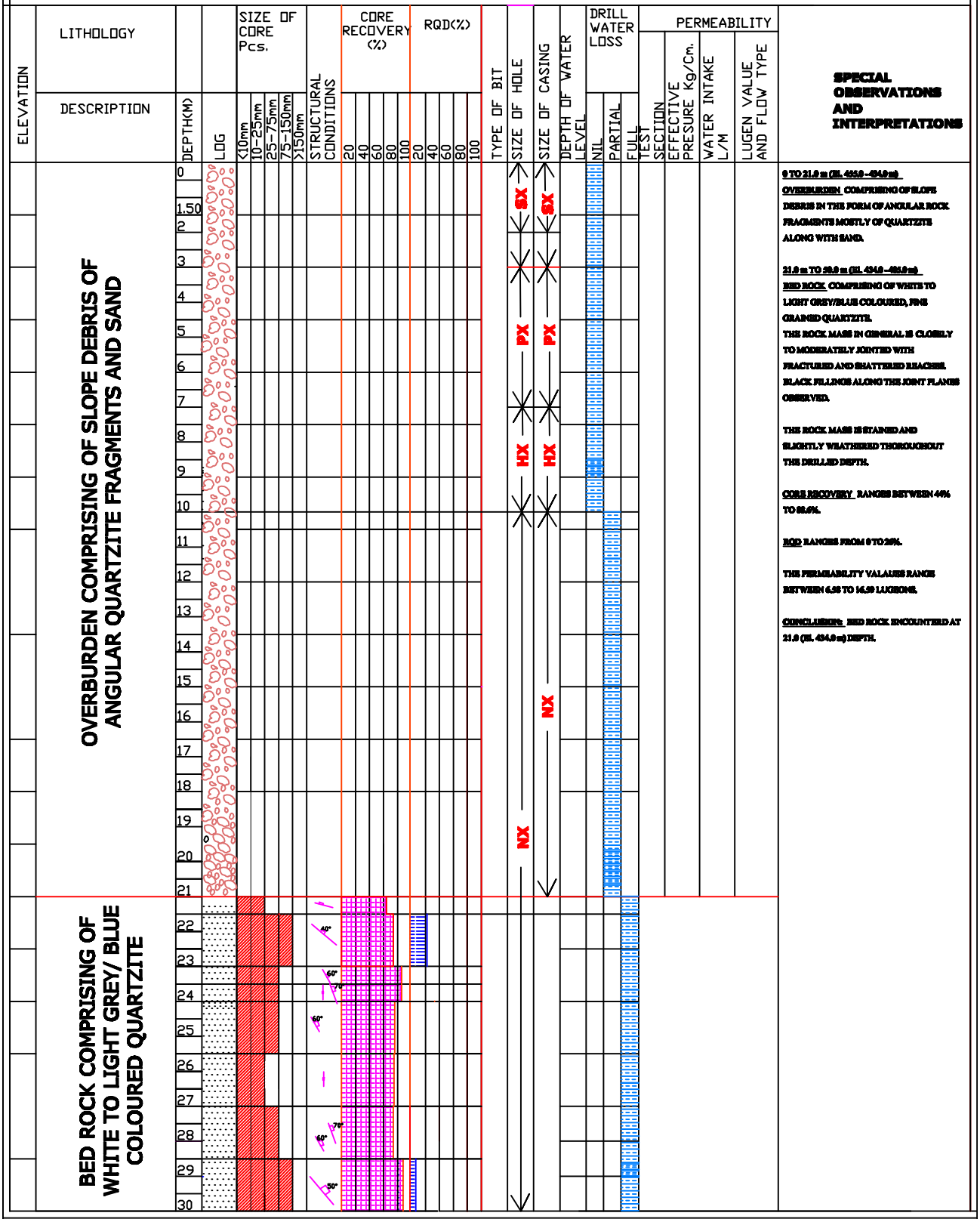
PROJECT: **WANGCHU H.E.PROJECT** CO-ORDINATES: N: E: HOLE NO. DH-9

LOCATION : DAM SITE FEATURES: DIVERSION TUNNEL OUTLET

BEARING OF HOLE : - ANGLE WITH HORIZONTAL: 90°

COLLAR ELEVATION : GROUND ELEVATION: 455.0 m

DATE OF START : 27.05.2011 DATE OF COMPLETION : 18.06.2011 TOTAL DEPTH : 50.0 m



0 TO 21.0 m (EL. 455.0 - 434.0 m)

OVERBURDEN COMPRISING OF SLOPE DEBRIS IN THE FORM OF ANGULAR ROCK FRAGMENTS MOSTLY OF QUARTZITE ALONG WITH SAND.

21.0 m TO 50.0 m (EL. 434.0 - 405.0 m)

BED ROCK COMPRISING OF WHITE TO LIGHT GREY/BLUE COLOURED, FINE GRAINED QUARTZITE.

THE ROCK MASS IN GENERAL IS CLOSELY TO MODERATELY JOINTED WITH FRACTURED AND SHATTERED REACHES. BLACK FILLINGS ALONG THE JOINT PLANES OBSERVED.

THE ROCK MASS IS STAINED AND SLIGHTLY WEATHERED THOROUGHOUT THE DRILLED DEPTH.

CORE RECOVERY RANGES BETWEEN 44% TO 88.6%.

RQD RANGES FROM 0 TO 26%.

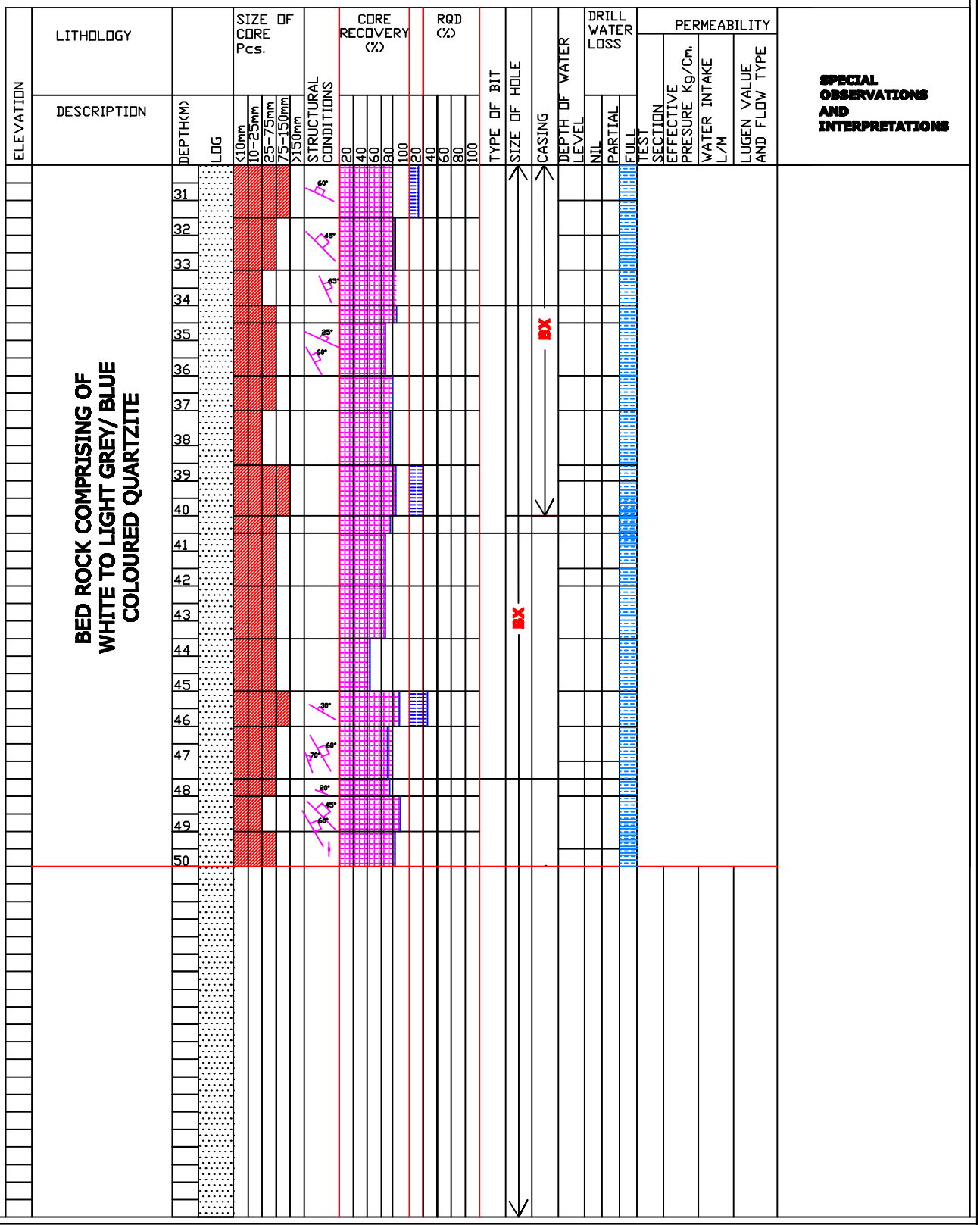
THE PERMEABILITY VALAUES RANGE BETWEEN 6.58 TO 14.50 LUGEONS.

CONCLUSION: BED ROCK ENCOUNTERD AT 21.0 (EL. 434.0 m) DEPTH.

SJVN LIMITED

Appendix - 9
SHEET NO-2/2

PROJECT: WANGCHU H.E.PROJECT **CO-ORDINATES: N:** HOLE NO. DH-9
E:
LOCATION : DAM SITE **FEATURES: DIVERSION TUNNEL OUTLET**
BEARING OF HOLE : - **ANGLE WITH HORIZONTAL: 90°**
COLLAR ELEVATION : **GROUND ELEVATION: 455.0 m**
DATE OF START : 27.05.2011 **DATE OF COMPLETION : 18.06.2011** **TOTAL DEPTH : 50.0 m**



SJVN Ltd.

Appendix - 10

SHEET NO-1/3

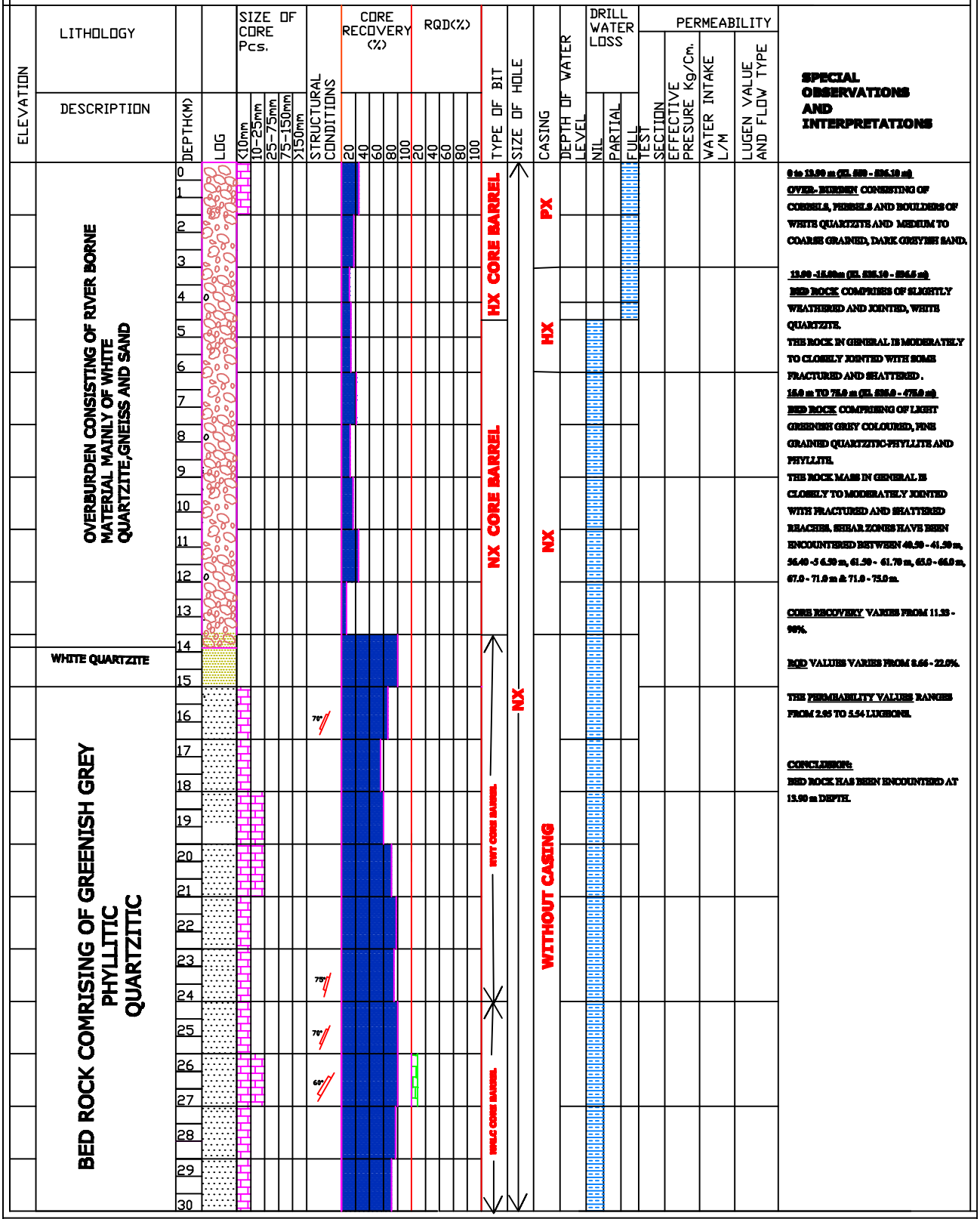
PROJECT: WANGCHU H.E.PROJECT **CO-ORDINATES: N 51040.000 E 41580.000** HOLE NO .HRT-1

LOCATION : HRT 1 (SILUNG NALA)

BEARING OF HOLE : - **ANGLE WITH HORIZANTAL: 90°**

COLLAR ELEVATION :550.150M **GROUND ELEVATION: 550.00 M**

DATE OF START :09.07.2011 **DATE OF COMPLETION : 05.09.2011** **TOTAL DEPTH :75.00 m**



0 to 13.90 m (EL 550 - 536.10 m)

OVER- BURDEN CONSISTING OF COBBELS, PEBBELS AND BOULDERS OF WHITE QUARTZITE AND MEDIUM TO COARSE GRAINED, DARK GREYISH SAND.

13.90 -15.90m (EL 536.10 - 534.6 m)

BED ROCK COMPRISES OF SLIGHTLY WEATHERED AND JOINTED, WHITE QUARTZITE.

THE ROCK IN GENERAL IS MODERATELY TO CLOSELY JOINTED WITH SOME FRACTURED AND SHATTERED .

15.0 m TO 75.0 m (EL 535.0 - 475.0 m)

BED ROCK COMPRISING OF LIGHT GREENISH GREY COLOURED, FINE GRAINED QUARTZITIC-PHYLLITE AND PHYLLITE.

THE ROCK MASS IN GENERAL IS CLOSELY TO MODERATELY JOINTED WITH FRACTURED AND SHATTERED REACHES. SHEAR ZONES HAVE BEEN ENCOUNTERED BETWEEN 40.50 - 41.50 m, 56.40 -5 6.50 m, 61.50 - 61.70 m, 65.0 - 66.0 m, 67.0 - 71.0 m & 71.0 - 75.0 m.

CORE RECOVERY VARIES FROM 11.33 - 90%.

RQD VALUES VARIES FROM 8.66 - 22.0%.

THE **PERMEABILITY VALUES** RANGES FROM 2.95 TO 5.54 LUGEONS.

CONCLUSION:

BED ROCK HAS BEEN ENCOUNTERED AT 13.90 m DEPTH.

SJVN LIMITED

PROJECT: WANGCHU H.E.P., BHUTAN

LOCATION : DAM SITE, DAM AXIS

BEARING OF HOLE : N40°E

COLLAR ELEVATION : 404.588 m

DATE OF START : 23.10.11

CO-ORDINATES: N: 50074.586
E: 39938.709

FEATURES: RIVER BED, RIGHT BANK

ANGLE WITH HORIZONTAL: 70°

GROUND ELEVATION: 404.438 m

DATE OF COMPLETION : 30.11.11

HOLE NO. DH- 10A

TOTAL DEPTH : 75.0 m

ELEVATION	LITHOLOGY DESCRIPTION	DEPTH(M)	LOG	SIZE OF CORE Pcs. <10mm	10-25mm	25-75mm	75-150mm	>150mm	STRUCTURAL CONDITIONS	CORE RECOVERY (%) 20	40	60	80	100	RQD (%) 20	40	60	80	100	TYPE OF BIT	SIZE OF HOLE	CASING	DEPTH OF WATER LEVEL	DRILL WATER LOSS NIL	PARTIAL	FULL	PERMEABILITY TEST SECTION	EFFECTIVE PRESURE Kg/Cm.	WATER INTAKE Lit/Min/Meter	LUGEN VALUE AND FLOW TYPE	SPECIAL OBSERVATIONS AND INTERPRETATIONS
404.43	OVERBURDEN CONSISTS OF BOULDERS OF QUARTZITE, BIOTITE GNEISS, AMPHIBOLITE AND SAND																			PX												
403.43		01																														
402.43		02																														
401.43		03																														
400.43		04																				HX	HX	0.50m								
399.43		05																														
398.43		06																														
397.43		07																														
396.43		08																														
395.43		09																				HX										
394.43		10																														
393.43		11																														
392.43		12																														
391.43		13																														
390.43		14																														
389.43		15																														
388.43		16																														
387.43		17																														
386.43		18																														
385.43		19																														
384.43		20																														
383.43		21																														
382.43		22																														
381.43		23																														
380.43		24																														
379.43		25																														
378.43		26																														
377.43		27																														
376.43		28																														
375.43		29																														
374.43		30																														

NX

NX

NWT CORE BIT

0.55m

0.56m

0 TO 49.50 m (EL:+ 404.438 TO 360.938m)
OVERBURDEN COMPRISING OF TALUS/ SLOPE DEBRIS FORMED OF ANGULAR FRAGMENTS OF QUARTZITE, PHYLLITIC QUARTZITE AND DOLOMITE.
49.05 TO 75.00 m (360.938 TO 329.438 m)
BED ROCK COMPRISES MAINLY OF WHITE QUARTZITE WITH SHEAR ZONES BETWEEN 61.50m TO 72.00 m OF CRUSHED ROCK.

THE ROCK MASS IN GENERAL IS FRESH IN NATURE.

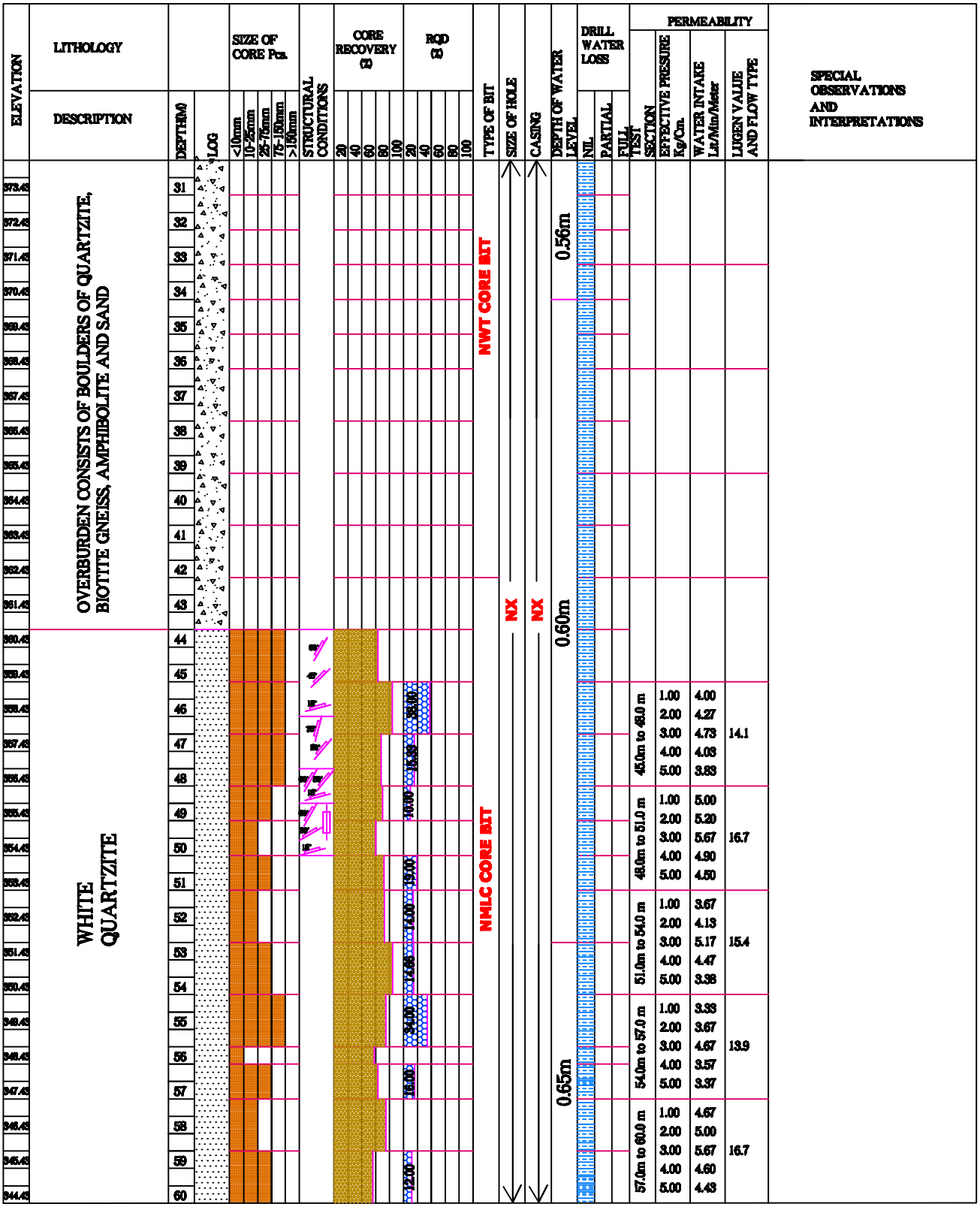
CORE RECOVERY IS VERY POOR DUE TO FISSILE/FRAGILE NATURE OF THE ROCK. IN SOME REACHES SIGNS OF REDRILLING AND MECHANICAL BREAKAGE OBSERVED.

RQD HAS BEEN OBSERVED IN THE ROCK. 10% TO 30%

THE PERMEABILITY VALAUES RANGE BETWEEN 13.70 TO 18.1 LUGEONS.

CONCLUSION: BED ROCK ENCOUNTERD AT 49.50 (EL 360.938 m) DEPTH.

Drawn By:SANJAY KUMAR Logged By:KULBHUSHAN THAKUR Checked/Approved By:



Drawn By:SANJAY KUMAR Logged By:KULBHUSHAN THAKUR Checked/Approved By:

ELEVATION	LITHOLOGY DESCRIPTION	DEPTH(M)	LOG	SIZE OF CORE Pcs. <10mm	10-25mm	25-75mm	75-150mm	>150mm	STRUCTURAL CONDITIONS	CORE RECOVERY (%) 20	40	60	80	100	RQD (%) 20	40	60	80	100	TYPE OF BIT	SIZE OF HOLE	CASING	DEPTH OF WATER LEVEL	DRILL WATER LOSS NIL	PARTIAL	FULL	TEST SECTION	PERMEABILITY EFFECTIVE PRESSURE Kg/Cm.	WATER INTAKE Lit/Min/Meter	LUGEN VALUE AND FLOW TYPE	SPECIAL OBSERVATIONS AND INTERPRETATIONS
343.45	WHITE QUARTZITE	61																		NMLC CORE BIT	NX	NX	0.65m				60.0m to 63.0 m	1.00	3.67		
																													2.00	4.33		
342.45		62																											3.00	5.83	17.4	
																													4.00	4.27		
341.45		63																											5.00	3.90		
																												63.0m to 66.0 m	1.00	4.67		
340.45		64																											2.00	5.17		
																													3.00	6.10	18.1	
339.45		65																											4.00	4.93		
																													5.00	4.33		
338.45		66																											66.0m to 69.0 m	1.00	4.33		
																													2.00	4.67		
337.45	SHEARED ZONE /CRUSHED ROCK	67																											3.00	5.33	15.8	
																													4.00	4.50		
336.45		68																											5.00	4.20		
																												69.0m to 72.0 m	1.00	4.03		
335.45		69																											2.00	4.20		
																													3.00	4.60	13.7	
334.45		70																											4.00	4.07		
																													5.00	3.80		
333.45		71																														
332.45		72																														
331.45	WHITE QUARTZITE	73																											72.0m to 75.0 m	1.00	4.87		
																													2.00	5.00		
330.45		74																											3.00	5.33	15.7	
																													4.00	4.67		
329.45		75																											5.00	4.57		

Drawn By:SANJAY KUMAR Logged By:KULBHUSHAN THAKUR Checked/Approved By:

SJVN LIMITD

PROJECT: WANGCHU H.E.P., BHUTAN

CO-ORDINATES: N: 50019.783
E: 39871.911

HOLE NO. DH-11A

LOCATION : DAM SITE

FEATURES: RIGHT BANK, DAM AXIS

BEARING OF HOLE: S40°W

ANGLE WITH HORIZONTAL : 45°

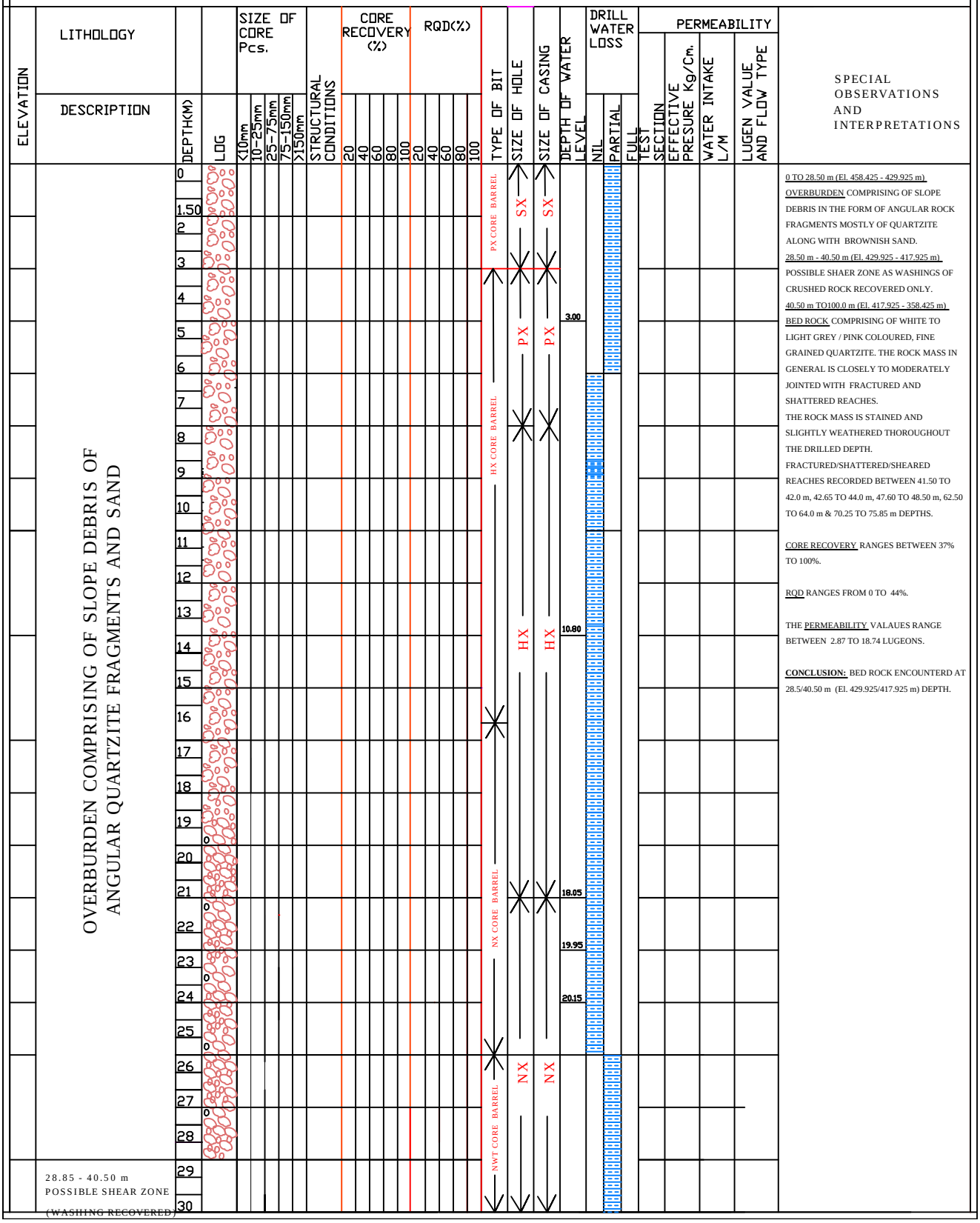
COLLAR ELEVATION : 458.62m

GROUND ELEVATION: 458.425 m

DATE OF START : 19.11.2011

DATE OF COMPLETION : 01.01.2012

TOTAL DEPTH : 100.0 m



0 TO 28.50 m (El. 458.425 - 429.925 m) OVERBURDEN COMPRISING OF SLOPE DEBRIS IN THE FORM OF ANGULAR ROCK FRAGMENTS MOSTLY OF QUARTZITE ALONG WITH BROWNISH SAND.

28.50 m - 40.50 m (El. 429.925 - 417.925 m) POSSIBLE SHAER ZONE AS WASHINGS OF CRUSHED ROCK RECOVERED ONLY.

40.50 m TO100.0 m (El. 417.925 - 358.425 m) BED ROCK COMPRISING OF WHITE TO LIGHT GREY / PINK COLOURED, FINE GRAINED QUARTZITE. THE ROCK MASS IN GENERAL IS CLOSELY TO MODERATELY JOINTED WITH FRACTURED AND SHATTERED REACHES.

THE ROCK MASS IS STAINED AND SLIGHTLY WEATHERED THOROUGHOUT THE DRILLED DEPTH.

FRACTURED/SHATTERED/SHEARED REACHES RECORDED BETWEEN 41.50 TO 42.0 m, 42.65 TO 44.0 m, 47.60 TO 48.50 m, 62.50 TO 64.0 m & 70.25 TO 75.85 m DEPTHS.

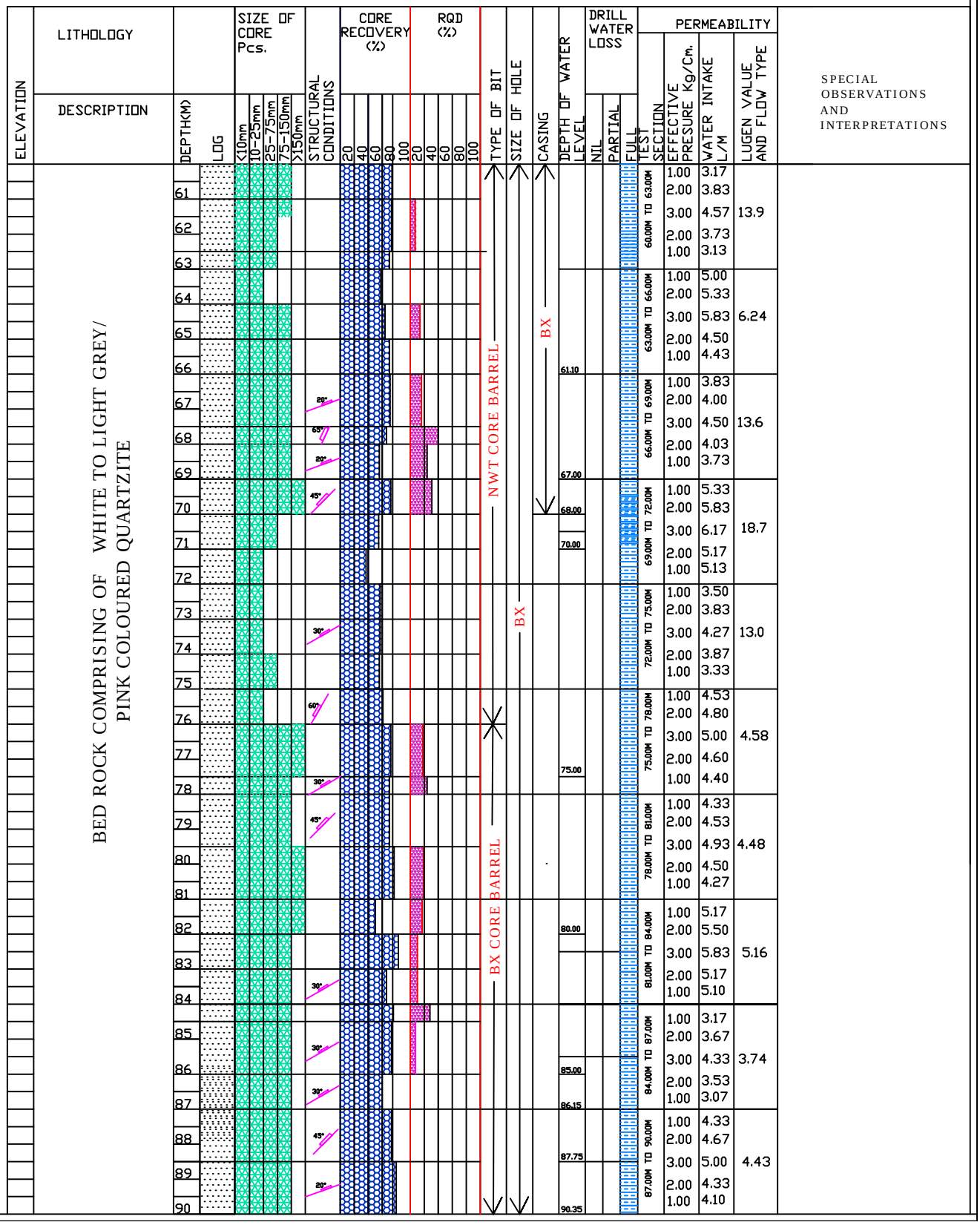
CORE RECOVERY RANGES BETWEEN 37% TO 100%.

RQD RANGES FROM 0 TO 44%.

THE PERMEABILITY VALAUES RANGE BETWEEN 2.87 TO 18.74 LUGEONS.

CONCLUSION: BED ROCK ENCOUNTERD AT 28.5/40.50 m (El. 429.925/417.925 m) DEPTH.

ELEVATION
LITHOLOGY
DESCRIPTION
DEPTH(M)
LOG
SIZE OF CORE Pcs.
<10mm
10-25mm
25-75mm
75-150mm
>150mm
STRUCTURAL CONDITIONS
CORE RECOVERY (%)
RQD (%)
20
40
60
80
100
TYPE OF BIT
SIZE OF HOLE
CASING
DEPTH OF WATER LEVEL
DRILL WATER LOSS
NIL
PARTIAL
FULL
PERMEABILITY
TEST SECTION
EFFECTIVE PRESURE Kg/Cm.
WATER INTAKE L/M
LUGEN VALUE AND FLOW TYPE
SPECIAL OBSERVATIONS AND INTERPRETATIONS
POSSIBLE SHEAR ZONE
(WASHING RECOVERED)
BED ROCK COMPRISING OF
WHITE TO LIGHT GREY/ PINK
COLOURED QUARTZITE
NWT CORE BARREL
NMLC CORE BARREL
BX
NX
35.00
36.50
37.10
39.15
41.19
41.50
42.10
42.00M TD 45.00M
45.00M TD 48.00M
48.00M TD 51.00M
51.00M TD 54.00M
54.00M TD 57.00M
57.00M TD 60.00M
1.00 5.00
2.00 5.33
3.00 5.67 17.7
2.00 5.27
1.00 4.60
1.00 4.00
2.00 4.10
3.00 5.13 6.65
2.00 4.07
1.00 3.73
1.00 4.27
2.00 4.47
3.00 4.67 5.84
2.00 4.40
1.00 4.13
1.00 3.83
2.00 3.93
3.00 4.33 5.34
2.00 3.73
1.00 3.67
1.00 5.67
2.00 5.80
3.00 6.17 7.34
2.00 5.77
1.00 5.60
1.00 4.17
2.00 4.50
3.00 5.17 15.6
2.00 4.40
1.00 3.93


ELEVATION
LITHOLOGY
DESCRIPTION
DEPTH(M)
LOG
SIZE OF CORE Pcs.
<10mm
10-25mm
25-75mm
75-150mm
>150mm
STRUCTURAL CONDITIONS
CORE RECOVERY (%)
RQD (%)
20 40 60 80 100
20 40 60 80 100
TYPE OF BIT
SIZE OF HOLE
CASING
DEPTH OF WATER LEVEL
DRILL WATER LOSS
NIL
PARTIAL
FULL
PERMEABILITY
TEST SECTION
EFFECTIVE PRESURE Kg/Cm.
WATER INTAKE L/M
LUGEN VALUE AND FLOW TYPE
SPECIAL OBSERVATIONS AND INTERPRETATIONS
BED ROCK COMPRISING OF WHITE TO LIGHT GREY/ PINK COLOURED QUARTZITE
NWT CORE BARREL
BX CORE BARREL
BX
BX
61
62
63
64
65
66
67
68
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
20°
65°
20°
45°
30°
60°
30°
45°
30°
30°
30°
45°
20°
61.10
67.00
68.00
70.00
75.00
80.00
85.00
86.15
87.75
90.35
60.00M TD 63.00M
63.00M TD 66.00M
66.00M TD 69.00M
69.00M TD 72.00M
72.00M TD 75.00M
75.00M TD 78.00M
78.00M TD 81.00M
81.00M TD 84.00M
84.00M TD 87.00M
87.00M TD 90.00M
1.00 2.00 3.00 2.00 1.00
3.17 3.83 4.57 3.73 3.13
13.9
1.00 2.00 3.00 2.00 1.00
5.00 5.33 5.83 4.50 4.43
6.24
1.00 2.00 3.00 2.00 1.00
3.83 4.00 4.50 4.03 3.73
13.6
1.00 2.00 3.00 2.00 1.00
5.33 5.83 6.17 5.17 5.13
18.7
1.00 2.00 3.00 2.00 1.00
3.50 3.83 4.27 3.87 3.33
13.0
1.00 2.00 3.00 2.00 1.00
4.53 4.80 5.00 4.60 4.40
4.58
1.00 2.00 3.00 2.00 1.00
4.33 4.53 4.93 4.50 4.27
4.48
1.00 2.00 3.00 2.00 1.00
5.17 5.50 5.83 5.17 5.10
5.16
1.00 2.00 3.00 2.00 1.00
3.17 3.67 4.33 3.53 3.07
3.74
1.00 2.00 3.00 2.00 1.00
4.33 4.67 5.00 4.33 4.10
4.43

ELEVATION	LITHOLOGY DESCRIPTION	DEPTH(M)	LOG	SIZE OF CORE Pcs. <10mm	10-25mm	25-75mm	75-150mm	>150mm	STRUCTURAL CONDITIONS	CORE RECOVERY (%) 20 40 60 80 100	RQD (%) 20 40 60 80 100	TYPE OF BIT	SIZE OF HOLE	CASING	DEPTH OF WATER LEVEL	DRILL WATER LOSS NIL	PARTIAL	FULL	PERMEABILITY TEST SECTION	EFFECTIVE PRESURE Kg/Cm.	WATER INTAKE L/M	LUGEN VALUE AND FLOW TYPE	SPECIAL OBSERVATIONS AND INTERPRETATIONS
	BED ROCK COMPRISING OF WHITE TO LIGHT GREY/ PINK COLOURED QUARTZITE	91							45°			BX CORE BARREL	BX	BX					90.00M TO 93.00M	1.00	2.83		
																				2.00	3.17		
		92																		3.00	3.67	2.87	
									60°											2.00	3.17		
		93													90.35					1.00	3.00		
																			93.00M TO 96.00M	1.00	3.83		
		94							20°											2.00	4.17		
															90.70					3.00	4.50	3.63	
		95																		2.00	4.17		
															92.50					1.00	3.73		
		96																					
		97																	96.00M TO 99.00M	1.00	4.83		
																				2.00	4.90		
		98							20°											3.00	5.50		
																				2.00	4.67	3.90	
		99													97.10					1.00	4.50		
									20°														
		100													98.25								

SJVN LIMITED

PROJECT: WANGCHHU HEP, BHUTAN

CO-ORDINATES: N:50114.13 E:39958.27

HOLE NO.- DH-12A

LOCATION: DAM AXIS

FEATURE : LEFT BANK, RIVER BED

BEARING OF HOLE :-

ANGLE WITH HORIZANTAL: 69°

TOTAL DEPTH : 75.0 m

COLLAR ELEVATION : 404.20 m

GROUND ELEVATION: 404.083 m

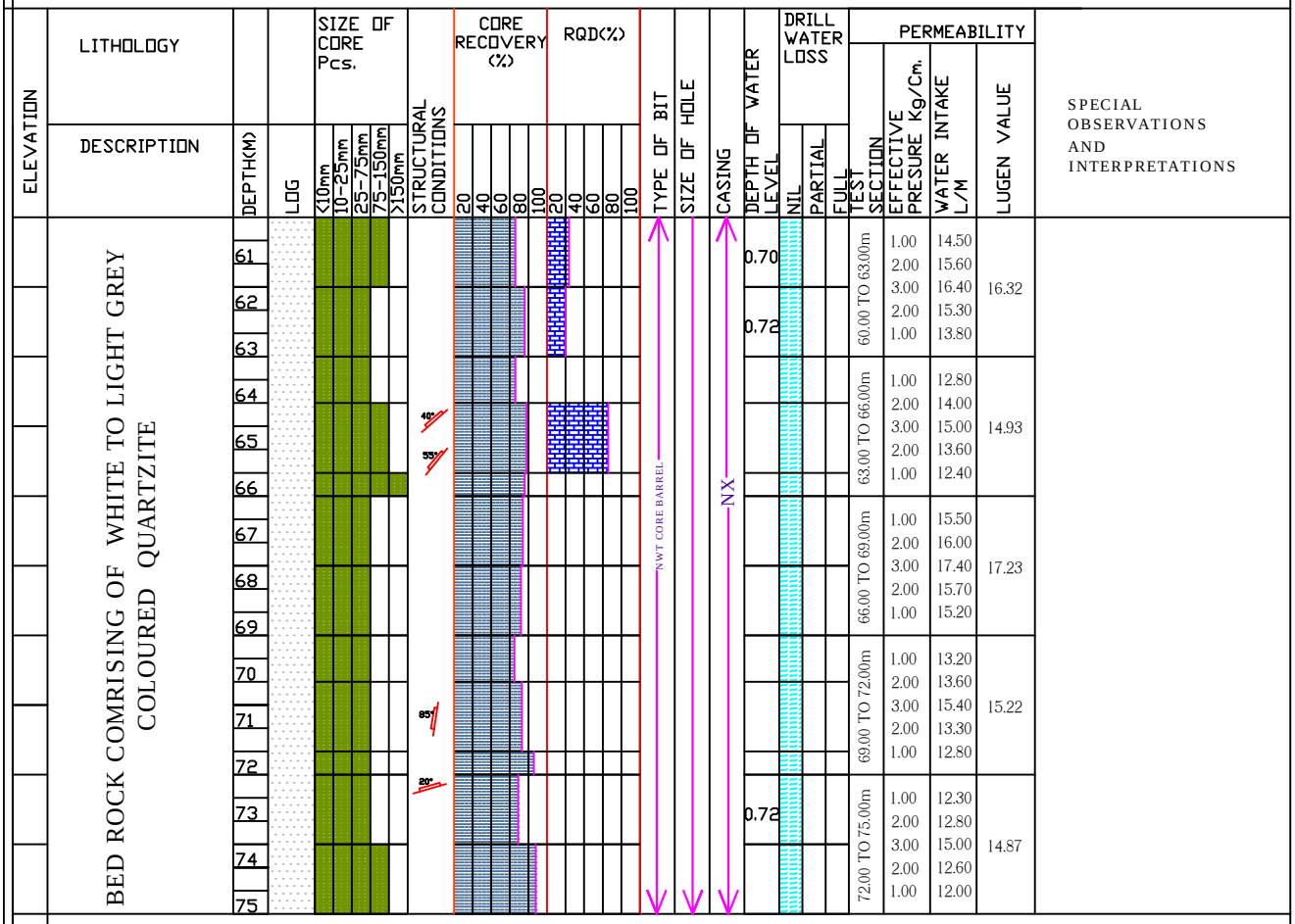
DATE OF START: 20.12.2011

DATE OF COMPLETION: 01.02.2012

ELEVATION	LITHOLOGY DESCRIPTION	DEPTH(M)	LOG	SIZE OF CORE Pcs. <10mm	10-25mm	25-75mm	75-150mm	>150mm	STRUCTURAL CONDITIONS	CORE RECOVERY (%) 20 40 60 80 100	RQD(%) 20 40 60 80 100	TYPE OF BIT	SIZE OF HOLE	CASING	DEPTH OF WATER LEVEL	DRILL WATER LOSS NIL	PARTIAL	FULL	TEST SECTION	PERMEABILITY EFFECTIVE PRESURE Kg/Cm.	WATER INTAKE L/M	LUGEN VALUE	SPECIAL OBSERVATIONS AND INTERPRETATIONS
	OVERBURDEN CONSISTING OF RIVER BORNE MATERIAL AND SAND	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30										PX CORE; HX CORE BARREL; NX CORE BARREL	PX; NX	PX; HX; NX	0.33; 0.50; 0.50; 0.52; 0.52; 0.55; 0.55; 0.58; 0.58; 0.60								**0 to 42.00 m (El. 404.083 - 364.583 m)** **OVER- BURDEN** CONSISTING OF COBBELS, PEBBLES AND BOUNDESRS OF WHITE QUARTZITE AND MEDIUM TO COARSE GRAINED, DARK-GREYISH SAND. **42.00 -75.0 m (El. 364.583 - 334.333 m)** BED ROCK COMPRISES OF WHITE TO LIGHT GREY COLOURED, FINE GRAINED QUARTZITE. THE ROCK IN GENERAL IS MODERATELY TO CLOSELY JOINTED WITH SOME FRACTURED, SHATTERED REACHES AND A SHEAR ZONE BETWEEN 46.50 m TO 49.50 m DEPTH. CORE RECOVERY VARIES BETWEEN 55.33% TO 90%. RQD VALUES RANGES FROM 0% TO 26.6%. PERMEABILITY VALAUES RANGE BETWEEN 10.51 TO 17.23 LUGEONS. **CONCLUSION:** BED ROCK HAS BEEN ENCOUNTERD AT 42.00 m (el. 364.583 m) DEPTH.

DH-12 A
SHEET NO-2/3

ELEVATION	LITHOLOGY DESCRIPTION	DEPTH(M)	LOG	SIZE OF CORE Pcs. <10mm 10-25mm 25-75mm 75-150mm >150mm	STRUCTURAL CONDITIONS	CORE RECOVERY (%) 20 40 60 80 100	RQD(%) 20 40 60 80 100	TYPE OF BIT	SIZE OF HOLE	CASING	DEPTH OF WATER LEVEL	DRILL WATER LOSS NIL PARTIAL FULL	PERMEABILITY TEST SECTION	EFFECTIVE PRESURE Kg/Cm.	WATER INTAKE L/M	LUGEN VALUE	SPECIAL OBSERVATIONS AND INTERPRETATIONS
	OVERBURDEN CONSISTING OF RIVER BORNE MATERIAL AND SAND	31 32 33 34 35 36 37 38 39 40 41 42									0.60 0.65 0.65		39.00 TO 42.00m	1.00 2.00 3.00 2.00 1.00	8.70 10.00 11.40 9.90 8.40	11.37	
	BED ROCK COMRISING OF WHITE TO LIGHT GREY COLOURED QUARTZITE	43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60			30° SHEAR ZONE 80° 50°			NWT CORE BARREL NMLC CORE BARREL NWT CORE BARREL	NX NX	NX NX	0.70		42.00 TO 45.00m 45.00 TO 48.00m 48.00 TO 51.00m 51.00 TO 54.00m 54.00 TO 57.00m 57.00 TO 60.00m	1.00 2.00 3.00 2.00 1.00 1.00 2.00 3.00 2.00 1.00 1.00 2.00 3.00 2.00 1.00 1.00 2.00 3.00 2.00 1.00 1.00 2.00 3.00 2.00 1.00	9.50 10.20 10.60 9.90 9.30 11.70 12.20 13.10 11.80 11.40 10.50 13.50 13.00 11.20 10.40 13.50 14.50 16.90 14.00 13.00 12.80 13.60 14.60 13.50 12.60 15.00 16.00 17.00 14.60 14.30	10.51 13.05 12.94 16.69 14.46 16.79	


ELEVATION
LITHOLOGY
DESCRIPTION
DEPTH(M)
LOG
SIZE OF CORE Pcs.
<10mm
10-25mm
25-75mm
75-150mm
>150mm
STRUCTURAL CONDITIONS
CORE RECOVERY (%)
RQD(%)
20 40 60 80 100
20 40 60 80 100
TYPE OF BIT
SIZE OF HOLE
CASING
DEPTH OF WATER LEVEL
DRILL WATER LOSS
NIL
PARTIAL
FULL
PERMEABILITY
TEST SECTION
EFFECTIVE PRESURE Kg/Cm.
WATER INTAKE L/M
LUGEN VALUE
SPECIAL OBSERVATIONS AND INTERPRETATIONS
61
62
63
64
65
66
67
68
69
70
71
72
73
74
75
40°
55°
85°
20°
0.70
0.72
0.72
NWT CORE BARREL
NX
60.00 TO 63.00m
1.00 2.00 3.00 2.00 1.00
14.50 15.60 16.40 15.30 13.80
16.32
63.00 TO 66.00m
1.00 2.00 3.00 2.00 1.00
12.80 14.00 15.00 13.60 12.40
14.93
66.00 TO 69.00m
1.00 2.00 3.00 2.00 1.00
15.50 16.00 17.40 15.70 15.20
17.23
69.00 TO 72.00m
1.00 2.00 3.00 2.00 1.00
13.20 13.60 15.40 13.30 12.80
15.22
72.00 TO 75.00m
1.00 2.00 3.00 2.00 1.00
12.30 12.80 15.00 12.60 12.00
14.87
BED ROCK COMRISING OF WHITE TO LIGHT GREY COLOURED QUARTZITE

SJVN LIMITED

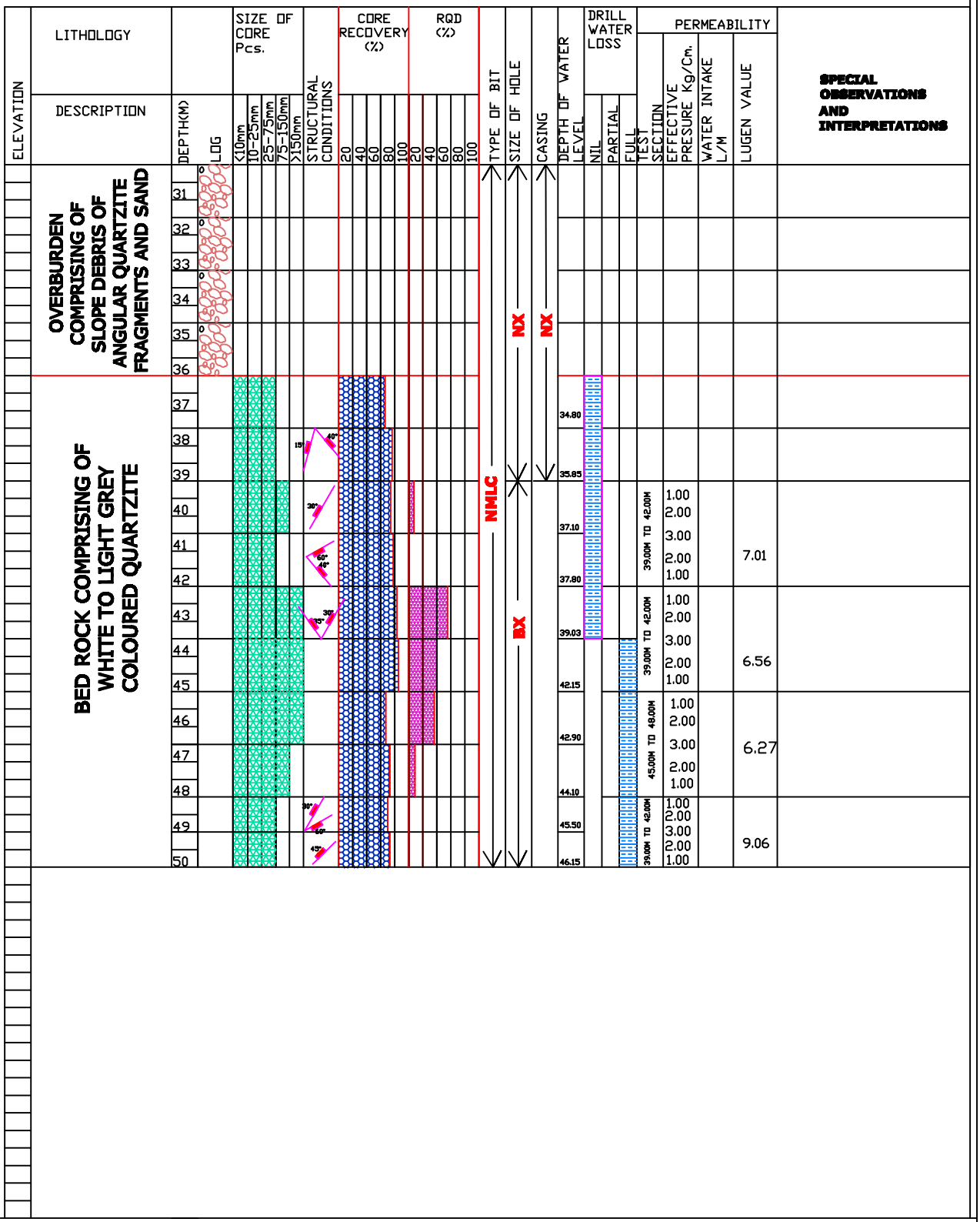
PROJECT: WANGCHU H.E.PROJECT **CO-ORDINATES: N: 49955.027 E: 39867.686** HOLE NO. DH-13

LOCATION : DAM SITE **FEATURE: 32.5 m D/S OF DAM AXIS, RIGHT BANK**

ANGLE WITH HORIZONTAL : 90°

COLLAR ELEVATION : 483.20m **GROUND ELEVATION: 483.0 m**

DATE OF START : 06.02.2012 **DATE OF COMPLETION : 14.03.2012** **TOTAL DEPTH : 50.0 m**



SJVN LIMITED

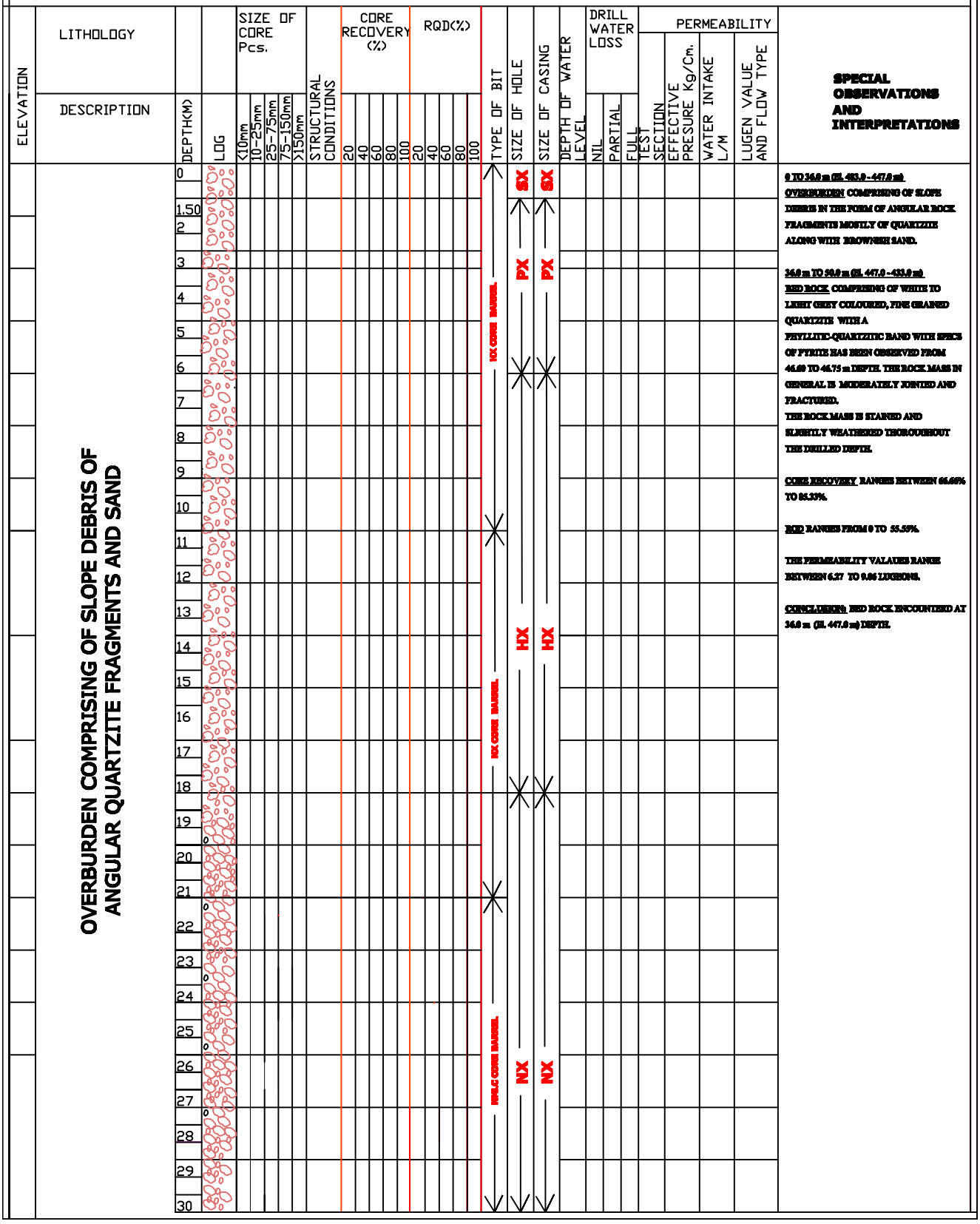
PROJECT: WANGCHU H.E.PROJECT | **CO-ORDINATES: N: 49955.027 E: 39867.686** | HOLE NO. DH-13

LOCATION : DAM SITE | **FEATURE: 32.5 m D/S OF DAM AXIS, RIGHT BANK**

ANGLE WITH HORIZONTAL : 90°

COLLAR ELEVATION : 483.20m | **GROUND ELEVATION: 483.0 m**

DATE OF START : 06.02.2012 | **DATE OF COMPLETION : 14.03.2012** | **TOTAL DEPTH : 50.0 m**



0 TO 36.0 m (EL 483.0 - 447.0 m)
OVERBURDEN COMPRISING OF SLOPE DEBRIS IN THE FORM OF ANGULAR ROCK FRAGMENTS MOSTLY OF QUARTZITE ALONG WITH BROWNISH SAND.

36.0 m TO 50.0 m (EL 447.0 - 433.0 m)
BED ROCK COMPRISING OF WHITE TO LIGHT GREY COLOURED, FINE GRAINED QUARTZITE WITH A PHYLLITIC-QUARTZITIC BAND WITH SPECS OF PYRITE HAS BEEN OBSERVED FROM 46.60 TO 46.75 m DEPTH. THE ROCK MASS IN GENERAL IS MODERATELY JOINTED AND FRACTURED.
THE ROCK MASS IS STAINED AND SLIGHTLY WEATHERED THOROUGHOUT THE DRILLED DEPTH.

CORE RECOVERY RANGES BETWEEN 66.66% TO 85.33%.

RQD RANGES FROM 0 TO 55.55%.

THE PERMEABILITY VALUES RANGE BETWEEN 6.37 TO 9.86 LUGEONS.

CONCLUSION: BED ROCK ENCOUNTERED AT 36.0 m (EL 447.0 m) DEPTH.

DH-14

ELEVATION	LITHOLOGY DESCRIPTION	DEPTH(M)	LOG	SIZE OF CORE Pcs. <10mm	10-25mm	25-75mm	75-150mm	>150mm	STRUCTURAL CONDITIONS	CORE RECOVERY (%) 20 40 60 80 100	RQD (%) 20 40 60 80 100	TYPE OF BIT	SIZE OF HOLE	CASING	DEPTH OF WATER LEVEL	DRILL WATER LOSS NIL	PARTIAL	FULL	PERMEABILITY TEST SECTION	EFFECTIVE PRESURE Kg/Cm.	WATER INTAKE L/M	LUGEN VALUE AND FLOW TYPE	SPECIAL OBSERVATIONS AND INTERPRETATIONS
	BED ROCK COMPRISING OF WHITE TO GREYISH WHITE COLOURED QUARTZITE	31										NWT CORE BARREL	NX							1.00	9.20		
																				2.00	10.20		
		32																	30.00M TO 33.00M	3.00	11.80	10.85	
																				2.00	10.00		
		33													4.05					1.00	9.00		
																				1.00	8.20		
		34													4.15					2.00	9.60		
																			33.00M TO 36.00M	3.00	10.40	9.38	
		35																		2.00	8.80		
		36																		1.00	8.00		
																				1.00	7.50		
		37																		2.00	8.30		
																			36.00M TO 39.00M	3.00	9.50	8.33	
		38													4.50					2.00	8.20		
		39													4.90					1.00	7.00		
																				1.00	9.60		
		40																		2.00	10.90		
																			39.00M TO 42.00M	3.00	12.80	11.54	
		41																		2.00	10.40		
		42																		1.00	9.80		
																				1.00	11.50		
		43																		2.00	12.20		
																			42.00M TO 45.00M	3.00	12.80	11.23	
		44																		2.00	11.30		
		45																		1.00	10.80		
																				1.00	11.90		
		46																		2.00	12.40		
																			45.00M TO 48.00M	3.00	13.80	12.12	
		47																		2.00	12.20		
		48																		1.00	11.30		
																				1.00	7.60		
		49																		2.00	8.20		
																			48.00M TO 51.00M	3.00	9.00	8.13	
		50													5.05					2.00	7.80		
		51													5.10					1.00	7.20		
									65°											1.00	10.20		
		52																		2.00	11.00		
																			51.00M TO 54.00M	3.00	12.40	10.83	
		53													5.20					2.00	11.00		
		54																		1.00	9.60		
																				1.00	7.60		
		55																		2.00	8.40		
																			54.00M TO 57.00M	3.00	10.20	8.90	
		56													5.20					2.00	9.50		
		57																		1.00	7.30		
																				1.00	12.80		
		58																		2.00	13.60		
																			57.00M TO 60.00M	3.00	15.40	13.80	
		59																		2.00	12.50		
		60							65°											1.00	12.10		

ELEVATION	LITHOLOGY DESCRIPTION	DEPTH(M)	LOG	SIZE OF CORE Pcs. <10mm	10-25mm	25-75mm	75-150mm	>150mm	STRUCTURAL CONDITIONS	CORE RECOVERY (%) 20 40 60 80 100	RQD (%) 20 40 60 80 100	TYPE OF BIT	SIZE OF HOLE	CASING	DEPTH OF WATER LEVEL	DRILL WATER LOSS NIL	PARTIAL	FULL	PERMEABILITY TEST SECTION	EFFECTIVE PRESURE Kg/Cm.	WATER INTAKE L/M	LUGEN VALUE AND FLOW TYPE	SPECIAL OBSERVATIONS AND INTERPRETATIONS
	BED ROCK COMPRISING OF WHITE TO GREYISH WHITE COLOURED QUARTZITE	91										NMLC CORE BARREL			8.30				90.00M TO 93.00M	1.00	10.30		
																				2.00	11.20		
		92																		3.00	12.90	10.19	
															8.65					2.00	11.00		
		93													9.20					1.00	9.60		
												NWT CORE BARREL								1.00	12.20		
		94																		2.00	13.00		
															9.22				93.00M TO 96.00M	3.00	14.00	11.35	
		95																		2.00	12.70		
																				1.00	11.50		
		96													9.30					1.00	11.00		
												NMLC CORE BARREL								2.00	12.30		
		97													9.45				96.00M TO 99.00M	3.00	13.80	10.82	
																				2.00	11.70		
		98																		1.00	10.60		
															9.55					1.00	10.20		
		99																		2.00	11.40		
												NWT CORE BARREL							99.00M TO 102.00M	3.00	13.00	10.17	
		100																		2.00	11.00		
															9.61						10.20		
		101																		1.00	12.80		
																				2.00	14.60		
		102							55°										102.00M TO 105.00M	3.00	17.40	13.55	
															9.90					2.00	14.10		
		103																			12.80		
																				1.00	10.60		
		104							85°											2.00	11.20		
															9.90					3.00	11.70	9.20	
		105																	105.00M TO 108.00M	2.00	10.90		
																				1.00	10.20		
		106													10.45					1.00	13.50		
																				2.00	14.30		
		107																		3.00	15.30	11.71	
																				2.00	13.50		
		108																	108.00M TO 111.00M	1.00	13.20		
																				1.00	11.20		
		109																		2.00	11.50		
																				3.00	12.30	9.47	
		110																		2.00	11.80		
																				1.00	10.70		
		111													10.50				111.00M TO 114.00M				
															10.55					1.00	10.80		
		112																		2.00	11.90		
																				3.00	12.80	9.82	
		113																		2.00	10.10		
																				1.00	9.70		
		114																	114.00M TO 117.00M				
															10.60					1.00	9.10		
		115																		2.00	11.70		
																				3.00	14.00	10.72	
		116																		2.00	11.20		
																				1.00	10.00		
		117																	117.00M TO 120.00M				
		118							55°														
		119																					
		120																					

NMLC CORE BARREL

NWT CORE BARREL

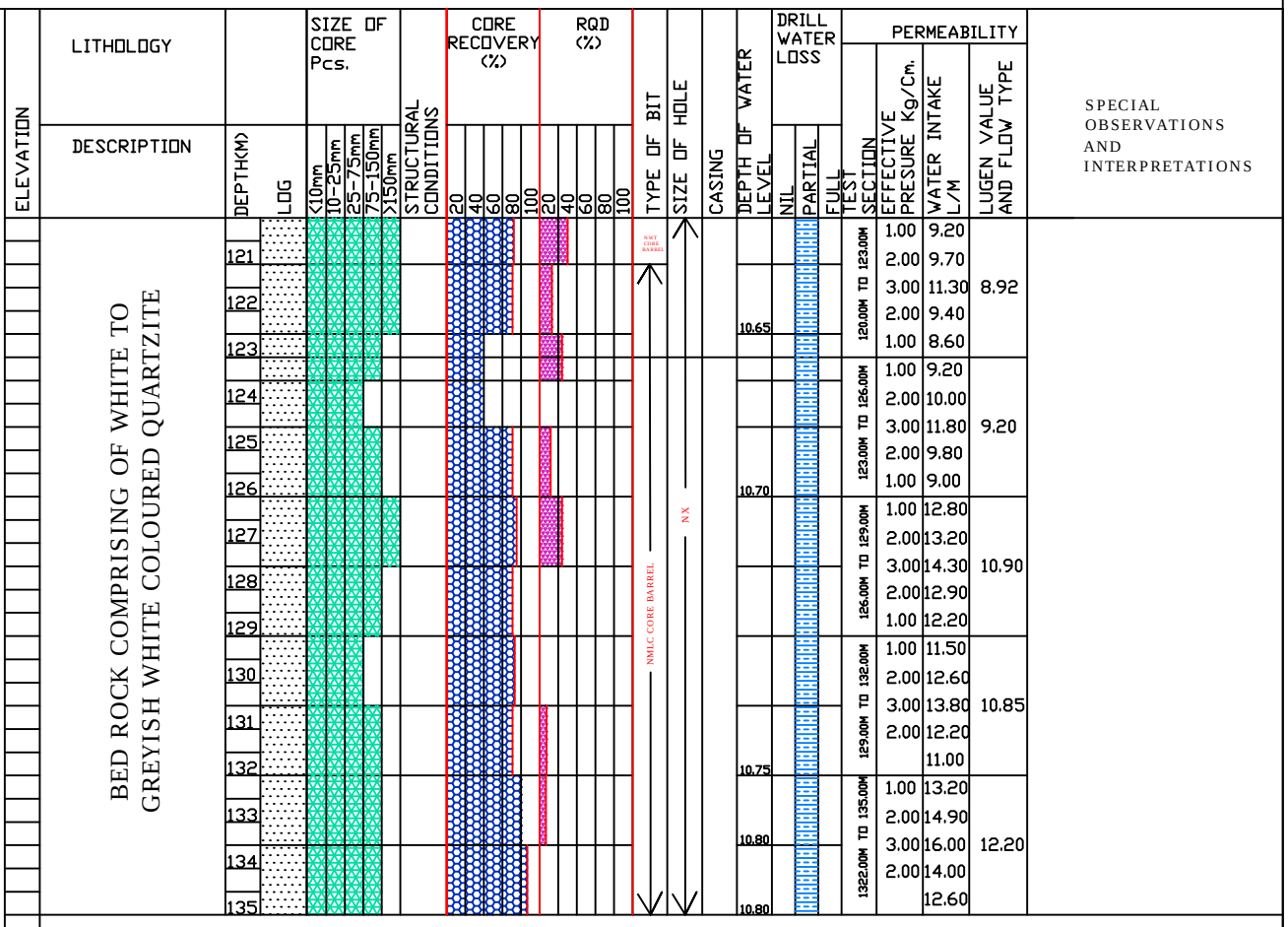
NMLC CORE BARREL

NWT CORE BARREL

NMLC CORE BARREL

NX

DH-14


ELEVATION
LITHOLOGY
DESCRIPTION
DEPTH(M)
LOG
SIZE OF CORE Pcs.
<10mm
10-25mm
25-75mm
75-150mm
>150mm
STRUCTURAL CONDITIONS
CORE RECOVERY (%)
RQD (%)
20 40 60 80 100
20 40 60 80 100
TYPE OF BIT
SIZE OF HOLE
CASING
DEPTH OF WATER LEVEL
10.65
10.70
10.75
10.80
10.80
DRILL WATER LOSS
NIL
PARTIAL
FULL
PERMEABILITY
TEST SECTION
EFFECTIVE PRESURE Kg/Cm.
WATER INTAKE L/M
LUGEN VALUE AND FLOW TYPE
120.00M TO 123.00M
1.00 9.20
2.00 9.70
3.00 11.30 8.92
2.00 9.40
1.00 8.60
123.00M TO 126.00M
1.00 9.20
2.00 10.00
3.00 11.80 9.20
2.00 9.80
1.00 9.00
126.00M TO 129.00M
1.00 12.80
2.00 13.20
3.00 14.30 10.90
2.00 12.90
1.00 12.20
129.00M TO 132.00M
1.00 11.50
2.00 12.60
3.00 13.80 10.85
2.00 12.20
11.00
1322.00M TO 135.00M
1.00 13.20
2.00 14.90
3.00 16.00 12.20
2.00 14.00
12.60
121
122
123
124
125
126
127
128
129
130
131
132
133
134
135
NMLC CORE BARREL
NX
BED ROCK COMPRISING OF WHITE TO GREYISH WHITE COLOURED QUARTZITE
SPECIAL OBSERVATIONS AND INTERPRETATIONS

SJVN LIMITED

PROJECT: **WANGCHU H.E.PROJECT**

CO-ORDINATES: N:
E:

HOLE NO. DH-14 (1-H)

LOCATION : D/S DAM AXIS

FEATURES:

BEARING OF HOLE : -

ANGLE WITH HORIZONTAL: 90°

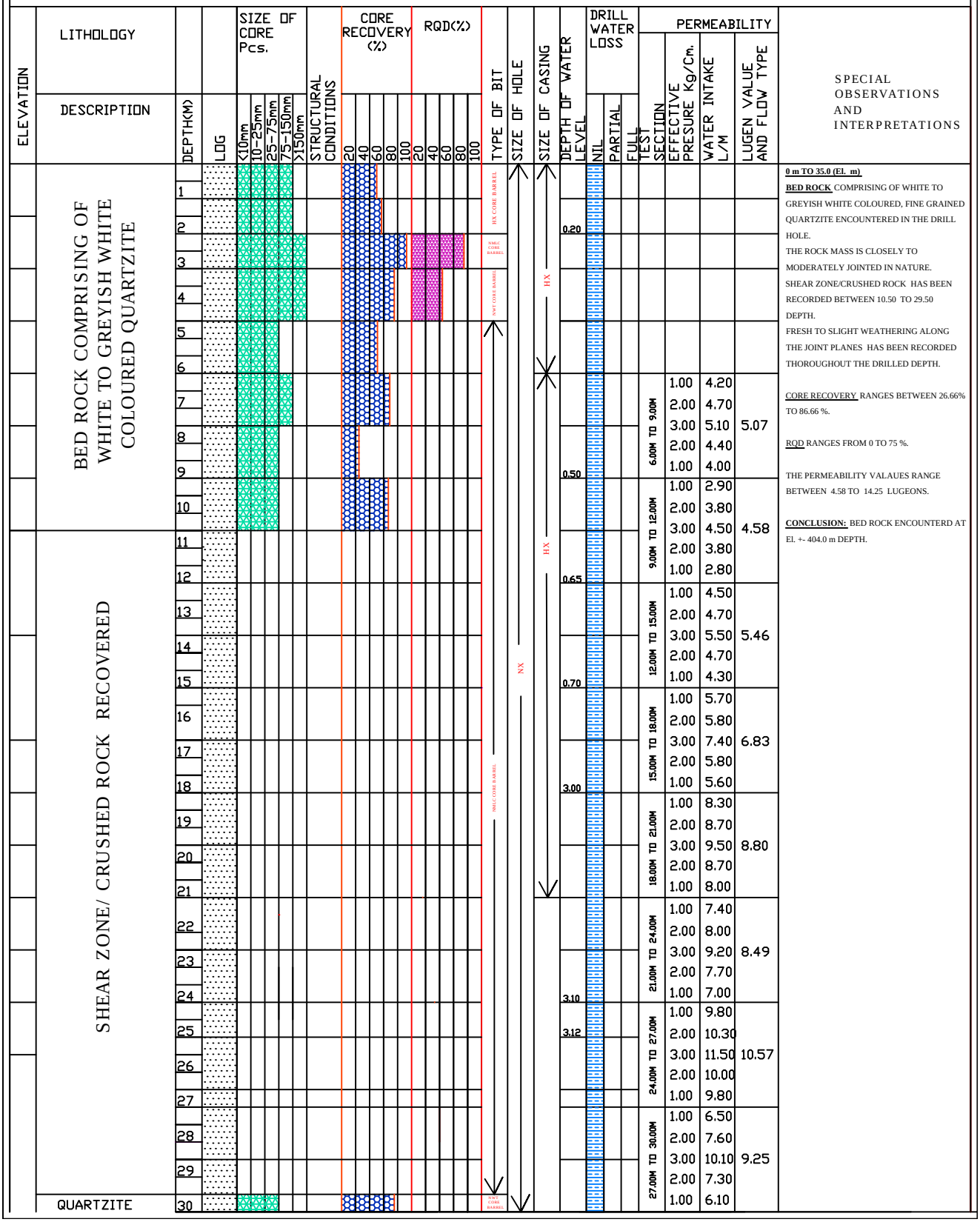
COLLAR ELEVATION :

GROUND ELEVATION:

DATE OF START : 05.06.2012

DATE OF COMPLETION : 20.07.2012

TOTAL DEPTH : 135.0 m



0 m TO 35.0 (El. m)

BED ROCK COMPRISING OF WHITE TO GREYISH WHITE COLOURED, FINE GRAINED QUARTZITE ENCOUNTERED IN THE DRILL HOLE.

THE ROCK MASS IS CLOSELY TO MODERATELY JOINTED IN NATURE.

SHEAR ZONE/CRUSHED ROCK HAS BEEN RECORDED BETWEEN 10.50 TO 29.50 DEPTH.

FRESH TO SLIGHT WEATHERING ALONG THE JOINT PLANES HAS BEEN RECORDED THOROUGHOUT THE DRILLED DEPTH.

CORE RECOVERY RANGES BETWEEN 26.66% TO 86.66 %.

RQD RANGES FROM 0 TO 75 %.

THE PERMEABILITY VALAUES RANGE BETWEEN 4.58 TO 14.25 LUGEONS.

CONCLUSION: BED ROCK ENCOUNTERD AT El. +- 404.0 m DEPTH.

ELEVATION	LITHOLOGY DESCRIPTION	DEPTH(M)	LOG	SIZE OF CORE Pcs. <10mm	10-25mm	25-75mm	75-150mm	>150mm	STRUCTURAL CONDITIONS	CORE RECOVERY (%) 20 40 60 80 100	RQD (%) 20 40 60 80 100	TYPE OF BIT	SIZE OF HOLE	CASING	DEPTH OF WATER LEVEL	DRILL WATER LOSS NIL	PARTIAL	FULL	PERMEABILITY TEST SECTION	EFFECTIVE PRESURE Kg/Cm.	WATER INTAKE L/M	LUGEN VALUE AND FLOW TYPE	SPECIAL OBSERVATIONS AND INTERPRETATIONS
	BED ROCK COMPRISING OF WHITE TO GREYISH WHITE COLOURED QUARTZITE	61										NWT CORE BARREL	NX						60.00M TO 63.00M	1.00	9.20		
																				2.00	10.40		
		62																		3.00	11.80	10.42	
																				2.00	10.30		
		63																		1.00	8.90		
																			63.00M TO 66.00M	1.00	14.20		
		64																		2.00	14.80		
																				3.00	16.40	14.25	
		65																		2.00	14.10		
																				1.00	13.10		
		66																					
																			66.00M TO 69.00M	1.00	12.30		
		67																		2.00	13.60		
																				3.00	14.50	13.10	
		68																		2.00	12.10		
																				1.00	11.60		
		69																					
																			69.00M TO 72.00M	1.00	10.50		
		70																		2.00	11.70		
																				3.00	14.20	12.72	
		71																		2.00	11.40		
																				1.00	10.20		
		72																					
																			72.00M TO 75.00M	1.00	12.80		
		73																		2.00	13.30		
															5.20					3.00	14.50	12.64	
		74																		2.00	13.00		
															5.22					1.00	12.20		
		75																					
																			75.00M TO 78.00M	1.00	14.00		
		76																		2.00	14.50		
																				3.00	15.80	13.75	
		77																		2.00	14.10		
																				1.00	13.30		
		78																					
																			78.00M TO 81.00M	1.00	8.80		
		79																		2.00	11.00		
																				3.00	13.40	12.01	
		80																		2.00	10.70		
																				1.00	8.40		
		81																					
																			81.00M TO 84.00M	1.00	11.80		
		82																		2.00	13.50		
																				3.00	14.60	12.87	
		83																		2.00	13.20		
																				1.00	11.60		
		84																					
																			84.00M TO 87.00M	1.00	10.20		
		85																		2.00	10.60		
															5.60					3.00	11.90	10.37	
		86																		2.00	9.60		
																				1.00	9.30		
		87																					
																			87.00M TO 90.00M	1.00	13.00		
		88																		2.00	14.40		
															5.62					3.00	15.90	13.54	
		89																		2.00	13.50		
																				1.00	12.00		
		90																					

SJVN LIMITED

PROJECT: WANGCHU H.E.PROJECT, BHUTAN **CO-ORDINATES: N:** HOLE NO. DH-15

E:

LOCATION : DAM SITE **FEATURES: DAM AXIS, RIGHT BANK**

BEARING OF HOLE : - **ANGLE WITH HORIZONTAL: 90°**

COLLAR ELEVATION : 463.150 m **GROUND ELEVATION: +- 463 .0 m**

DATE OF START : 02.08.2012 **DATE OF COMPLETION : 16.08.2012** **TOTAL DEPTH : 35.0 m**

ELEVATION	LITHOLOGY DESCRIPTION	DEPTH(M)	LOG	SIZE OF CORE Pcs. <10mm	10-25mm	25-75mm	75-150mm	>150mm	STRUCTURAL CONDITIONS	CORE RECOVERY (%) 20	40	60	80	100	RQD(%) 20	40	60	80	100	TYPE OF BIT	SIZE OF HOLE	SIZE OF CASING	DEPTH OF WATER LEVEL	DRILL WATER LOSS NIL	PARTIAL	FULL	PERMEABILITY TEST SECTION	EFFECTIVE PRESURE Kg/Cm.	WATER INTAKE L/M	LUGEN VALUE AND FLOW TYPE	SPECIAL OBSERVATIONS AND INTERPRETATIONS
	OVERBURDEN	1																		PX CORE BARREL	PX	PX									
		2																		NX CORE BARREL	NX	NX									
		3																														
		4																			PX	PX									
		5																														
		6																														
		7																		NX CORE BARREL	NX	NX									
		8																														
		9																														
		10																														
		11																														
		12																														
	CRUSHED /SHEARED / QUARTZITE ROCK MASS	13																					0.44									
		14																														
		15																														
		16																					0.45									
		17																		HWLC CORE BARREL												
		18																														
	WHITE TO LIGHT GREY COLOURED QUARTZITE ROCK	19																					0.50					18 TO 21m	1.00	8.30		
		20																											2.00	8.80		
		21																					0.55						3.00	9.40	9.44	
		22																										21 TO 24m	2.00	8.20		
		23																											1.00	7.30		
		24																											1.00	13.40		
		25																		WHT CORE BARREL			0.44						2.00	7.20		
		26																											3.00	7.50	7.54	
		27																					0.44						2.00	6.90		
		28																		HWLC CORE BARREL									1.00	6.40		
		29																											1.00	5.00		
		30																											2.00	6.40		
																													3.00	7.30	7.31	
																												24 TO 27m	2.00	6.20		
																							0.44						1.00	6.00		
																													1.00	5.90		
																													2.00	6.50		
																												27 TO 30m	3.00	7.30	7.31	
																													2.00	6.80		
																													1.00	6.20		

0 m to 12.0 m (EL 463.0 to 451.0 m)
OVERBURDEN COMPRISING OF SLOPE DEBRIS IN THE FORM OF ANGULAR ROCK FRAGMENTS, MAINLY OF QUARTZITE ROCK.

12.0 m to 18.0 m (EL 451.0 to 445.0 m)
POSSIBLE SHEAR ZONE AS WASHINGS OF CORE RECOVERED ONLY.

18.0 to 35.0 m (EL 445.0 to 428.0 m)
BED ROCK COMPRISING OF WHITE TO LIGHT GREY, FINE GRAINED QUARTZITE. THE ROCK MASS IN GENERAL IS CLOSELY TO MODERATELY JOINTED WITH SHATTERED/FRACTURED ZONES.

THE ROCK IN GENERAL IS FRESH IN NATURE WITH SOME OCCASIONAL STAINING ALONG THE JOINT PLANES.

CORE RECOVERY RANGES BETWEEN 54 TO 85.39%.

RQD RANGES FROM NIL TO 32.22%.

PERMEABILITY VALUES RANGE BETWEEN 6.26 TO 9.44 LUGEONS.

CONCLUSION: BED ROCK HAS BEEN RECORDED AT 12 m DEPTH (EL 451.0 m)

SJVN LIMITED

PROJECT: WANGCHU H.E.PROJECT, BHUTAN **CO-ORDINATES: N:** HOLE NO. DH-15

E:

LOCATION : DAM SITE **FEATURES: DAM AXIS, RIGHT BANK**

BEARING OF HOLE : - **ANGLE WITH HORIZONTAL: 90°**

COLLAR ELEVATION : 463.150 m **GROUND ELEVATION: +- 463 .0 m**

DATE OF START : 02.08.2012 **DATE OF COMPLETION : 16.08.2012** **TOTAL DEPTH : 35.0 m**

ELEVATION	LITHOLOGY DESCRIPTION	DEPTH(M)	LOG	SIZE OF CORE Pcs. <10mm	10-25mm	25-75mm	75-150mm	>150mm	STRUCTURAL CONDITIONS	CORE RECOVERY (%) 20 40 60 80 100	RQD(%) 20 40 60 80 100	TYPE OF BIT	SIZE OF HOLE	SIZE OF CASING	DEPTH OF WATER LEVEL	DRILL WATER LOSS NIL	PARTIAL	FULL	TEST SECTION	PERMEABILITY EFFECTIVE PRESURE Kg/Cm.	WATER INTAKE L/M	LUGEN VALUE AND FLOW TYPE	SPECIAL OBSERVATIONS AND INTERPRETATIONS
	WHITE TO LIGHT GREY COLOURED QUARTZITE ROCK	31										WIRELINE CORE BARREL	NX	NX	0.39				30 TO 33m	1.00	6.00		
		32																		2.00	6.30		
		33													0.44					3.00	6.20	6.26	
		34																		2.00	5.80		
		35																		1.00	5.40		

SJVN Ltd.

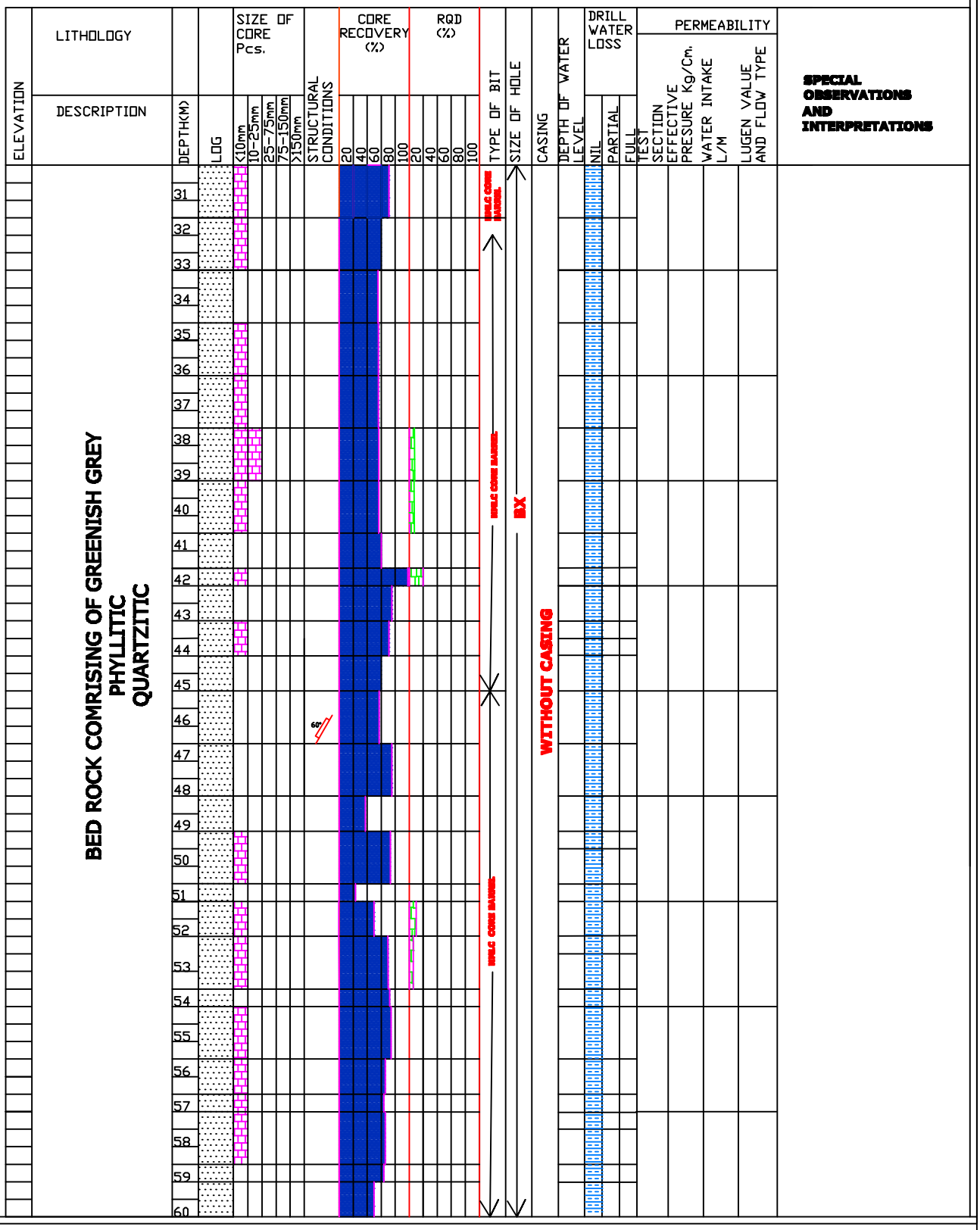
PROJECT: WANGCHU H.E.PROJECT **CO-ORDINATES: N 51040.000 E 41580.000** HOLE NO .HRT-1

LOCATION : HRT 1 (SiLUNG NALA)

BEARING OF HOLE : - **ANGLE WITH HORIZANTAL: 90°**

COLLAR ELEVATION :550.150M **GROUND ELEVATION: 550.00 M**

DATE OF START :09.07.2011 **DATE OF COMPLETION : 05.09.2011** **TOTAL DEPTH :75.00 m**



SJVN Ltd.

Appendix - 10

SHEET NO-3/3

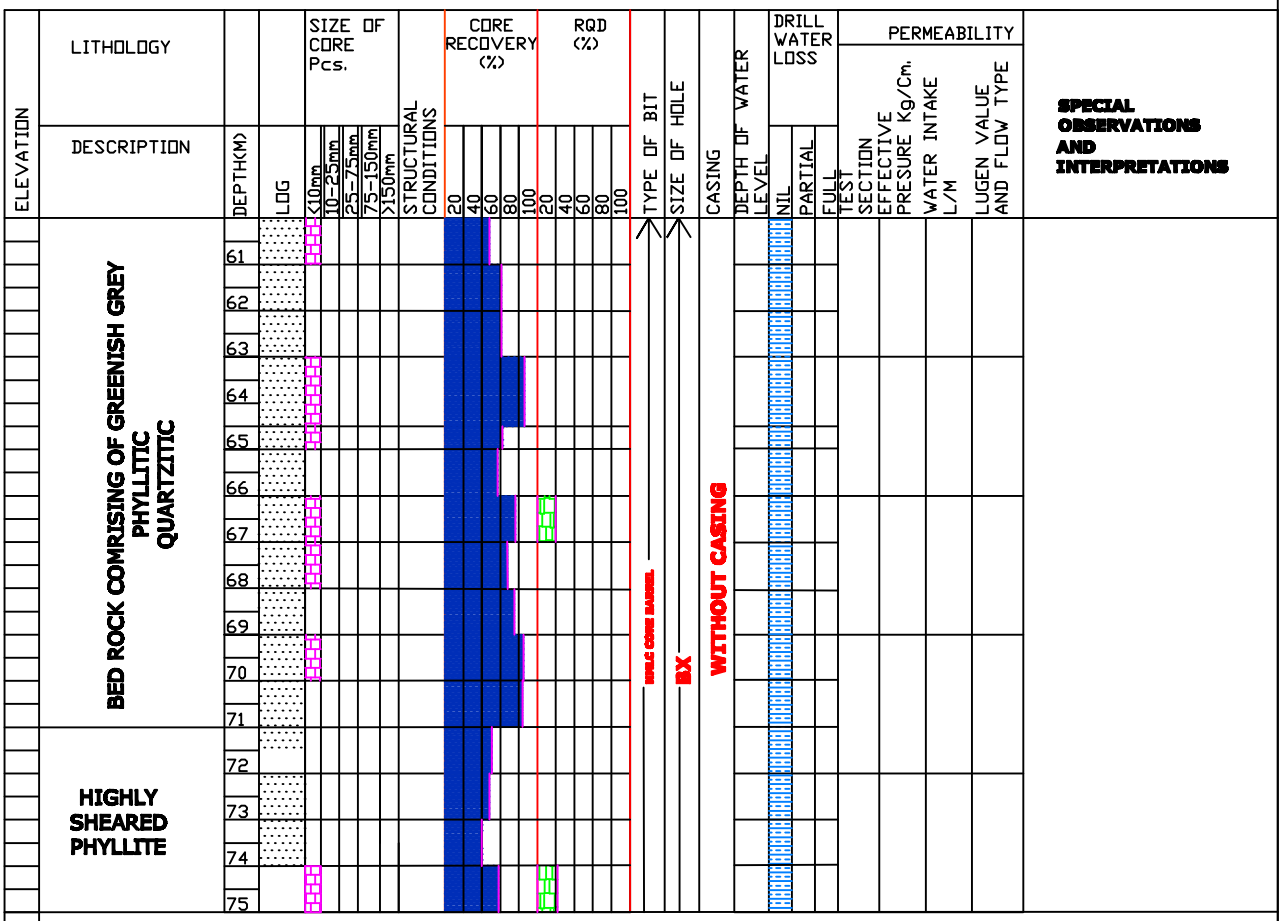
PROJECT: WANGCHU H.E.PROJECT **CO-ORDINATES: N 51040.000 E 41580.000** HOLE NO .HRT-1

LOCATION : HRT 1 (SILUNG NALA)

BEARING OF HOLE : - **ANGLE WITH HORIZANTAL: 90°**

COLLAR ELEVATION :550.150M **GROUND ELEVATION: 550.00 M**

DATE OF START :09.07.2011 **DATE OF COMPLETION : 05.09.2011** **TOTAL DEPTH :75.00 m**



SJVN LIMITED

PROJECT: **WANGCHU H E P, BHUTAN**

CO-ORDINATES: N 51650.051
E 42535.504

HOLE NO.: HRT-2

LOCATION : HRT-Zilung nallah crossing (d/s arm)

BEARING OF HOLE :

ANGLE WITH HORIZANTAL: 90°

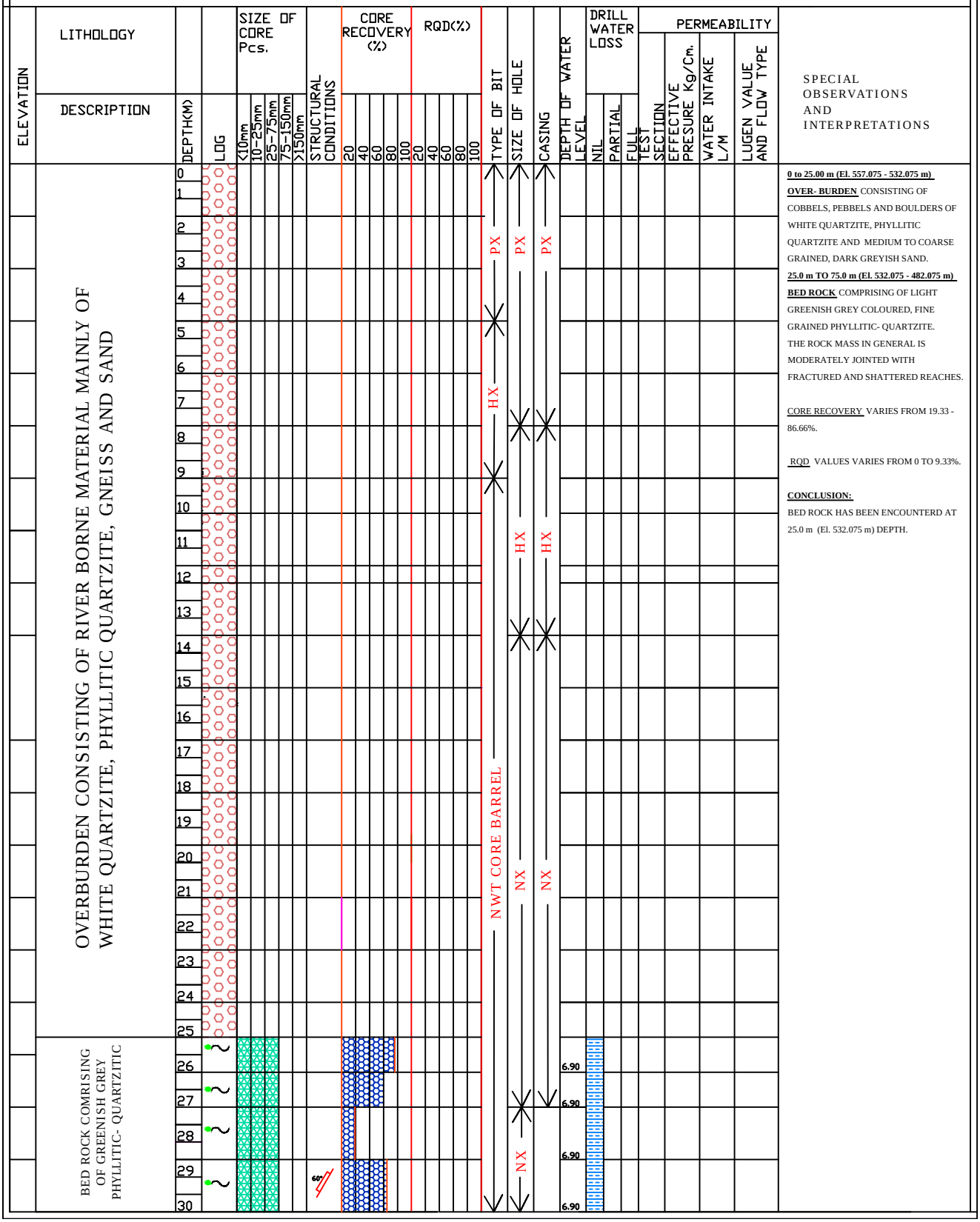
COLLAR ELEVATION : 557.095M

GROUND ELEVATION: 557.075 M

DATE OF START :29.10.2011

DATE OF COMPLETION : 08.12.2011

TOTAL DEPTH :75.00 m



0 to 25.00 m (El. 557.075 - 532.075 m)

OVER- BURDEN CONSISTING OF COBBELS, PEBBELS AND BOULDERS OF WHITE QUARTZITE, PHYLLITIC QUARTZITE AND MEDIUM TO COARSE GRAINED, DARK GREYISH SAND.

25.0 m TO 75.0 m (El. 532.075 - 482.075 m)

BED ROCK COMPRISING OF LIGHT GREENISH GREY COLOURED, FINE GRAINED PHYLLITIC- QUARTZITE. THE ROCK MASS IN GENERAL IS MODERATELY JOINTED WITH FRACTURED AND SHATTERED REACHES.

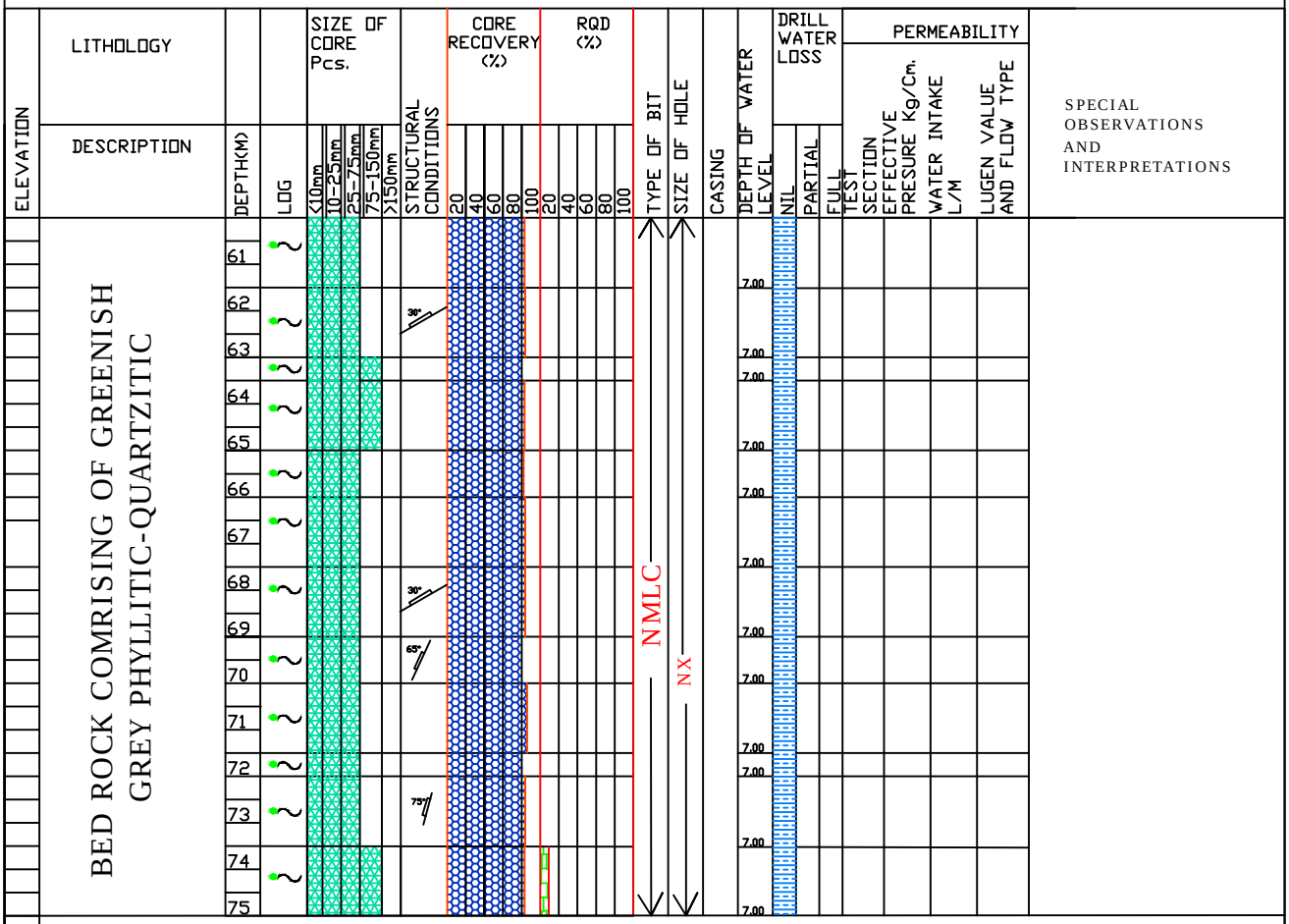
CORE RECOVERY VARIES FROM 19.33 - 86.66%.

RQD VALUES VARIES FROM 0 TO 9.33%.

CONCLUSION:

BED ROCK HAS BEEN ENCOUNTERD AT 25.0 m (El. 532.075 m) DEPTH.

ELEVATION	LITHOLOGY DESCRIPTION	DEPTH(M)	LOG	SIZE OF CORE Pcs. <10mm	10-25mm	25-75mm	75-150mm	>150mm	STRUCTURAL CONDITIONS	CORE RECOVERY (%) 20 40 60 80 100	RQD (%) 20 40 60 80 100	TYPE OF BIT	SIZE OF HOLE	CASING	DEPTH OF WATER LEVEL	DRILL WATER LOSS NIL	PARTIAL	FULL	PERMEABILITY TEST SECTIION	EFFECTIVE PRESURE Kg/Cm.	WATER INTAKE L/M	LUGEN VALUE AND FLOW TYPE	SPECIAL OBSERVATIONS AND INTERPRETATIONS
	BED ROCK COMRISING OF GREENISH GREY PHYLLITIC-QUARTZITIC	31										NWT CORE BARREL	NX		6.90								
		32													6.90								
		33													6.90								
		34													6.90								
		35							25°						7.00								
		36													7.00								
		37													7.00								
		38							25°						7.00								
		39													7.00								
		40													7.00								
		41							35°						7.00								
		42													7.00								
		43													7.00								
		44													7.00								
		45													7.00								
		46													7.00								
		47													7.00								
		48													7.00								
		49							30°						7.00								
		50													7.00								
		51													7.00								
		52							30°						7.00								
		53													7.00								
		54													7.00								
		55							35°						7.00								
		56													7.00								
		57													7.00								
		58													7.00								
		59													7.00								
		60													7.00								


ELEVATION
LITHOLOGY
DESCRIPTION
DEPTH(M)
LOG
SIZE OF CORE Pcs.
<10mm
10-25mm
25-75mm
75-150mm
>150mm
STRUCTURAL CONDITIONS
CORE RECOVERY (%)
RQD (%)
20
40
60
80
100
TYPE OF BIT
SIZE OF HOLE
CASING
DEPTH OF WATER LEVEL
DRILL WATER LOSS
NIL
PARTIAL
FULL
PERMEABILITY
TEST SECTION
EFFECTIVE PRESURE Kg/Cm.
WATER INTAKE L/M
LUGEN VALUE AND FLOW TYPE
SPECIAL OBSERVATIONS AND INTERPRETATIONS
61
62
63
64
65
66
67
68
69
70
71
72
73
74
75
30°
30°
65°
75°
NMLC
NX
7.00
BED ROCK COMRISING OF GREENISH GREY PHYLLITIC-QUARTZITIC

SJVN LIMITED

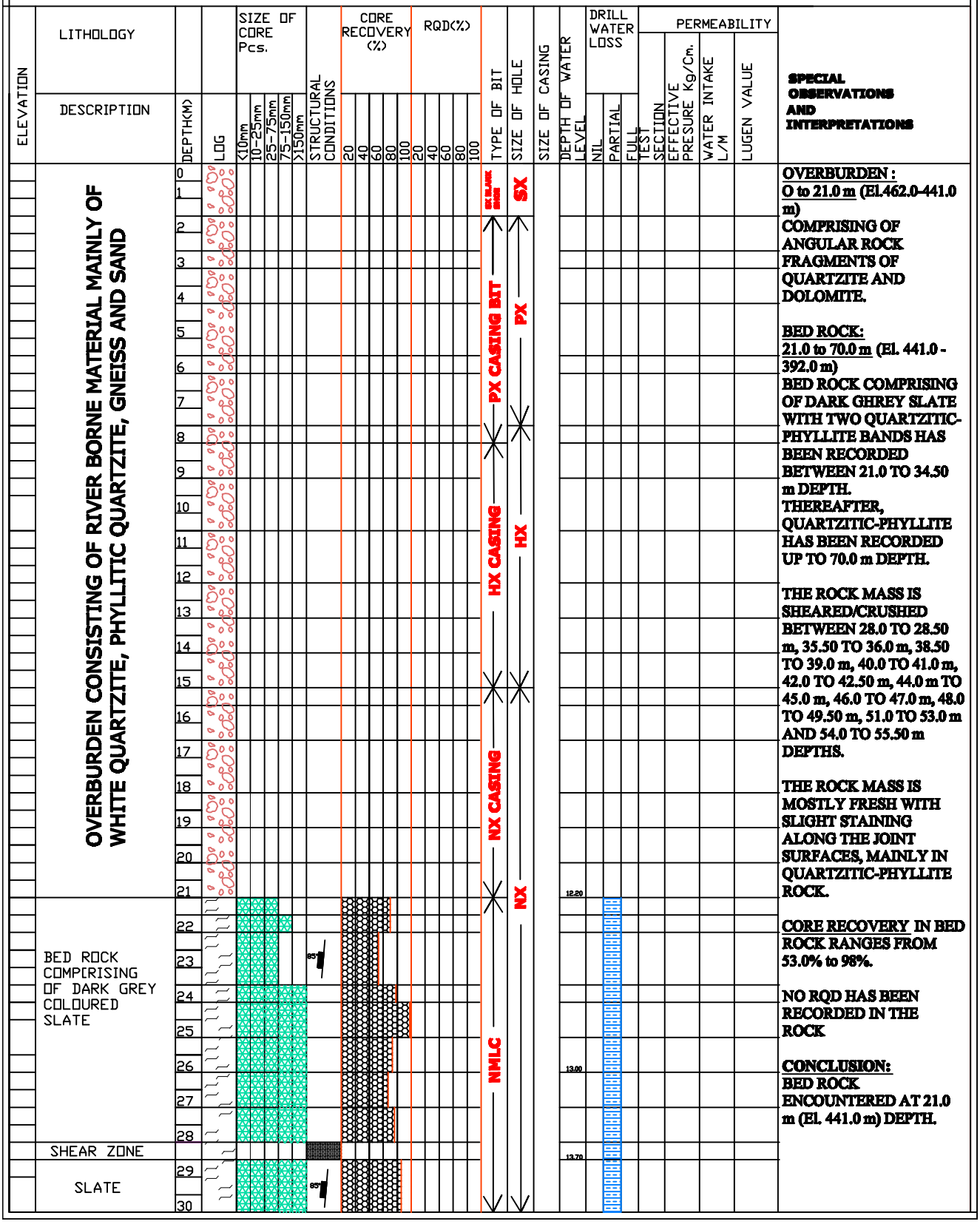
PROJECT: WANGCHU H.E.P., BHUTAN **CO-ORDINATES: N E** **HOLE NO.: HRT-3**

LOCATION : HRT- NALLAH CROSSING (U/S OF SURGE SHAFT)

BEARING OF HOLE : - **ANGLE WITH HORIZANTAL: 90°**

COLLAR ELEVATION : **GROUND ELEVATION: +- 460.0 m**

DATE OF START : 29.10.2011 **DATE OF COMPLETION : 07.12.2011** **TOTAL DEPTH : 70.0 m**



OVERBURDEN :
O to 21.0 m (El.462.0-441.0 m)
COMPRISING OF ANGULAR ROCK FRAGMENTS OF QUARTZITE AND DOLOMITE.

BED ROCK:
21.0 to 70.0 m (El. 441.0 - 392.0 m)
BED ROCK COMPRISING OF DARK GHREY SLATE WITH TWO QUARTZITIC-PHYLLITE BANDS HAS BEEN RECORDED BETWEEN 21.0 TO 34.50 m DEPTH. THEREAFTER, QUARTZITIC-PHYLLITE HAS BEEN RECORDED UP TO 70.0 m DEPTH.

THE ROCK MASS IS SHEARED/CRUSHED BETWEEN 28.0 TO 28.50 m, 35.50 TO 36.0 m, 38.50 TO 39.0 m, 40.0 TO 41.0 m, 42.0 TO 42.50 m, 44.0 m TO 45.0 m, 46.0 TO 47.0 m, 48.0 TO 49.50 m, 51.0 TO 53.0 m AND 54.0 TO 55.50 m DEPTHS.

THE ROCK MASS IS MOSTLY FRESH WITH SLIGHT STAINING ALONG THE JOINT SURFACES, MAINLY IN QUARTZITIC-PHYLLITE ROCK.

CORE RECOVERY IN BED ROCK RANGES FROM 53.0% to 98%.

NO RQD HAS BEEN RECORDED IN THE ROCK

CONCLUSION:
BED ROCK ENCOUNTERED AT 21.0 m (El. 441.0 m) DEPTH.

SJVN LIMITED

PROJECT: WANGCHU H.E.P., BHUTAN **CO-ORDINATES: N E** **HOLE NO.: HRT-3**

LOCATION : HRT- NALLAH CROSSING (U/S OF SURGE SHAFT)

BEARING OF HOLE : - **ANGLE WITH HORIZANTAL: 90°**

COLLAR ELEVATION : **GROUND ELEVATION: +- 460.0 m**

DATE OF START : 29.10.2011 **DATE OF COMPLETION : 07.12.2011** **TOTAL DEPTH : 70.0 m**

ELEVATION	LITHOLOGY DESCRIPTION	DEPTH(M)	LOG	SIZE OF CORE Pcs. <10mm	10-25mm	25-75mm	75-150mm	>150mm	STRUCTURAL CONDITIONS	CORE RECOVERY (%) 20 40 60 80 100	RQD (%) 20 40 60 80 100	TYPE OF BIT	SIZE OF HOLE	CASING	DEPTH OF WATER LEVEL	DRILL WATER LOSS NIL	PARTIAL	FULL	PERMEABILITY TEST SECTION	EFFECTIVE PRESURE Kg/Cm.	WATER INTAKE L/M	LUGEN VALUE	SPECIAL OBSERVATIONS AND INTERPRETATIONS
	QUARTZITIC-PHYLLITE	31										NMLC	NX	NX									
	SLATE	32																					
		33																					
		34													14.10								
	QUARTZITIC-PHYLLITE	35																					
	SHEAR ZONE	36																					
	QUARTZITIC-PHYLLITE	37																					
		38													14.35								
	SHEAR ZONE	39																					
	QUARTZITIC-PHYLLITE	40																					
	SHEAR ZONE/ CRUSHED ROCK	41																					
	QUARTZITIC-PHYLLITE	42													13.90								
	SHEAR ZONE																						
	QUARTZITIC-PHYLLITE	43																					
		44																					
	SHEAR ZONE/ CRUSHED ROCK	45																					
	QUARTZITIC-PHYLLITE	46													14.20								
	SHEAR ZONE	47																					
	QUARTZITIC-PHYLLITE	48													14.50								
	SHEAR ZONE/																						
	QUARTZITIC-PHYLLITE	49																					
		50																					
		51													14.80								
	SHEAR ZONE/ CRUSHED ROCK	52																					
		53																					
	QUARTZITIC-PHYLLITE	54													14.50								
	SHEAR ZONE/ CRUSHED ROCK	55																					
	QUARTZITIC-PHYLLITE	56																					
		57													14.80								
		58																					
		59																					
		60																					

SJVN LIMITED

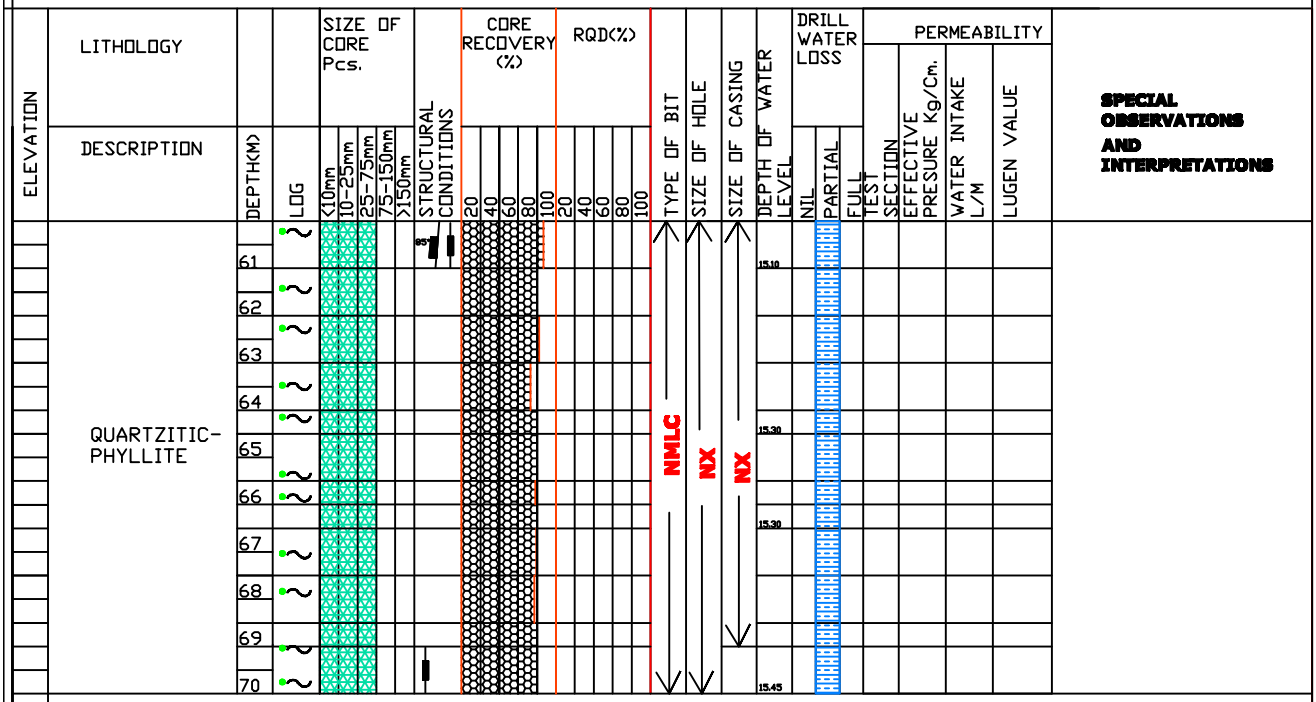
PROJECT: WANGCHU H.E.P., BHUTAN **CO-ORDINATES: N E** **HOLE NO.: HRT-3**

LOCATION : HRT- NALLAH CROSSING (U/S OF SURGE SHAFT)

BEARING OF HOLE : - **ANGLE WITH HORIZANTAL: 90°**

COLLAR ELEVATION : **GROUND ELEVATION: +- 460.0 m**

DATE OF START : 29.10.2011 **DATE OF COMPLETION : 07.12.2011** **TOTAL DEPTH : 70.0 m**



SJVN LIMITED

Appendix - 11

SHEET NO-1/3

PROJECT: WANGCHU H.E.PROJECT **CO-ORDINATES: N :44804.353 E :49900.015** DRILL HOLE NO. PS-2

LOCATION : PIPING POWER HOUSE SITE **FEATURES: PENSTOCK SLOPE, RIGHT BANK**

BEARING OF HOLE : - **ANGLE WITH HORIZANTAL: 90°**

COLLAR ELEVATION : **GROUND ELEVATION: ± 214.0M**

DATE OF START : **DATE OF COMPLETION :** **TOTAL DEPTH :75.00m**

ELEVATION	LITHOLOGY DESCRIPTION	DEPTH(M)	LOG	SIZE OF CORE Pcs. <10mm	10-25mm	25-75mm	75-150mm	>150mm	STRUCTURAL CONDITIONS	CORE RECOVERY (%) 20 40 60 80 100	RQD(%) 20 40 60 80 100	TYPE OF BIT	SIZE OF HOLE	SIZE OF CASING	DEPTH OF WATER LEVEL	DRILL WATER LOSS NIL	PARTIAL	FULL	PERMEABILITY TEST SECTION	EFFECTIVE PRESURE Kg/Cm.	WATER INTAKE L/M	LUGEN VALUE AND FLOW TYPE	SPECIAL OBSERVATIONS AND INTERPRETATIONS
	OVERBURDEN CONSISTING OF ANGULARS FRAGMENTS OF QUARTZITE, QUARTZITIC PHYLLITES & DOLOMITES.	0											SX	SX									
		1.50											PX	PX					00M TO 3.00M			7.23X10-3	
		2																					
		3																					
		4																	3.00M TO 6.00M			2.95X10-3	
		5																					
		6											HX	HX									
		7																					
		8																	6.00M TO 9.00M			2.95X10-3	
		9																					
		10																					
		11																	9.00M TO 12.00M			2.61X10-3	
		12																					
		13																					
		14																	12.00M TO 15.00M			2.91X10-3	
		15																					
		16																					
		17																	1500M TO 18.00M			2.42X10-3	
		18																					
		19																					
		20																	18.00M TO 21.00M			0.97X10-3	
		21											NX	NX									
		22																					
		23																	21.00M TO 24.00M			0.12X10-3	
		24																					
	BED ROCK CONSISTING OF CARBONACEOUS PHYLLITE	25																					
		26																					
		27													27.1				24.00M TO 27.00M			0.08X10-3	
		28																					
		29																					
		30																	27.00M TO 30.00M			0.16X10-3	

SPECIAL OBSERVATIONS AND INTERPRETATIONS

0 to 24.0 m (El. 214.0 - 190.0 m)
OVERBURDEN COMPRISING OF TALUS/ SLOPE DEBRIS, ANGULAR FRAGMENTS OF QUARTZITE, PHYLLITIC QUARTZITE AND DOLOMITE.

24.0 to 30.0 m (190.0 - 184.0 m)
BED ROCK COMPRISES MAINLY OF VERY THINLY FOLIATED, HIGHLY FRAGILE, FISSILE, SOFT CARBONACEOUS PHYLLITE. THE ROCK MASS IS SHEARED BETWEEN 24.0 TO 67.2 m, SHEARED, FRACTURED AND CLOSELY JOINTED BETWEEN 67.2 TO 71.0 m DEPTH AND SHEARED FROM 71.0 TO 75.0 m DEPTH.

CORE RECOVERY RANGES BETWEEN 40 TO 50%.

NO RQD HAS BEEN RECORDED IN THE ROCK.

THE PERMEABILITY VALAUES RANGE BETWEEN TO LUGEONS.

CONCLUSION:
BED ROCK ENCOUNTERED AT 24.0 m (El. 190.0 m) DEPTH.

SJVN LIMITED

PROJECT: WANGCHU H.E.PROJECT **CO-ORDINATES: N :44804.353 E :49900.015** DRILL HOLE NO. PS-2

LOCATION : PIPING POWER HOUSE SITE **FEATURES: PENSTOCK SLOPE, RIGHT BANK**

BEARING OF HOLE : - **ANGLE WITH HORIZANTAL: 90°**

COLLAR ELEVATION : **GROUND ELEVATION: ± 214.0M**

DATE OF COMPLETION : **TOTAL DEPTH :75.00m**

ELEVATION	LITHOLOGY DESCRIPTION	DEPTH(M)	LOG	SIZE OF CORE Pcs. <10mm	10-25mm	25-75mm	75-150mm	>150mm	STRUCTURAL CONDITIONS	CORE RECOVERY (%) 20	40	60	80	100	RQD (%) 20	40	60	80	100	TYPE OF BIT	SIZE OF HOLE	CASING	DEPTH OF WATER LEVEL	DRILL WATER LOSS NIL	PARTIAL	FULL	PERMEABILITY TEST SECTION	EFFECTIVE PRESURE Kg/Cm.	WATER INTAKE L/M	LUGEN VALUE AND FLOW TYPE	SPECIAL OBSERVATIONS AND INTERPRETATIONS
	BED ROCK CONSISTING OF CARBONACEOUS PHYLLITE	31																			NX	NX					30.00M TO 33.00M			0.24X10-3	
		32																													
		33																													
		34																									33.00M TO 36.00M			0.07X10-3	
		35																													
		36																													
		37																									36.00M TO 39.00M			0.16X10-3	
		38																													
		39																													
		40																									39.00M TO 42.00M			0.06x10-3	
		41																													
		42																													
		43																									42.00M TO 45.00M			0.02X10-3	
		44																													
		45																													
		46																									4500M TO 48.00M			0.04X10-3	
		47																													
		48																													
		49																									48.00M TO 51.00M			0.24X10-3	
		50																													
		51																													
		52																									51.00M TO 54.00M			0.06X10-3	
		53																													
		54																													
		55																									54.00M TO 57.00M			0.06X10-3	
		56																													
		57																													
		58																									57.00M TO 60.00M			0.05X10-3	
		59																													
		60																													

SJVN LIMITED

PROJECT: WANGCHU H.E.PROJECT **CO-ORDINATES: N :44804.353 E :49900.015** DRILL HOLE NO. PS-2

LOCATION : PIPING POWER HOUSE SITE **FEATURES: PENSTOCK SLOPE, RIGHT BANK**

BEARING OF HOLE : - **ANGLE WITH HORIZANTAL: 90°**

COLLAR ELEVATION : **GROUND ELEVATION: ± 214.0M**

DATE OF COMPLETION : **TOTAL DEPTH :75.00m**

ELEVATION	LITHOLOGY DESCRIPTION	DEPTH(M)	LOG	SIZE OF CORE Pcs. <10mm	10-25mm	25-75mm	75-150mm	>150mm	STRUCTURAL CONDITIONS	CORE RECOVERY (%) 20 40 60 80 100	RQD (%) 20 40 60 80 100	TYPE OF BIT	SIZE OF HOLE	CASING	DEPTH OF WATER LEVEL	DRILL WATER LOSS NIL	PARTIAL	FULL	PERMEABILITY TEST SECTION	EFFECTIVE PRESURE Kg/Cm.	WATER INTAKE L/M	LUGEN VALUE AND FLOW TYPE	SPECIAL OBSERVATIONS AND INTERPRETATIONS
	BED ROCK CONSISTING OF CARBONACEOUS PHYLLITE	61											NX	NX					60.00M TO 63.00M			0.03X10-3	
		62																					
		63																	63.00M TO 66.00M			0.05X10-3	
		64																					
		65																					
		66																	66.00M TO 69.00M			0.04X10-3	
		67																					
		68																					
		69																	69.00M TO 72.00M			0.03X10-3	
		70																					
		71																					
		72																					
		73																	69.00M TO 72.00M			0.04X10-3	
		74																					
		75																					

SJVN LIMITED

Appendix - 12

SHEET NO-1/2

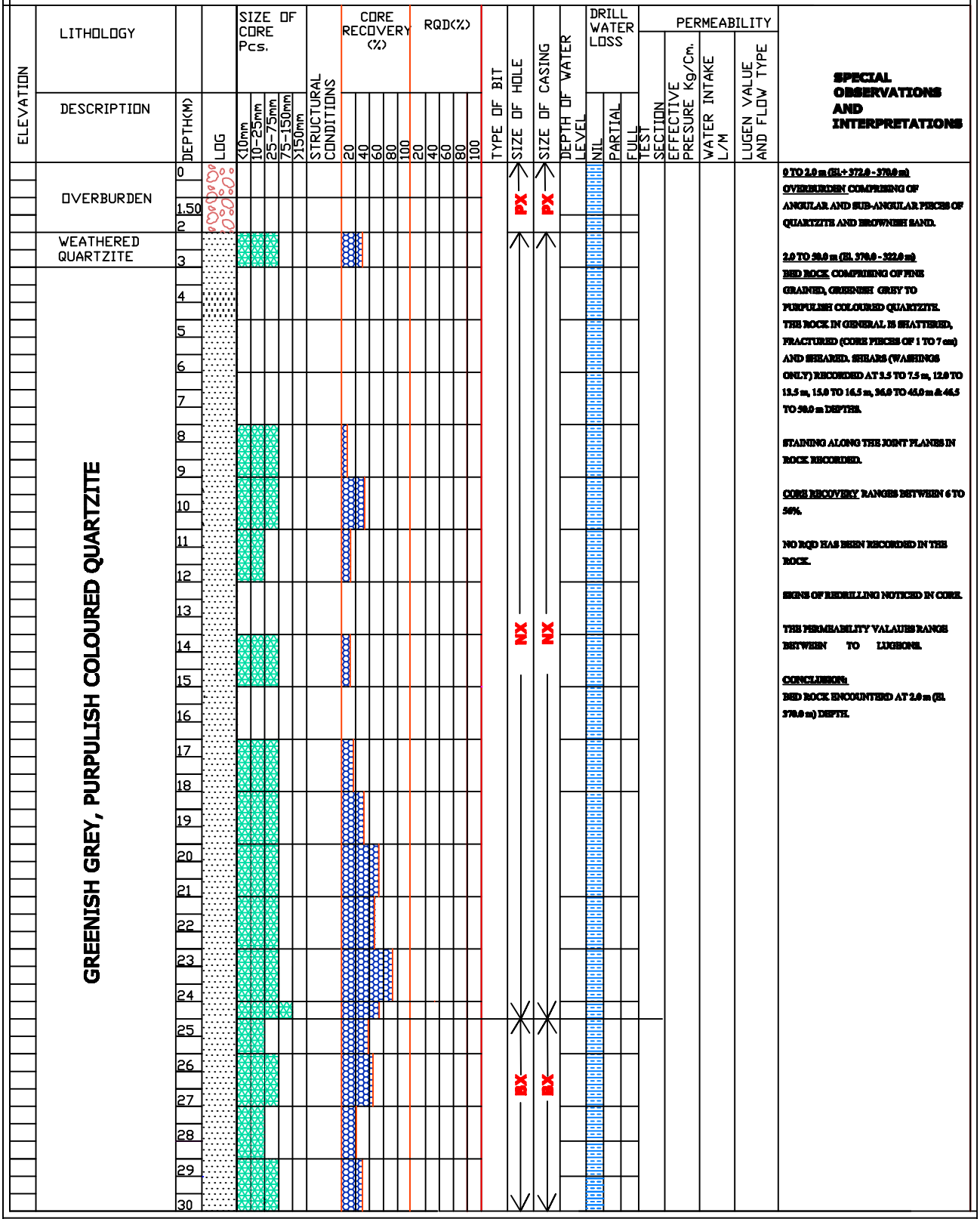
PROJECT: WANGCHU H.E.PROJECT **CO-ORDINATES: N 45005.681 E 49847.121** HOLE NO. PS-3

LOCATION : PIPING POWER HOUSE SITE **FEATURES: PENSTOCK SLOPE**

BEARING OF HOLE : - **ANGLE WITH HORIZANTAL: 90°**

COLLAR ELEVATION : **GROUND ELEVATION: 372.0 m**

DATE OF START : **DATE OF COMPLETION :** **TOTAL DEPTH :50.00m**



0 TO 2.0 m (El.+372.0 - 370.0 m)
OVERBURDEN COMPRISING OF ANGULAR AND SUB-ANGULAR PIECES OF QUARTZITE AND BROWNISH SAND.

2.0 TO 50.0 m (El. 370.0 - 322.0 m)
BED ROCK COMPRISING OF FINE GRAINED, GREENISH GREY TO PURPULISH COLOURED QUARTZITE. THE ROCK IN GENERAL IS SHATTERED, FRACTURED (CORE PIECES OF 1 TO 7 cm) AND SHEARED. SHEARS (WASHINGS ONLY) RECORDED AT 2.5 TO 7.5 m, 12.0 TO 13.5 m, 15.0 TO 16.5 m, 36.0 TO 45.0 m & 46.5 TO 50.0 m DEPTH.

STAINING ALONG THE JOINT PLANES IN ROCK RECORDED.

CORE RECOVERY RANGES BETWEEN 6 TO 56%.

NO RQD HAS BEEN RECORDED IN THE ROCK.

SIGNS OF REDRILLING NOTICED IN CORE.

THE PERMEABILITY VALAUES RANGE BETWEEN TO LUGEONS.

CONCLUSION:
BED ROCK ENCOUNTERD AT 2.0 m (El. 370.0 m) DEPTH.

SJVN LIMITED

PROJECT: **WANGCHU H.E.PROJECT**

CO-ORDINATES: N 45005.681
E 49847.121

HOLE NO. PS-3

LOCATION : PIPING POWER HOUSE SITE

FEATURES: PENSTOCK SLOPE

BEARING OF HOLE : -

ANGLE WITH HORIZANTAL: 90°

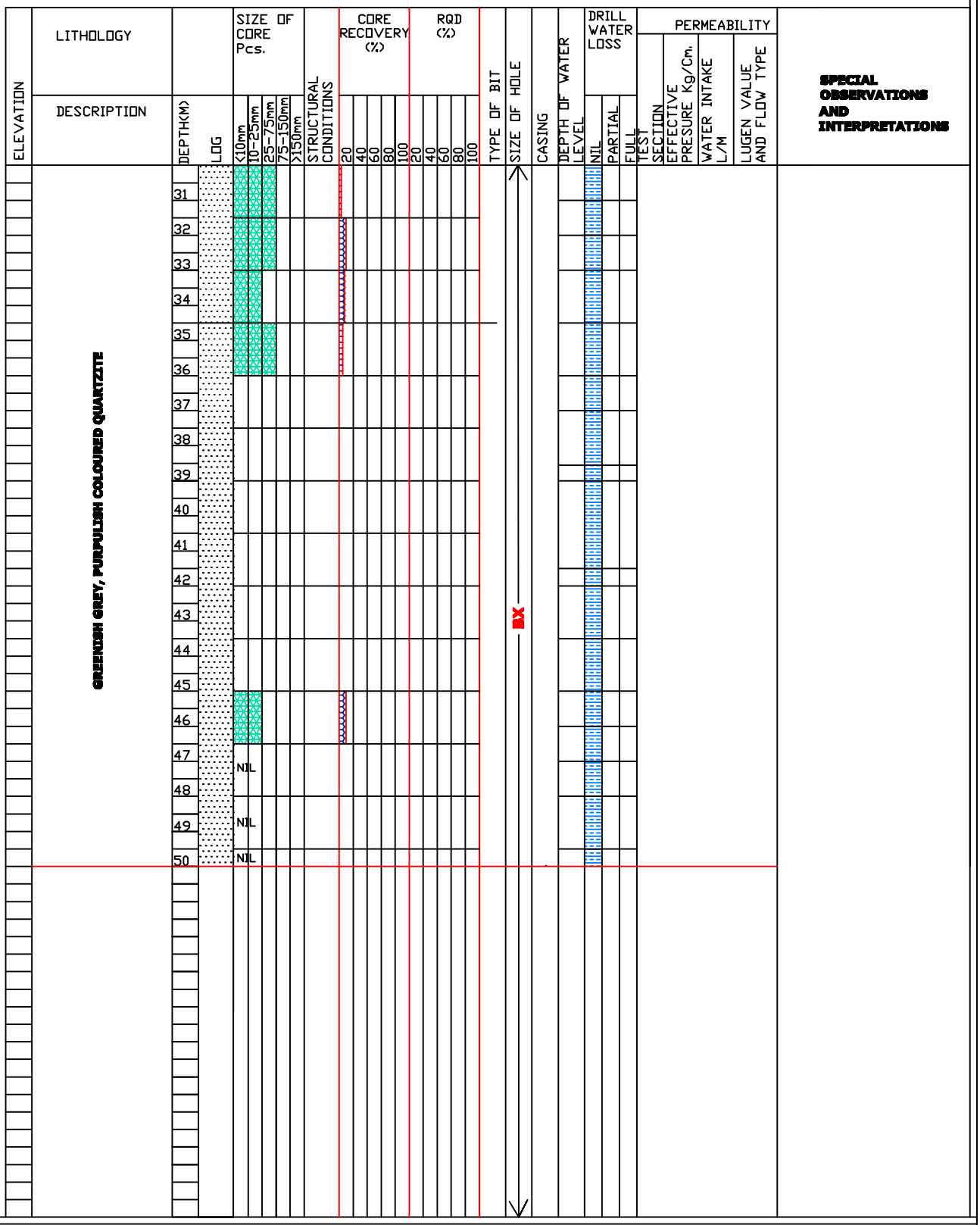
COLLAR ELEVATION :

GROUND ELEVATION: 372.0 m

DATE OF START :

DATE OF COMPLETION :

TOTAL DEPTH :50.00m



SJVN LIMITED

Appendix - 13

SHEET NO-1/3

HOLE NO. PS-4

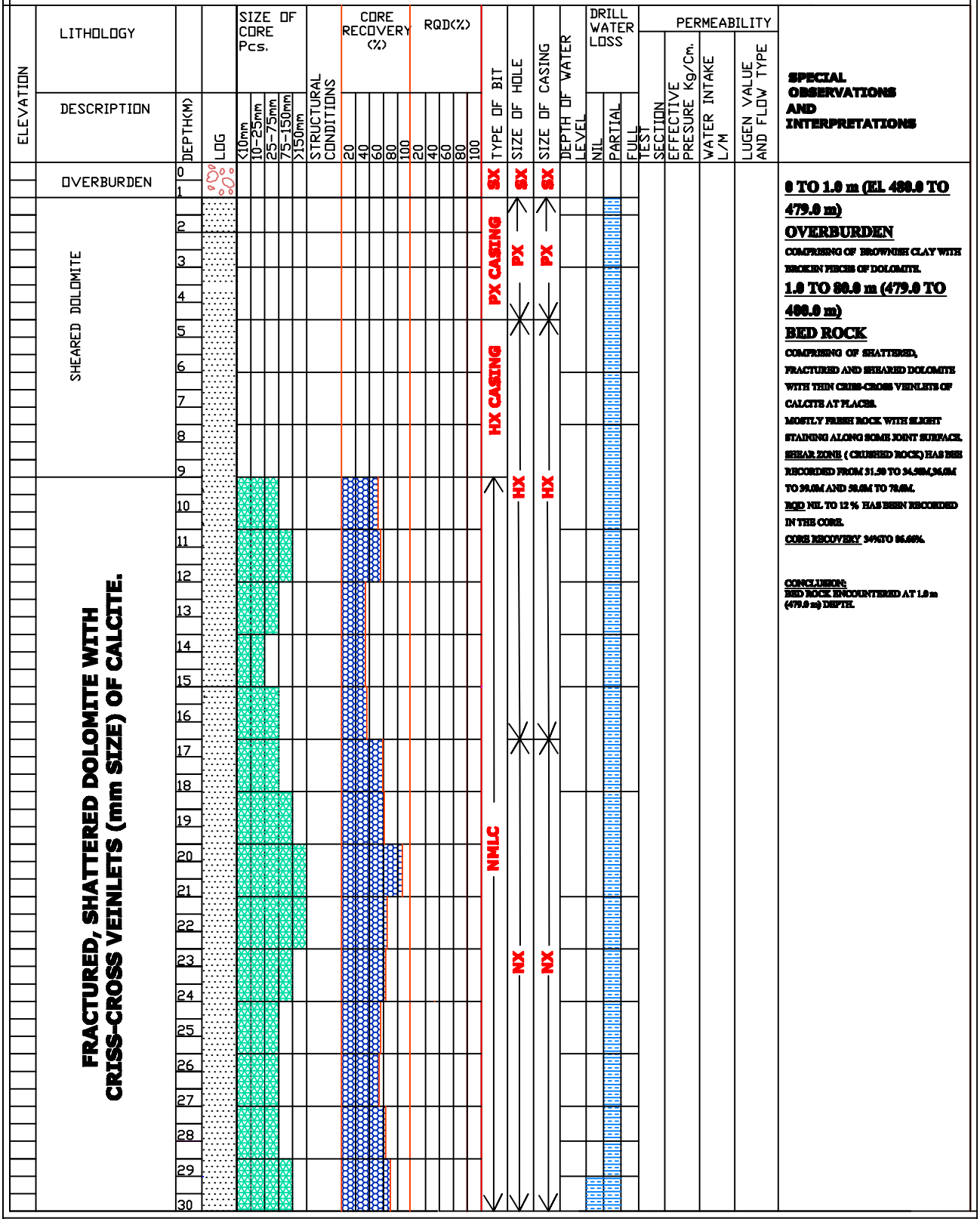
PROJECT: WANGCHU H.E.PROJECT **CO-ORDINATES: N**
E

LOCATION : PIPING POWER HOUSE SITE **FEATURES: PENSTOCK SLOPE**

BEARING OF HOLE : - **ANGLE WITH HORIZANTAL: 90°**

COLLAR ELEVATION :480.18m **GROUND ELEVATION: +_480.00m**

DATE OF START: 02.07.2011 **DATE OF COMPLETION: 17.08.2011** **TOTAL DEPTH :80.00m**



0 TO 1.0 m (EL 480.0 TO 479.0 m)

OVERBURDEN

COMPRISING OF BROWNISH CLAY WITH BROKEN PIECES OF DOLOMITE.

1.0 TO 80.0 m (479.0 TO 400.0 m)

BED ROCK

COMPRISING OF SHATTERED, FRACTURED AND SHEARED DOLOMITE WITH THIN CRISS-CROSS VEINLETS OF CALCITE AT PLACES.

MOSTLY FRESH ROCK WITH SLIGHT STAINING ALONG SOME JOINT SURFACE.

SHEAR ZONE (CRUSHED ROCK) HAS BEE RECORDED FROM 31.50 TO 34.90M,54.0M TO 59.0M AND 59.0M TO 78.0M.

RQD NIL TO 12 % HAS BEEN RECORDED IN THE CORE.

CORE RECOVERY 34%TO 86.60%.

CONCLUSION:
BED ROCK ENCOUNTERED AT 1.0 m (479.0 m) DEPTH.

SJVN LIMITED

PROJECT: **WANGCHU H.E.PROJECT** CO-ORDINATES: N E

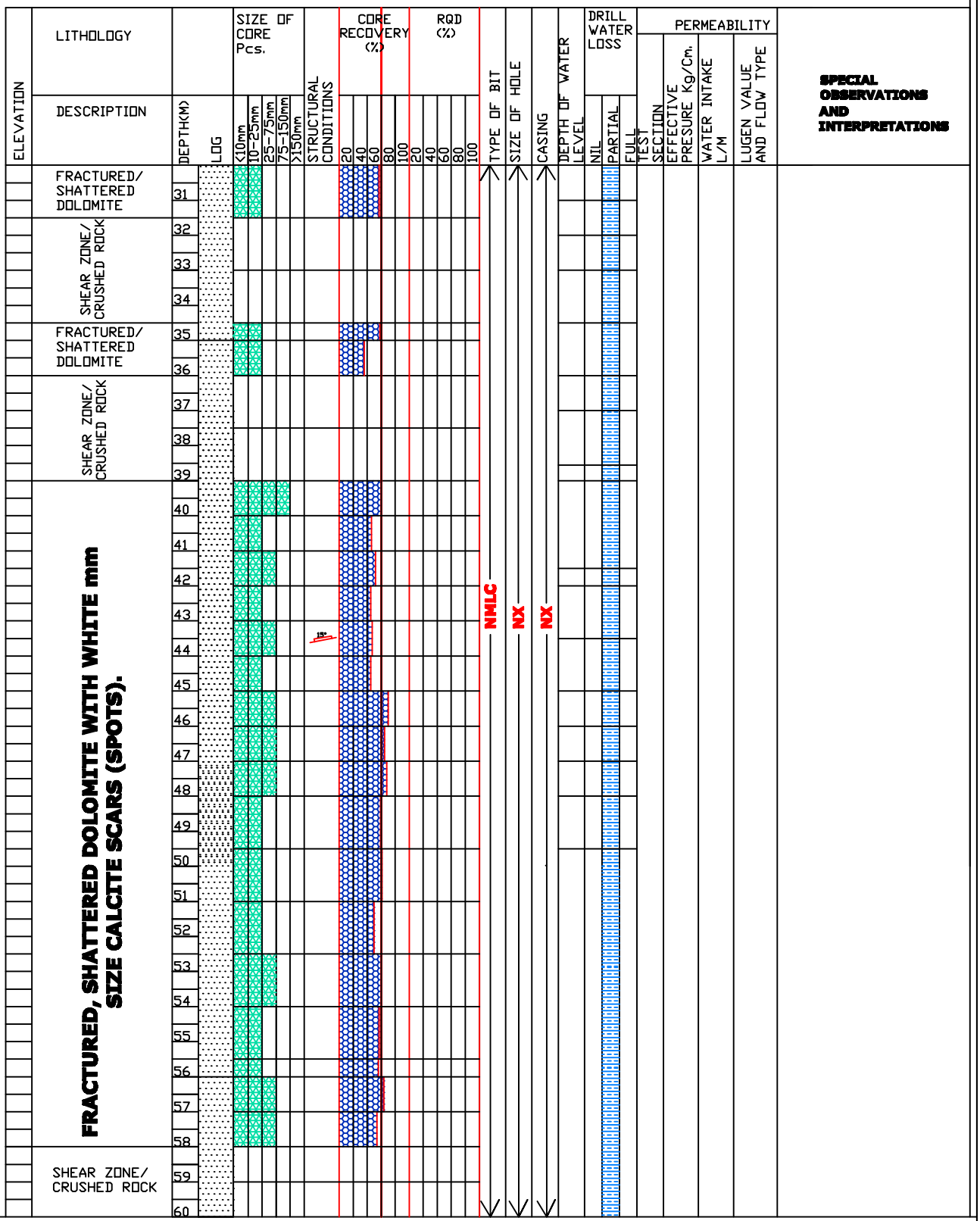
HOLE NO. PS-4

LOCATION : PIPING POWER HOUSE SITE FEATURES: PENSTOCK SLOPE

BEARING OF HOLE : - ANGLE WITH HORIZANTAL: 90°

COLLAR ELEVATION :480.18m GROUND ELEVATION: +_480.00m

DATE OF START: 02.07.2011 DATE OF COMPLETION: 17.08.2011 TOTAL DEPTH :80.00m



SJVN LIMITED

Appendix - 13

SHEET NO-3/3

PROJECT: **WANGCHU H.E.PROJECT**

CO-ORDINATES: N
E

HOLE NO. PS-4

LOCATION : PIPING POWER HOUSE SITE

FEATURES: PENSTOCK SLOPE

BEARING OF HOLE : -

ANGLE WITH HORIZANTAL: 90°

COLLAR ELEVATION :480.18m

GROUND ELEVATION: +_480.00m

DATE OF START: 02.07.2011

DATE OF COMPLETION: 17.08.2011

TOTAL DEPTH :80.00m

ELEVATION	LITHOLOGY / DESCRIPTION	DEPTH(M)	LOG	SIZE OF CORE Pcs. <10mm	10-25mm	25-75mm	75-150mm	>150mm	STRUCTURAL CONDITIONS	CORE RECOVERY (%) 20 40 60 80 100	RQD(%) 20 40 60 80 100	TYPE OF BIT	SIZE OF HOLE	SIZE OF CASING	DEPTH OF WATER LEVEL	DRILL WATER LOSS NIL	PARTIAL	FULL	PERMEABILITY TEST SECTION	EFFECTIVE PRESURE Kg/Cm.	WATER INTAKE L/M	LUGEN VALUE AND FLOW TYPE	SPECIAL OBSERVATIONS AND INTERPRETATIONS
	SHEAR ZONE / CRUSHED ROCK	61										NX	NX	NX									
		62																					
		63																					
		64																					
		65																					
		66																					
		67																					
		68																					
		69																					
		70																					
		71																					
		72																					
		73																					
		74																					
		75																					
		76																					
		77																					
		78																					
	FRACTURED/ SHATTERED DOLOMITE	79																					
		80																					

SJVN LIMITED

Appendix - 14

SHEET NO-1/2

PROJECT: WANGCHU H.E.PROJECT

CO-ORDINATES: N 44702.833
E 49926.654

DRILL HOLE NO. PH-5

LOCATION : CENTRE OF POWER HOUSE

BEARING OF HOLE : -

ANGLE WITH HORIZANTAL: 90°

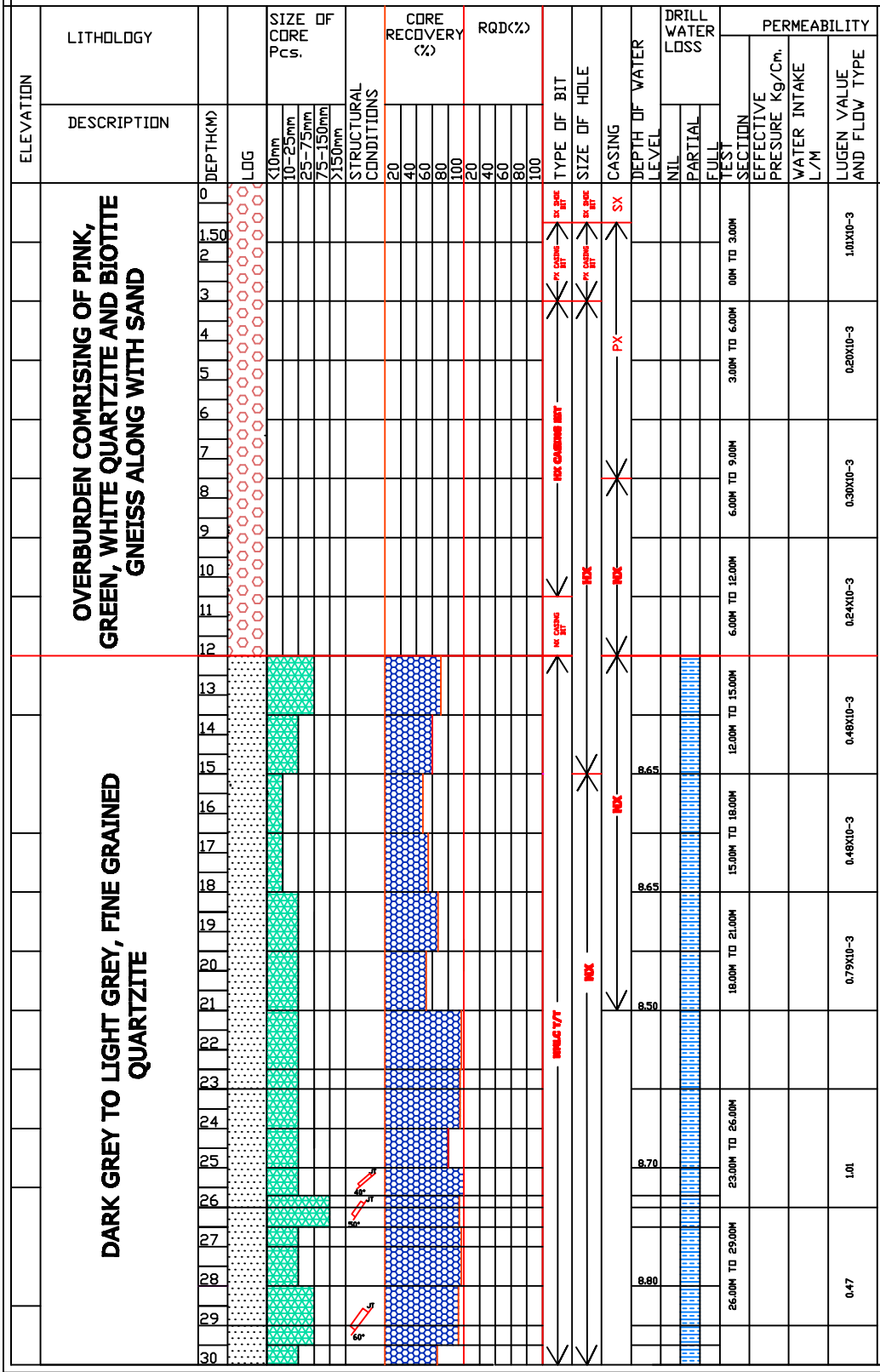
COLLAR ELEVATION : 179.20 M

GROUND ELEVATION: 179.00M

DATE OF START : 28-02-2011

DATE OF COMPLETION : 19-03-2011

TOTAL DEPTH :50.00m



SPECIAL OBSERVATIONS AND INTERPRETATIONS

0 TO 12.0 m (El. 179.0 - 167.0 m)

OVERBURDEN CONSISTING OF RIVERINE MATERIAL OF BOULDERS, COBBELS AND PEBBELS OF PINK, GREEN, WHITE COLOURED QUARTZITE, BIOTITE GNEISS AND MEDIUM TO COARSE GRAINED DARK GREY COLOURED SAND.

12.0 TO 50.0 m (El. 167.0 - 129.0 m)

BED ROCK COMPRISES OF DARK GREY TO LIGHT GREY COLOURED, FINE GRAINED QUARTZITE. THE ROCK IN GENERAL IS FRACTURED AND SHATTERED WITH CORE PIECES MOSTLY OF 1 TO 6 cm AND RARELY OF 10 cm. MINOR SHEARING HAS BEEN OBSERVED BETWEEN 45.00 TO 47.00M.

FRESH ROCK HAS BEEN ENCOUNTERED IN THE WHOLE DRILLED DEPTH.

CORE RECOVERY RANGES BETWEEN 36.66 TO 85%.

NO RQD HAS BEEN RECORDED IN THE CORE.

THE PERMEABILITY VALAUES RANGE BETWEEN TO LUGEONS.

CONCLUSION:

BED ROCK HAS BEEN ENCOUNTERED AT 12.0 m (El. 167.0 m) DEPTH.

SJVN LIMITED

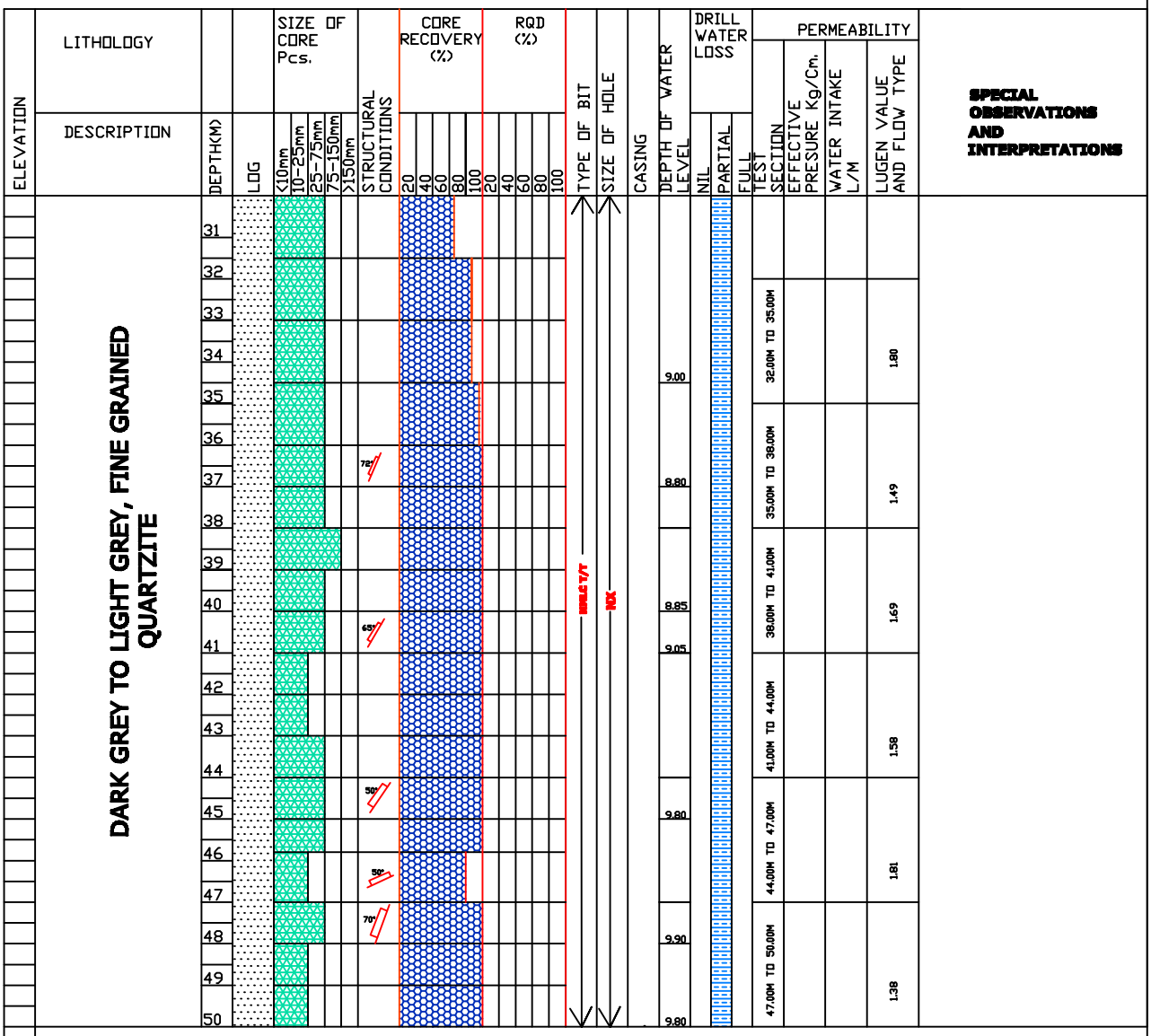
PROJECT: WANGCHU H.E.PROJECT **CO-ORDINATES: N 44702.833 E 49926.654** DRILL HOLE NO. PH-5

LOCATION : CENTRE OF POWER HOUSE

BEARING OF HOLE : - **ANGLE WITH HORIZANTAL: 90°**

COLLAR ELEVATION : 179.20 M **GROUND ELEVATION: 179.00M**

DATE OF START : 28-02-2011 **DATE OF COMPLETION : 19-03-2011** **TOTAL DEPTH :50.00m**



SJVN LIMITED

Appendix - 15

SHEET NO-1/2

PROJECT: WANGCHU H.E.PROJECT **CO-ORDINATES: N 44677.392 E 49829.944** HOLE NO. PH-6

LOCATION : POWER HOUSE **FEATURES: POWER HOUSE TERRACE, LEFT BANK OF RIVER**

BEARING OF HOLE : - **ANGLE WITH HORIZANTAL: 90°**

COLLAR ELEVATION :179.18m **GROUND ELEVATION: 179.00m**

DATE OF START : 19.04.2011 **DATE OF COMPLETION : 16.05.2011** **TOTAL DEPTH :50.00m**

ELEVATION	LITHOLOGY DESCRIPTION	DEPTH(M)	LOG	SIZE OF CORE Pcs. <10mm / 10-25mm / 25-75mm / 75-150mm / >150mm	STRUCTURAL CONDITIONS	CORE RECOVERY (%) 20 40 60 80 100	RQD(%) 20 40 60 80 100	TYPE OF BIT	SIZE OF HOLE	SIZE OF CASING	DEPTH OF WATER LEVEL	DRILL WATER LOSS NIL / PARTIAL / FULL	PERMEABILITY TEST SECTION	EFFECTIVE PRESURE Kg/Cm.	WATER INTAKE L/M	LUGEN VALUE AND FLOW TYPE	SPECIAL OBSERVATIONS AND INTERPRETATIONS
		0						SX	SX	SX							
		1															
		2															
		3															
		4						PX CASING SHOE	PX	PX							
		5															
		6						HEX CASING SHOE									
		7															
		8						HEX CASING SHOE	PX	PX							
		9															
		10															
		11															
		12															
		13															
		14															
		15						HEX CORE BIT									
		16															
		17															
		18															
		19															
		20							NX	NX							
		21															
	GREENISH GREY, PURPULE COLOURED QUARTZITE	22						NWT									
		23															
		24									9.90						
		25															
		26						NMLC									
		27															
		28															
		29									9.80						
		30															

TEST SECTION	EFFECTIVE PRESURE Kg/Cm.	WATER INTAKE L/M	LUGEN VALUE AND FLOW TYPE
00M TO 3.00M			0.85X10-3
3.00M TO 6.00M			0.36X10-3
6.00M TO 9.00M			0.24X10-3
6.00M TO 12.00M			0.24X10-3
12.00M TO 15.00M			0.39X10-3
15.00M TO 18.00M			0.39X10-3
18.00M TO 21.00M			0.32X10-3
21.00M TO 24.00M			0.45X10-3
24.00M TO 27.00M			0.56X10-3
27.00M TO 30.00M			0.48X10-3

SPECIAL OBSERVATIONS AND INTERPRETATIONS

0 TO 21.0 m (EL 179.0 - 158.0 m)
OVERBURDEN CONSISTING OF RIVERINE MATERIAL OF BOULDERS, COBBELS AND PEBBELS OF PINK, LIGHT GREEN, WHITE QUARTZITE AND BASIC ROCK.

21.0 TO 50.0 m (EL 158.0 - 129.0 m)
BED ROCK COMPRISING MAINLY OF GREENISH GREY, PURPLE COLOURED QUARTZITE AND LIGHT GREEN COLOURED DOLOMITE.
THE ROCK MASS IS MOSTLY SHATTERED, FRACTURED AND SHEARED IN NATURE.
WASHING OF QUARTZITE HAVE BEEN OBSERVED FROM 38.0 TO 39.0 m , 40.0 TO 42.0 m, 43.0 TO 44.0m, 45.0 TO 46.0 m, 47.0 TO 48.0 m AND 49.0 TO 50.0 m DEPTH.

ROCK MASS IN GENERAL IS FRESH.

CORE RECOVERY RANGES BETWEEN 4.66 TO 14%.

NO RQD HAS BEEN RECORDED IN THE CORE/ SAMPLES.

SIGNS OF REDRILLING NOTICED IN CORE.

THE PERMEABILITY VALAUES RANGE BETWEEN TO LUGEONS.

CONCLUSION:
BED ROCK ENCOUNTERED AT 21.0 m (EL 158.0 m) DEPTH.

SJVN LIMITED

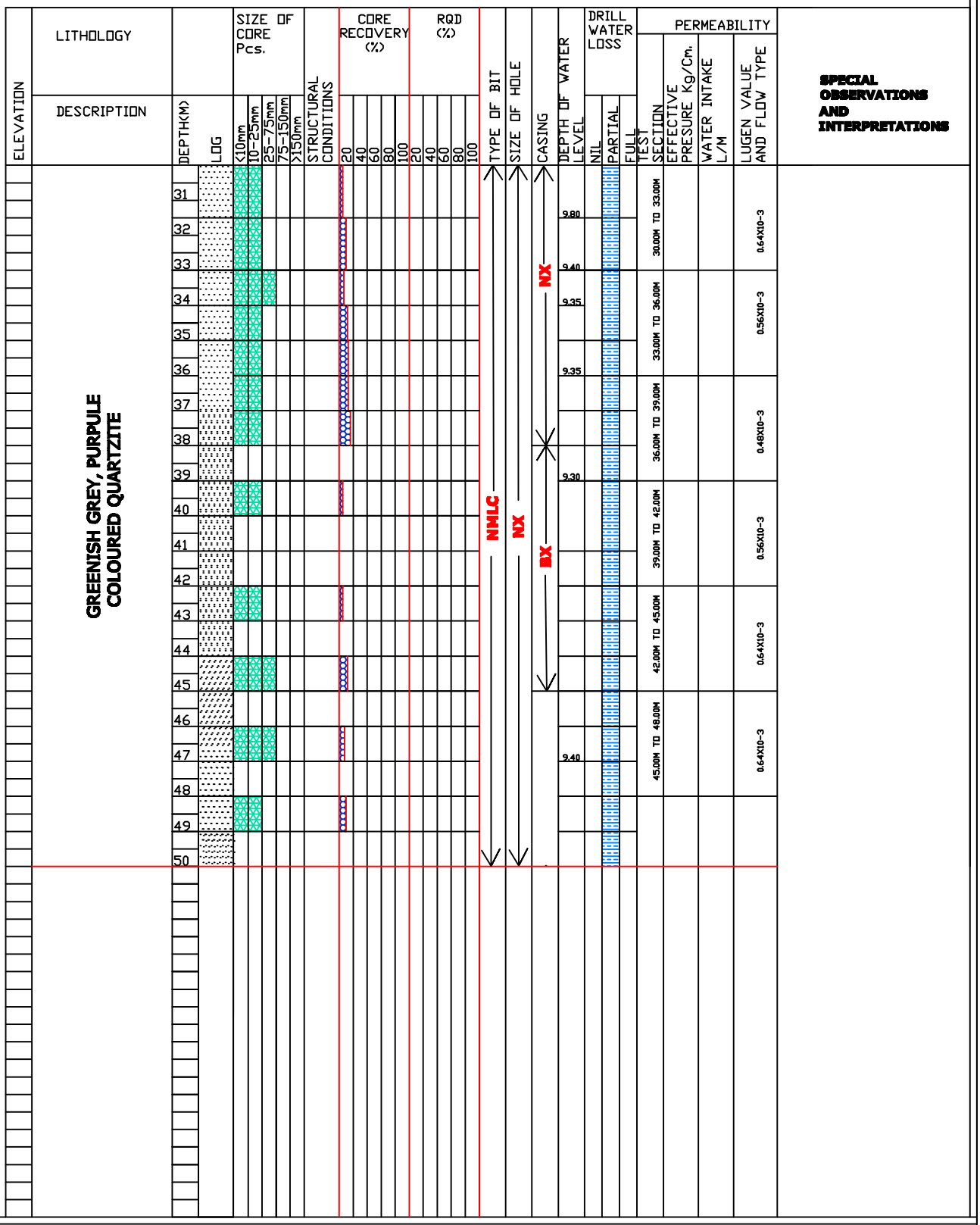
PROJECT: WANGCHU H.E.PROJECT **CO-ORDINATES: N 44677.392 E 49829.944** HOLE NO. PH-6

LOCATION : POWER HOUSE **FEATURES: POWER HOUSE TERRACE, LEFT BANK OF RIVER**

BEARING OF HOLE : - **ANGLE WITH HORIZANTAL: 90°**

COLLAR ELEVATION :179.18m **GROUND ELEVATION: 179.00m**

DATE OF START : 19.04.2011 **DATE OF COMPLETION : 16.05.2011** **TOTAL DEPTH :50.00m**



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Appendix - 16
SHEET NO-1

PROJECT: WANGCHU H.E.PROJECT **CO-ORDINATES: N:** HOLE NO. TRC-1
S:

LOCATION : PIPING POWER HOUSE SITE **FEATURES: TAIL RACE CHANNEL, LEFT BANK OF WANGCHU RIVER**

BEARING OF HOLE : - **ANGLE WITH HORIZANTAL: 90°**

COLLAR ELEVATION : **GROUND ELEVATION: ± 175.00M**

DATE OF START: **DATE OF COMPLETION :** **TOTAL DEPTH :30.00m**

ELEVATION	LITHOLOGY DESCRIPTION	DEPTH(M)	LOG	SIZE OF CORE Pcs. <10mm	10-25mm	25-75mm	75-150mm	>150mm	STRUCTURAL CONDITIONS	CORE RECOVERY (%) 20 40 60 80 100	RQD(%) 20 40 60 80 100	TYPE OF BIT	SIZE OF HOLE	SIZE OF CASING	DEPTH OF WATER LEVEL	DRILL WATER LOSS NIL	PARTIAL	FULL	PERMEABILITY TEST SECTION	EFFECTIVE PRESURE Kg/Cm.	WATER INTAKE L/M	LUGEN VALUE AND FLOW TYPE	SPECIAL OBSERVATIONS AND INTERPRETATIONS
	OVERBURDEN COMPRISING OF BOULDERS, COBBLES, PEBBLES OF QUARTZITE WITH DOLOMITE PIECES AND SAND/SILT SEAMS	0											SX	SX									9 TO 12.0M (EL+ 175.0 TO + 163.0M) OVER BURDEN COMPRISING OF BOULDERS, COBBLES AND PEBBLES OF QUARTZITE AND DOLOMITE ALONG WITH SAND/SILT SEAMS.
		1.50											PX										
		2																					
		3																					
		4												PX					00M TO 3.00M			16.85X10-3	
		5																					12.0 TO 30.0M (EL.+163.0 TO 145.0 m) BED ROCK COMPRISING OF FINE GRAINED, DARK GREY COLOURED QUARTZITE WITH SOME LIGHT GREY QUARTZITE BANDS. THE ROCK MASS IN GENERAL IS FRACTURED, SHATTERED AND VERY CLOSELY JOINTED WITH ROCK PIECES MOSTLY OF 1 TO 6 cm AND SOMETIMES UPTO 8 cm.
		6																	3.00M TO 6.00M			2.87X10-3	
		7																					
		8											HX	HX					6.00M TO 9.00M			2.79X10-3	
		9																					NO SIGNS OF WEATHERING IN ROCK OBSERVED.
		10																					
		11												PX					9.00M TO 12.00M			0.08x10-3	CORE RECOVERY VARIED BETWEEN 46.66% TO 85%.
		12																					
	BED ROCK COMPRISING OF DARK GREY QUARTZITE WITH SOME LIGHT GREY QUARTZITE BANDS.	13													4.85				12.00M TO 15.00M			0.03X10-3	NO RQD RECORDED IN THE ROCK.
		14																					
		15																					THE PERMEABILITY VALAUES RANGE BETWEEN TO LUGEONS.
		16													4.80				150M TO 18.00M			0.06X10-3	
		17																					
		18													4.80								CONCLUSION : BED ROCK ENCOUNTERED AT 12.0 DEPTH (EL.163.0 m)
		19																					
		20												NX									
		21													4.70				18.00M TO 21.00M			IMPERMEABLE	
		22							65°										21.00M TO 24.00M			3.54	
		23							30°														
		24																					
		25													4.49				24.00M TO 27.00M			4.69	
		26																					
		27							35°														
		28							70°										27.00M TO 30.00M			5.60	
		29																					
		30													4.44								

SJVN LIMITED

PROJECT: **WANGCHU H.E.PROJECT**

CO-ORDINATES: N:44699.500 E:49949.278

DRILL HOLE NO. PH-7(G)

LOCATION : SURFACE POWER HOUSE

FEATURES: ALONG LONG AXIS, DOWNSTREAM

BEARING OF HOLE :

ANGLE WITH HORIZANTAL: 90°

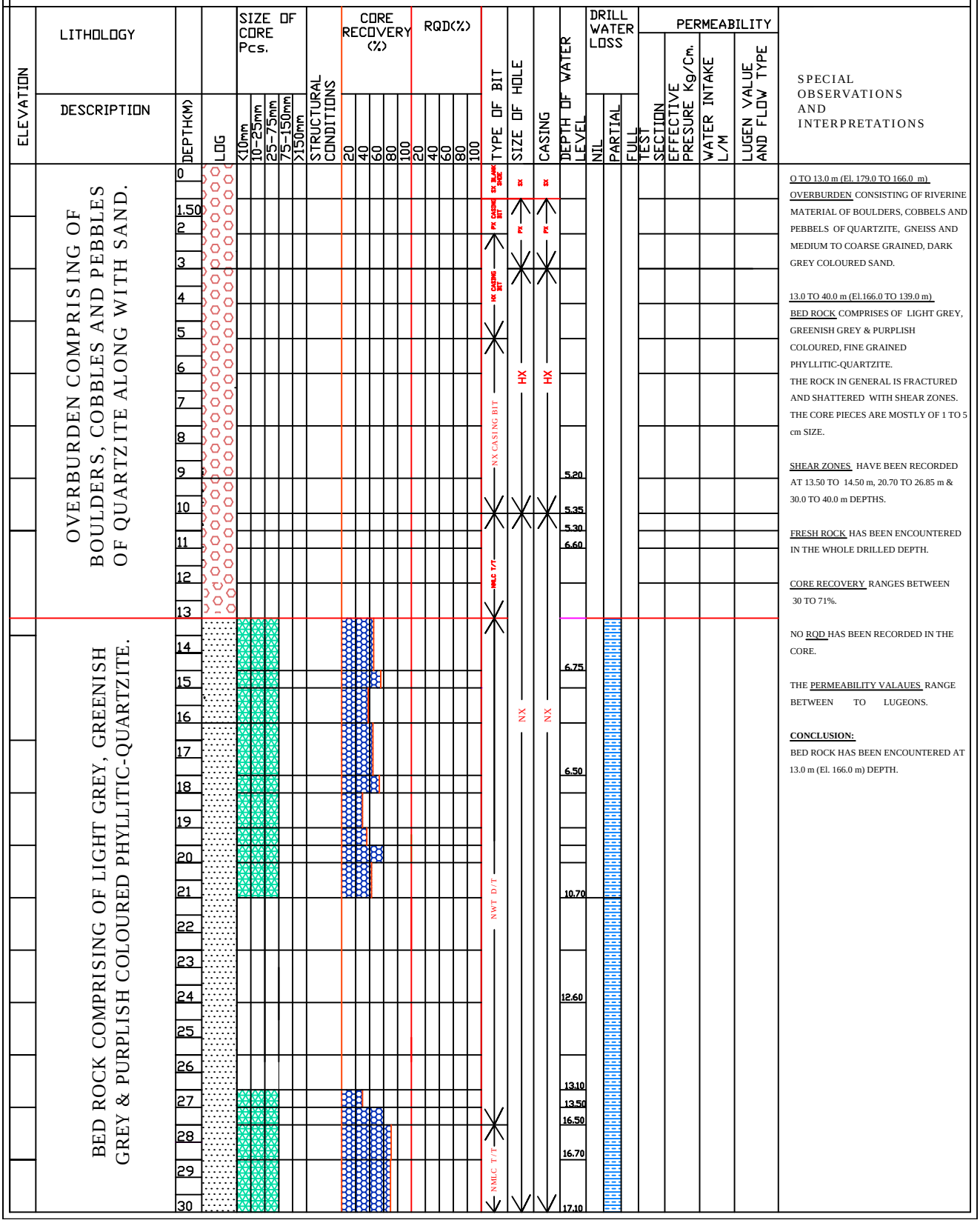
COLLAR ELEVATION :

GROUND ELEVATION: +-179 m

DATE OF START : 16-11-2011

DATE OF COMPLETION : 20-12-2011

TOTAL DEPTH :40.00m



O TO 13.0 m (El. 179.0 TO 166.0 m) OVERBURDEN CONSISTING OF RIVERINE MATERIAL OF BOULDERS, COBBELS AND PEBBELS OF QUARTZITE, GNEISS AND MEDIUM TO COARSE GRAINED, DARK GREY COLOURED SAND.

13.0 TO 40.0 m (El.166.0 TO 139.0 m) BED ROCK COMPRISES OF LIGHT GREY, GREENISH GREY & PURPLISH COLOURED, FINE GRAINED PHYLLITIC-QUARTZITE.
THE ROCK IN GENERAL IS FRACTURED AND SHATTERED WITH SHEAR ZONES. THE CORE PIECES ARE MOSTLY OF 1 TO 5 cm SIZE.

SHEAR ZONES HAVE BEEN RECORDED AT 13.50 TO 14.50 m, 20.70 TO 26.85 m & 30.0 TO 40.0 m DEPTHS.

FRESH ROCK HAS BEEN ENCOUNTERED IN THE WHOLE DRILLED DEPTH.

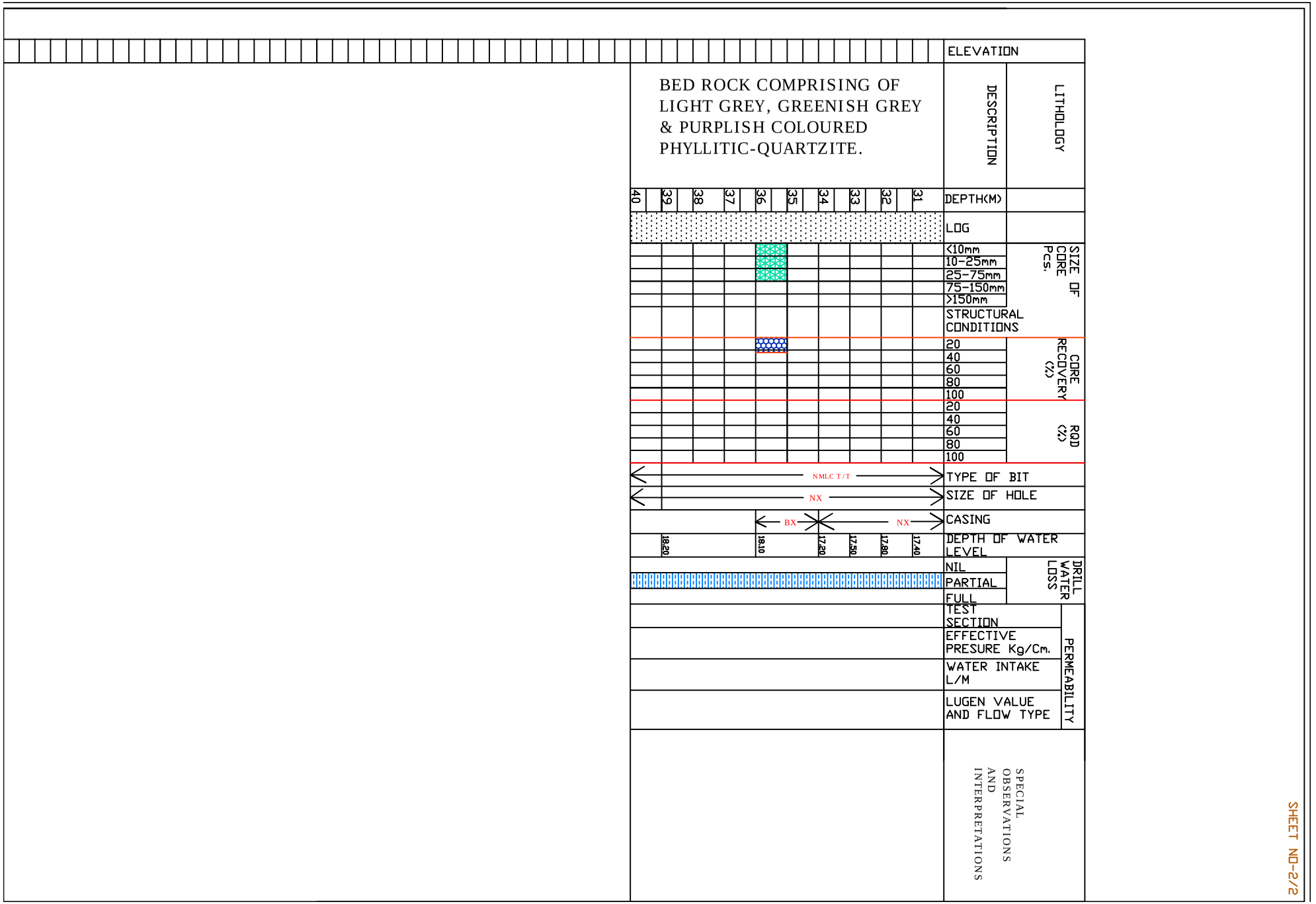
CORE RECOVERY RANGES BETWEEN 30 TO 71%.

NO RQD HAS BEEN RECORDED IN THE CORE.

THE PERMEABILITY VALAUES RANGE BETWEEN TO LUGEONS.

CONCLUSION:

BED ROCK HAS BEEN ENCOUNTERED AT 13.0 m (El. 166.0 m) DEPTH.


ELEVATION
LITHOLOGY
DESCRIPTION
BED ROCK COMPRISING OF LIGHT GREY, GREENISH GREY & PURPLISH COLOURED PHYLLITIC-QUARTZITE.
DEPTH(M)
40
39
38
37
36
35
34
33
32
31
LOG
SIZE OF CORE Pcs.
<10mm
10-25mm
25-75mm
75-150mm
>150mm
STRUCTURAL CONDITIONS
CORE RECOVERY (%)
20
40
60
80
100
RQD (%)
20
40
60
80
100
TYPE OF BIT
NMLC T/T
SIZE OF HOLE
NX
CASING
BX
NX
DEPTH OF WATER LEVEL
18.20
18.10
17.20
17.50
17.80
17.40
DRILL WATER LOSS
NIL
PARTIAL
FULL
PERMEABILITY
TEST SECTION
EFFECTIVE PRESURE Kg/Cm.
WATER INTAKE L/M
LUGEN VALUE AND FLOW TYPE
SPECIAL OBSERVATIONS AND INTERPRETATIONS

SJVN LIMITED

PROJECT: **WANGCHU H.E.PROJECT**

CO-ORDINATES: N:44684.859
E: 49905.261

HOLE NO. DH- PH-8 (I)

LOCATION : SURFACE POWER HOUSE TERRACE

FEATURES: ALONG SHORTER AXIS AND TOWARDS VALLEY

BEARING OF HOLE :

ANGLE WITH HORIZONTAL: 90°

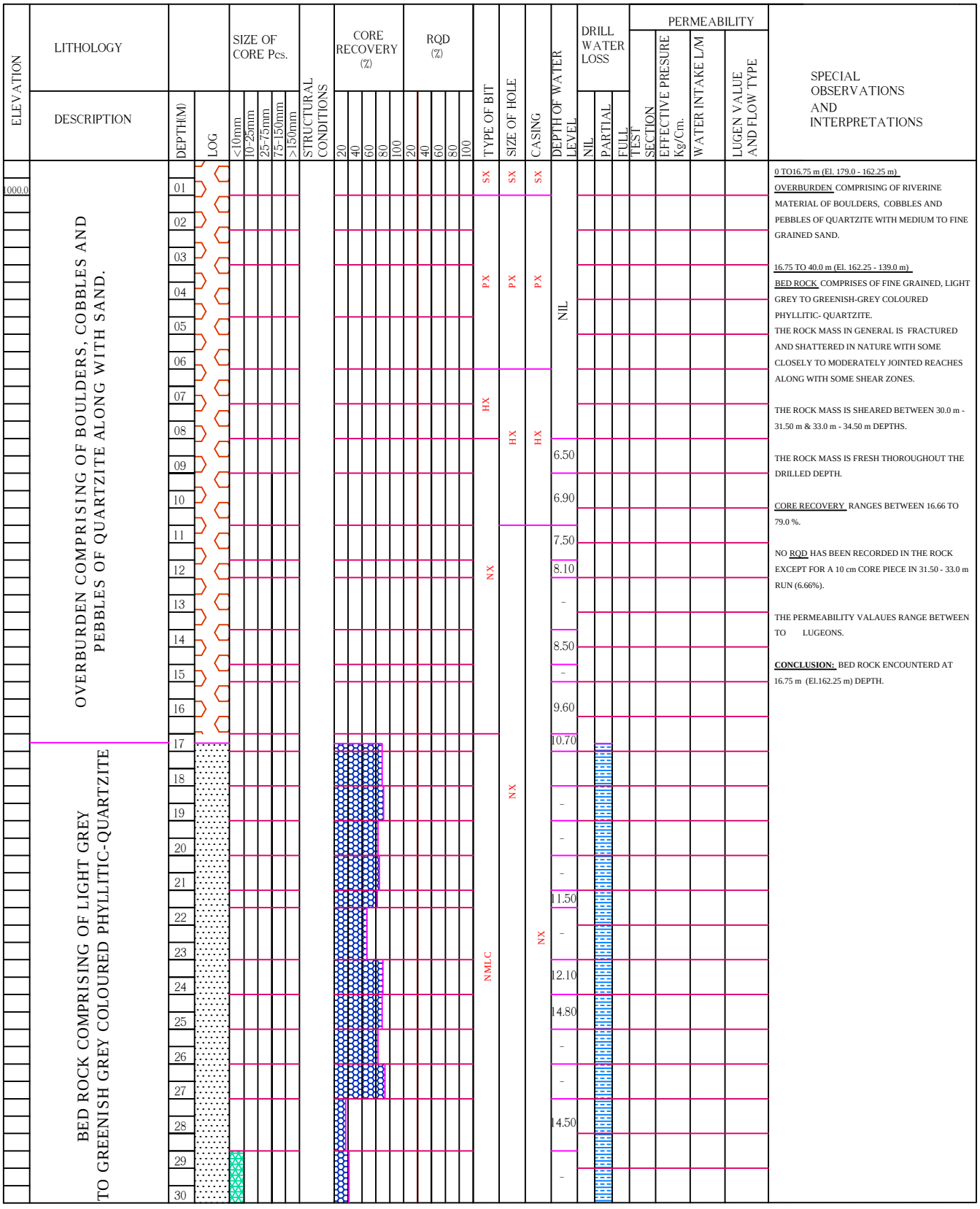
COLLAR ELEVATION : m

GROUND ELEVATION: +- 179.0 m

DATE OF START : 24.12.2011

DATE OF COMPLETION : 14.01.2012

TOTAL DEPTH : 40 m



0 TO16.75 m (El. 179.0 - 162.25 m)
OVERBURDEN COMPRISING OF RIVERINE MATERIAL OF BOULDERS, COBBLES AND PEBBLES OF QUARTZITE WITH MEDIUM TO FINE GRAINED SAND.

16.75 TO 40.0 m (El. 162.25 - 139.0 m)
BED ROCK COMPRISES OF FINE GRAINED, LIGHT GREY TO GREENISH-GREY COLOURED PHYLLITIC- QUARTZITE.
THE ROCK MASS IN GENERAL IS FRACTURED AND SHATTERED IN NATURE WITH SOME CLOSELY TO MODERATELY JOINTED REACHES ALONG WITH SOME SHEAR ZONES.

THE ROCK MASS IS SHEARED BETWEEN 30.0 m - 31.50 m & 33.0 m - 34.50 m DEPTHS.

THE ROCK MASS IS FRESH THOROUGHOUT THE DRILLED DEPTH.

CORE RECOVERY RANGES BETWEEN 16.66 TO 79.0 %.

NO RQD HAS BEEN RECORDED IN THE ROCK EXCEPT FOR A 10 cm CORE PIECE IN 31.50 - 33.0 m RUN (6.66%).

THE PERMEABILITY VALAUES RANGE BETWEEN TO LUGEONS.

CONCLUSION: BED ROCK ENCOUNTERD AT 16.75 m (El.162.25 m) DEPTH.

HOLE NO. DH- PH-8 (I)

ELEVATION	LITHOLOGY			SIZE OF CORE Pcs.					STRUCTURAL CONDITIONS	CORE RECOVERY (%)					RQD (%)					TYPE OF BIT	SIZE OF HOLE	CASING	DEPTH OF WATER LEVEL	DRILL WATER LOSS			PERMEABILITY				SPECIAL OBSERVATIONS AND INTERPRETATIONS
	DESCRIPTION	DEPTH(M)	LOG	<10mm	10-25mm	25-75mm	75-150mm	>150mm		20	40	60	80	100	20	40	60	80	100					NIL	PARTIAL	FULL	TEST SECTION	EFFECTIVE PRESURE Kg/Cm.	WATER INTAKE L/M	LUGEN VALUE AND FLOW TYPE	
	BED ROCK COMPRISING OF LIGHT GREY TO GREENISH GREY COLOURED PHYLLITIC-QUARTZITE	31																		NMLC	NX	NX	13.50								
		32																					-								
		33																													
		34																					15.30								
		35																					-								
		36																													
		37																					-								
		38																					-								
		39																					-								
		40																					-								

SJVN LIMITED

PROJECT: **WANGCHU H.E.PROJECT**

CO-ORDINATES: N:44715.28
E:49904.699

DRILL HOLE NO. PH-9 (C)

LOCATION : SURFACE POWER HOUSE

FEATURES: ALONG SHORTER AXIS AND TOWARDS HILL

BEARING OF HOLE : -

ANGLE WITH HORIZANTAL: 90°

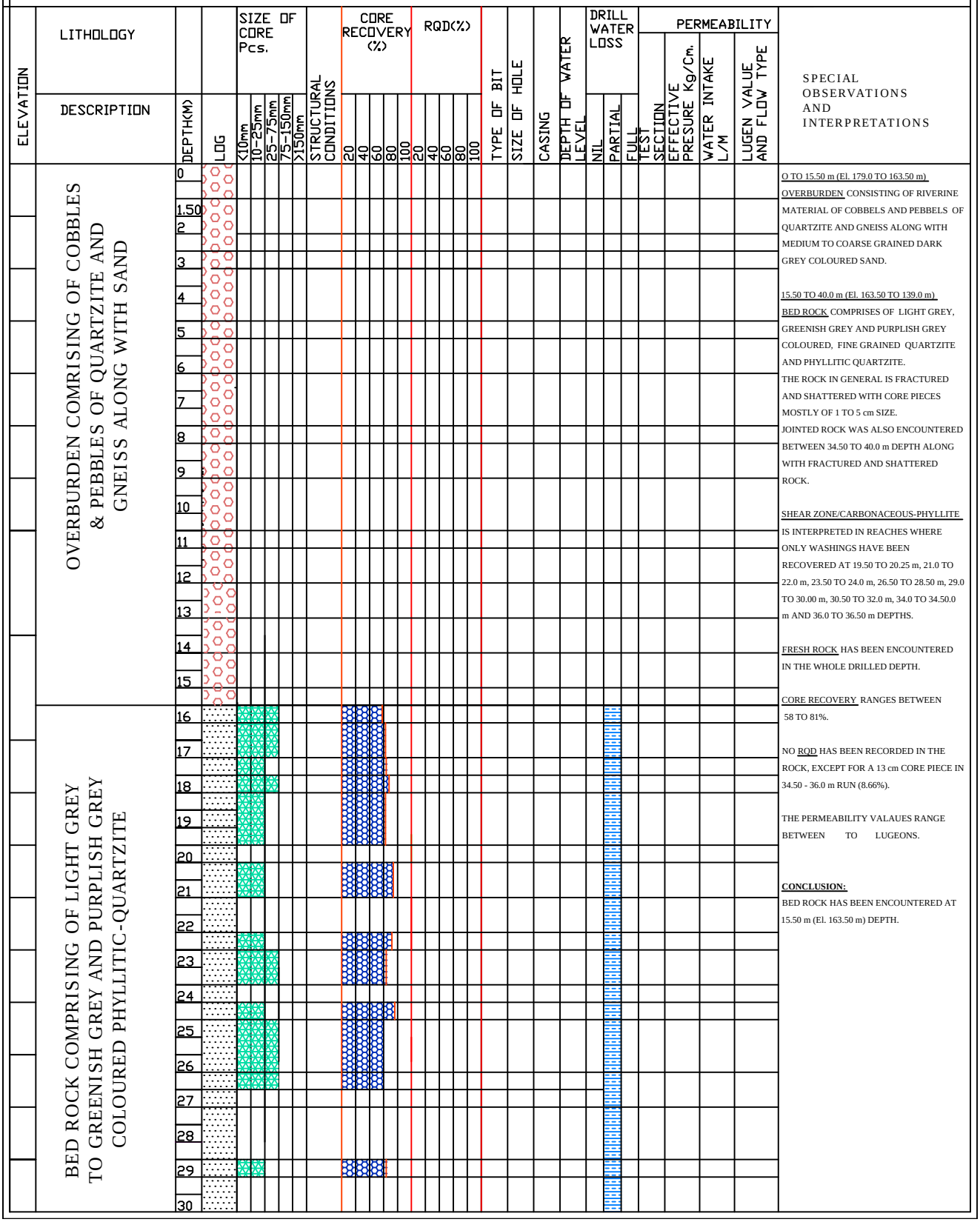
COLLAR ELEVATION :

GROUND ELEVATION: +-179 m

DATE OF START :

DATE OF COMPLETION :

TOTAL DEPTH :40.00 m



O TO 15.50 m (El. 179.0 TO 163.50 m) OVERBURDEN CONSISTING OF RIVERINE MATERIAL OF COBBELS AND PEBBELS OF QUARTZITE AND GNEISS ALONG WITH MEDIUM TO COARSE GRAINED DARK GREY COLOURED SAND.

15.50 TO 40.0 m (El. 163.50 TO 139.0 m) BED ROCK COMPRISES OF LIGHT GREY, GREENISH GREY AND PURPLISH GREY COLOURED, FINE GRAINED QUARTZITE AND PHYLLITIC QUARTZITE.
THE ROCK IN GENERAL IS FRACTURED AND SHATTERED WITH CORE PIECES MOSTLY OF 1 TO 5 cm SIZE.
JOINTED ROCK WAS ALSO ENCOUNTERED BETWEEN 34.50 TO 40.0 m DEPTH ALONG WITH FRACTURED AND SHATTERED ROCK.

SHEAR ZONE/CARBONACEOUS-PHYLLITE IS INTERPRETED IN REACHES WHERE ONLY WASHINGS HAVE BEEN RECOVERED AT 19.50 TO 20.25 m, 21.0 TO 22.0 m, 23.50 TO 24.0 m, 26.50 TO 28.50 m, 29.0 TO 30.00 m, 30.50 TO 32.0 m, 34.0 TO 34.50.0 m AND 36.0 TO 36.50 m DEPTHS.

FRESH ROCK HAS BEEN ENCOUNTERED IN THE WHOLE DRILLED DEPTH.

CORE RECOVERY RANGES BETWEEN 58 TO 81%.

NO RQD HAS BEEN RECORDED IN THE ROCK, EXCEPT FOR A 13 cm CORE PIECE IN 34.50 - 36.0 m RUN (8.66%).

THE PERMEABILITY VALAUES RANGE BETWEEN TO LUGEONS.

CONCLUSION:

BED ROCK HAS BEEN ENCOUNTERED AT 15.50 m (El. 163.50 m) DEPTH.

SJVN LIMITED

PROJECT: **WANGCHU H.E.PROJECT**

CO-ORDINATES: N:44715.28
E:49904.699

DRILL HOLE NO. PH-9 (C)

LOCATION : SURFACE POWER HOUSE

FEATURES: ALONG SHORTER AXIS AND TOWARDS HILL

BEARING OF HOLE : -

ANGLE WITH HORIZANTAL: 90°

COLLAR ELEVATION :

GROUND ELEVATION: +-179 m

DATE OF START :

DATE OF COMPLETION :

TOTAL DEPTH :40.00 m

ELEVATION	LITHOLOGY DESCRIPTION	DEPTH(M)	LOG	SIZE OF CORE Pcs. <10mm	10-25mm	25-75mm	75-150mm	>150mm	STRUCTURAL CONDITIONS	CORE RECOVERY (%)	RQD (%)	TYPE OF BIT	SIZE OF HOLE	CASING	DEPTH OF WATER LEVEL	DRILL WATER LOSS NIL	PARTIAL	FULL	PERMEABILITY TEST SECTION	EFFECTIVE PRESURE Kg/Cm.	WATER INTAKE L/M	LUGEN VALUE AND FLOW TYPE	SPECIAL OBSERVATIONS AND INTERPRETATIONS
		31																					
		32																					
	BED ROCK COMPRISING OF LIGHT GREY COLOURED QUARTZITE	33																					
		34																					
		35																					
		36																					
		37																					
		38																					
		39																					
		40																					

SJVN LIMITED

PROJECT: WANGCHU H.E.PROJECT **CO-ORDINATES: N 44699.063 E 49860.904** DRILL HOLE NO.: PH-10

LOCATION : SURFACE POWER HOUSE **FEATURE: ALONG LONG AXIS (U/S SIDE)**

BEARING OF HOLE : - **ANGLE WITH HORIZANTAL: 90°**

COLLAR ELEVATION : +- 179.0 m **GROUND ELEVATION: 179.0 m**

DATE OF START : **DATE OF COMPLETION :** **TOTAL DEPTH :40.0 m**

ELEVATION	LITHOLOGY DESCRIPTION	DEPTH(M)	LOG	SIZE OF CORE Pcs. <10mm	10-25mm	25-75mm	75-150mm	>150mm	STRUCTURAL CONDITIONS	CORE RECOVERY (%) 20	40	60	80	100	RQD(%) 20	40	60	80	100	TYPE OF BIT	SIZE OF HOLE	CASING	DEPTH OF WATER LEVEL	DRILL WATER LOSS NIL	PARTIAL	FULL	PERMEABILITY TEST SECTION	EFFECTIVE PRESURE Kg/Cm.	WATER INTAKE L/M	LUGEN VALUE	SPECIAL OBSERVATIONS AND INTERPRETATIONS
	OVERBURDEN COMRISING OFCOBBLES, PEBBLES AND GRAVELS OF QUARTZITE AND QUARTZITIC-PHYLLITE, ETC WITH SILT SEAMS.	0 1.50 2 3 4 5 6 7 8 9 10 11 12 13																														**0 TO 13.0 m (EL.179.0 -166.0 m) OVERBURDEN** RIVERINE MATERIAL CONSISTING OF COBBLES, PEBBLES AND GRAVELS OF QUARTZITE AND QUARTZITIC-PHYLLIE, ETC. WITH SILT SEAMS. **13.0 TO 40.0 m (EL 166.0 -139.0 m) BED ROCK** COMPRISING OF GREYISH-GREEN AND PURPLISH-GREEN COLOURED QUARTZITE. THE ROCK IN GENERAL IS FRACTURED AND SHATTERED WITH SHEAR ZONES. THE ROCK IN GENERAL IS FRESH IN NATURE. **CORE RECOVERY IN THE BED ROCK** RANGES BETWEEN 53.8% to 91.35%. NO RQD WAS RECORED IN THE ROCK. **CONCLUSION:** BED ROCK HAS BEEN ENCOUNTERED AT 13.0 m (EL 166.0 m) DEPTH.
	GREYISH- GREEN QUARTZITE AND PURPLISH-GREEN QUARTZITE	14 15 16 17																													
	SHEAR ZONE (WASHINGS ONLY)	18																													
	GREYISH GREEN QUARTZITE AND PURPLISH-GREEN QUARTZITE	19 20 21 22 23 24 25 26 27 28 29 30																													

ELEVATION	LITHOLOGY DESCRIPTION	DEPTH(M)	LOG	SIZE OF CORE Pcs. <10mm	10-25mm	25-75mm	75-150mm	>150mm	STRUCTURAL CONDITIONS	CORE RECOVERY (%) 20 40 60 80 100	RQD (%) 20 40 60 80 100	TYPE OF BIT	SIZE OF HOLE	CASING	DEPTH OF WATER LEVEL	DRILL WATER LOSS NIL	PARTIAL	FULL	PERMEABILITY TEST SECTION	EFFECTIVE PRESURE Kg/Cm.	WATER INTAKE L/M	LUGEN VALUE	SPECIAL OBSERVATIONS AND INTERPRETATIONS
	GREYISH GREEN QUARTZITE AND PURPLISH-GREEN QUARTZITE	31																					
		32																					
		33																					
		34																					
		35																					
		36																					
	SHEAR ZONE (WASHINGS ONLY)	37																					
		38																					
	GREYISH- GREEN QUARTZITE AND PURPLISH-GREEN QUARTZITE	39																					
		40																					

SJVN LIMITED

PROJECT: **WANGCHU H.E.PROJECT**

CO-ORDINATES: N :45339.176
E :49873.960

DRILL HOLE NO.: SS-1

LOCATION: CENTER LINE OF SURGE SHAFT

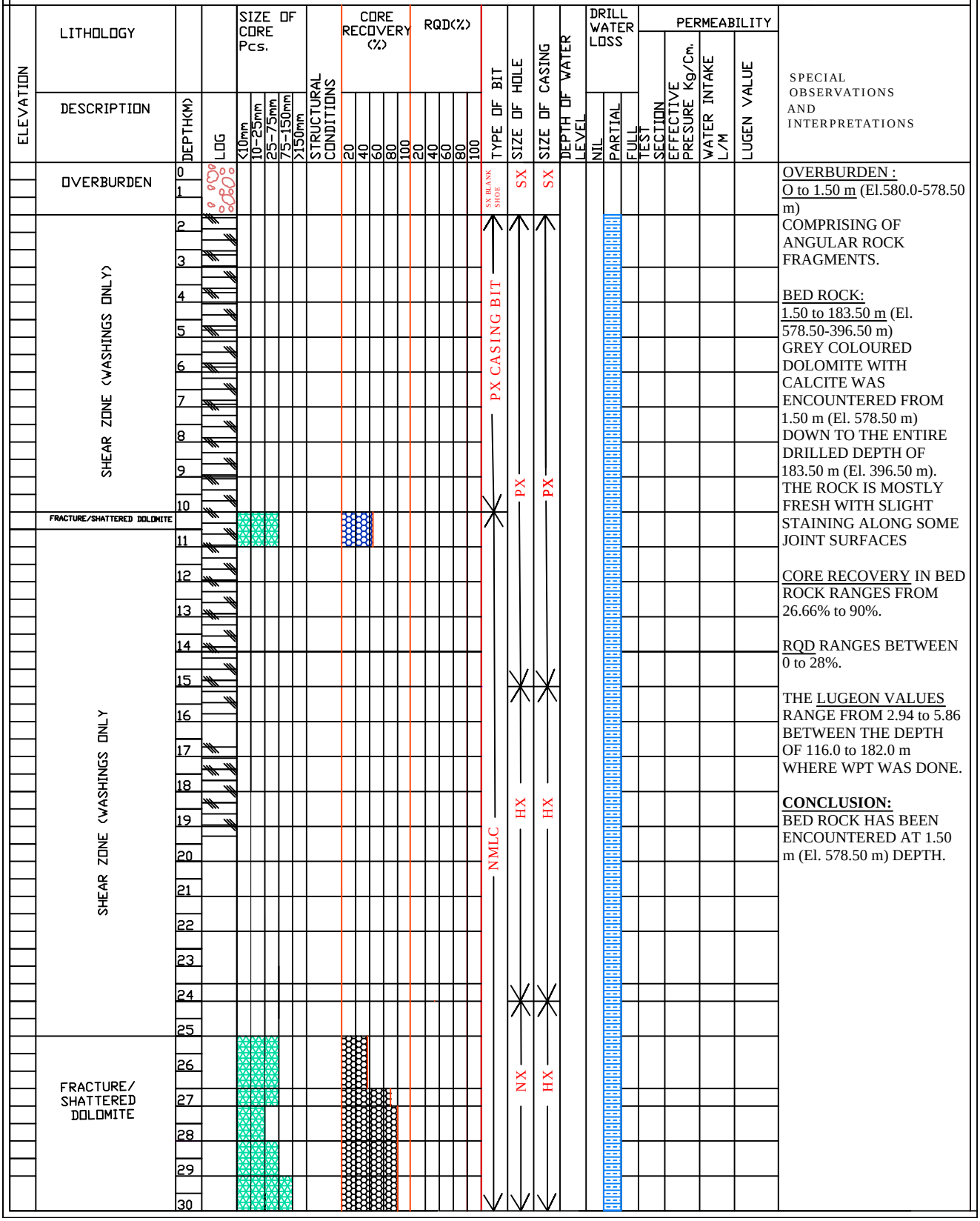
ANGLE WITH HORIZANTAL: 90°

GROUND ELEVATION: 578.50 m

DATE OF START: 027.09.2011

DATE OF COMPLETION: 15.03.2012

TOTAL DEPTH :183.50 m



OVERBURDEN :
O to 1.50 m (El.580.0-578.50 m)
COMPRISING OF ANGULAR ROCK FRAGMENTS.

BED ROCK:
1.50 to 183.50 m (El. 578.50-396.50 m)
GREY COLOURED DOLOMITE WITH CALCITE WAS ENCOUNTERED FROM 1.50 m (El. 578.50 m) DOWN TO THE ENTIRE DRILLED DEPTH OF 183.50 m (El. 396.50 m). THE ROCK IS MOSTLY FRESH WITH SLIGHT STAINING ALONG SOME JOINT SURFACES

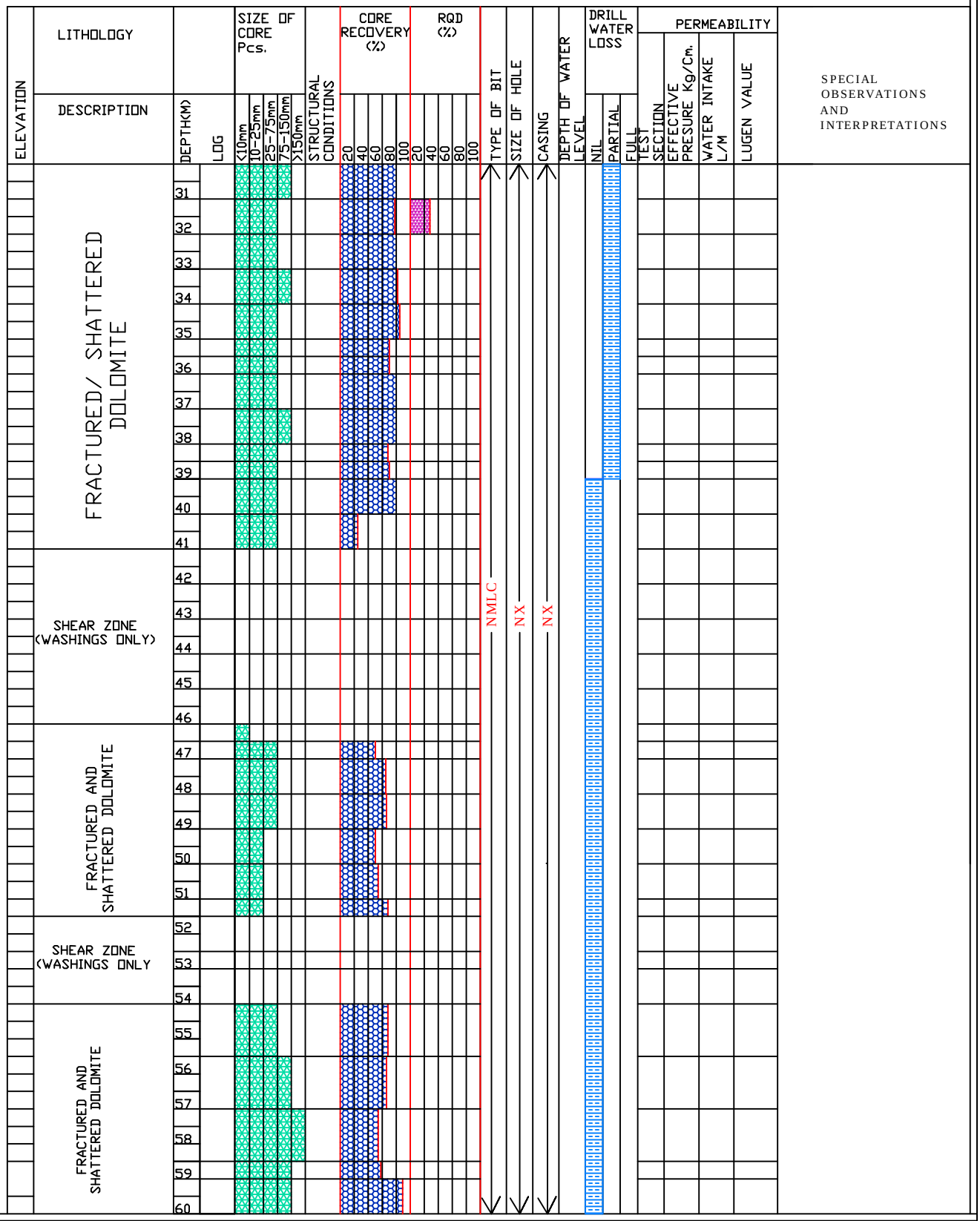
CORE RECOVERY IN BED ROCK RANGES FROM 26.66% to 90%.

RQD RANGES BETWEEN 0 to 28%.

THE LUGEON VALUES RANGE FROM 2.94 to 5.86 BETWEEN THE DEPTH OF 116.0 to 182.0 m WHERE WPT WAS DONE.

CONCLUSION:
BED ROCK HAS BEEN ENCOUNTERED AT 1.50 m (El. 578.50 m) DEPTH.

HOLE NO. SS-1
SHEET NO-2/7

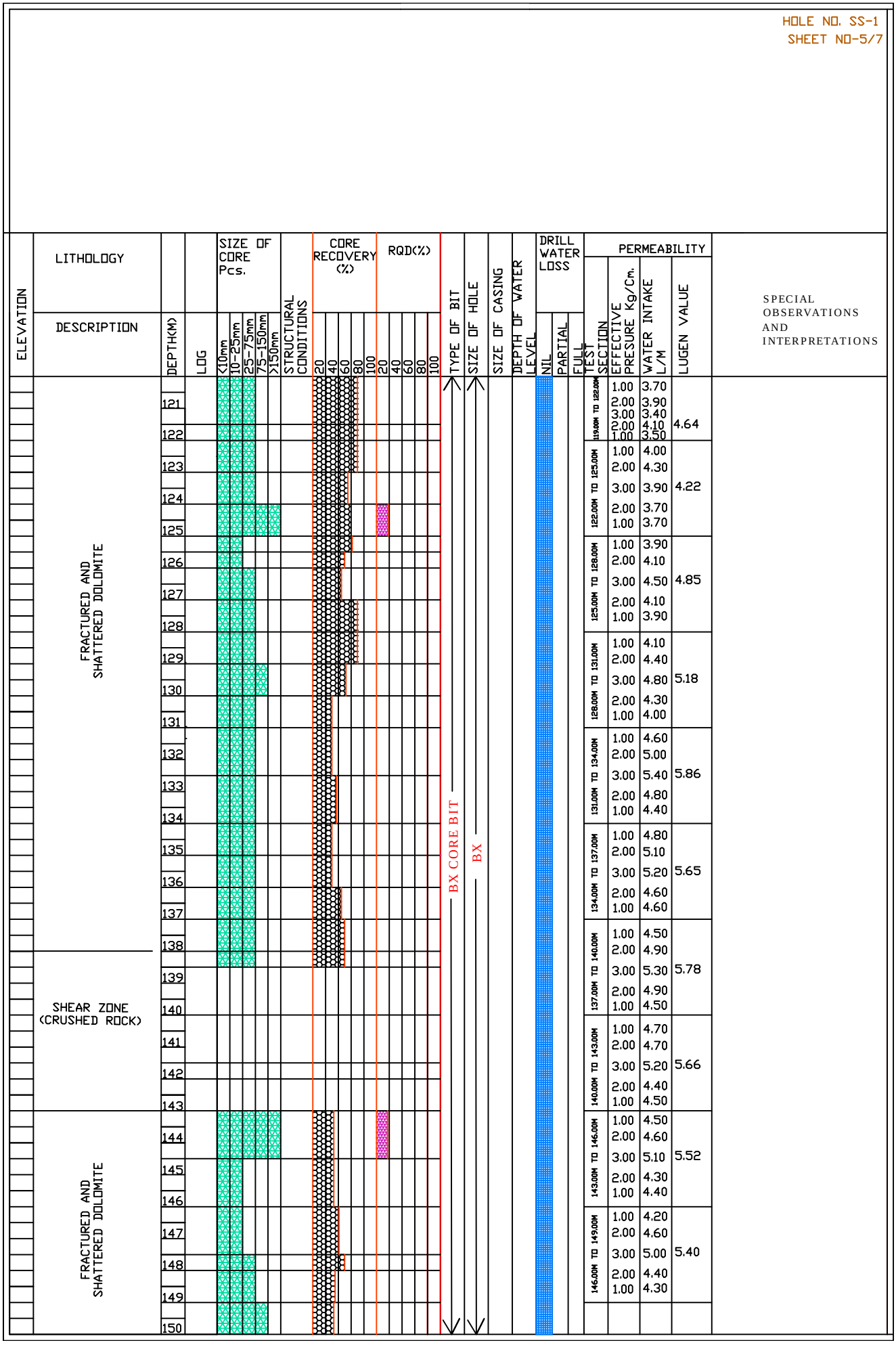


HOLE NO. SS-1
SHEET NO-3/7

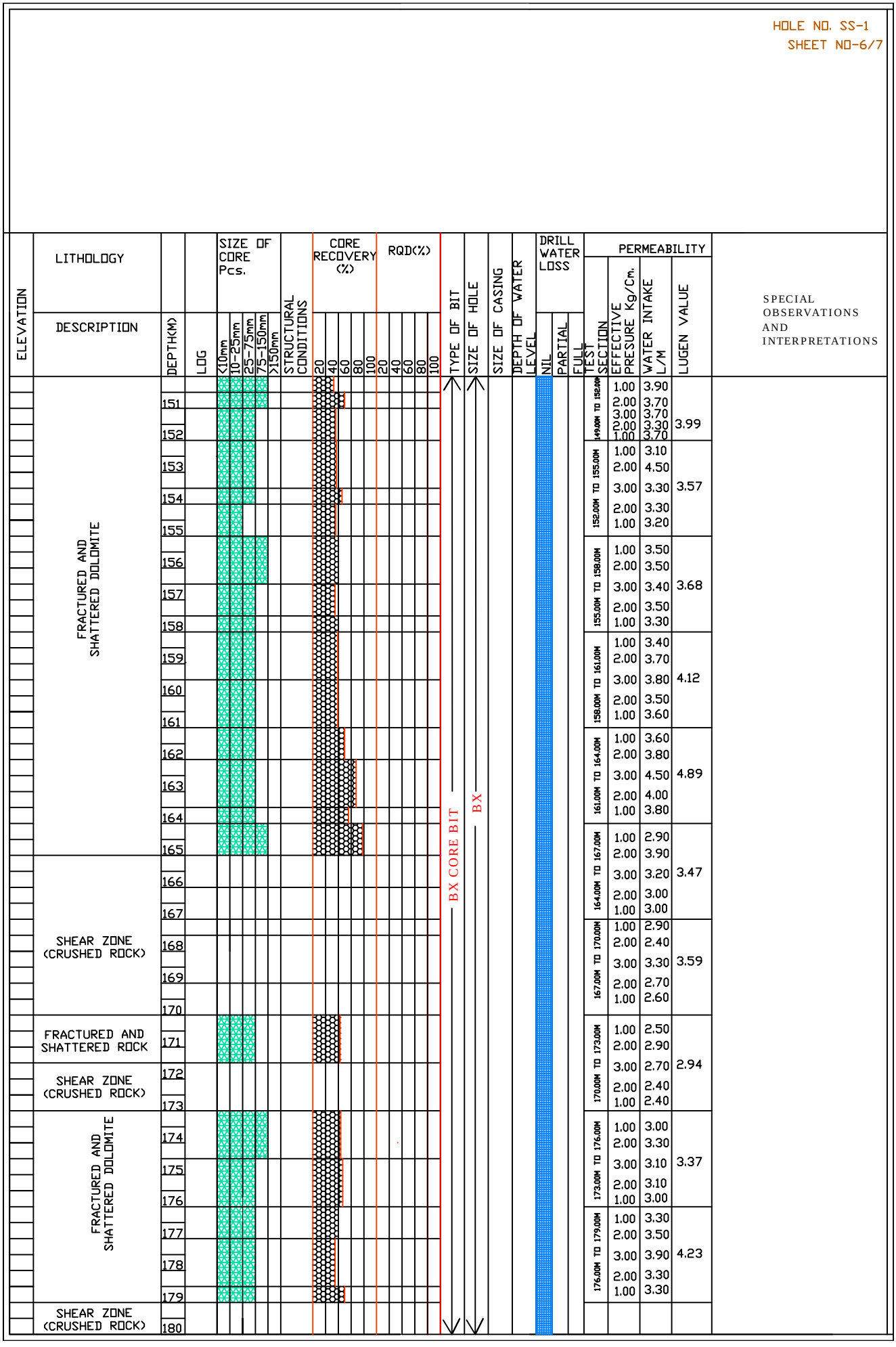
ELEVATION	LITHOLOGY / DESCRIPTION	DEPTH(M)	LOG	SIZE OF CORE Pcs. <10mm	10-25mm	25-75mm	75-150mm	>150mm	STRUCTURAL CONDITIONS	CORE RECOVERY (%) 20 40 60 80 100	RQD(%) 20 40 60 80 100	TYPE OF BIT	SIZE OF HOLE	SIZE OF CASING	DEPTH OF WATER LEVEL	DRILL WATER LOSS NIL	PARTIAL	FULL	PERMEABILITY TEST SECTION	EFFECTIVE PRESURE Kg/Cm.	WATER INTAKE L/M	LUGEN VALUE	SPECIAL OBSERVATIONS AND INTERPRETATIONS
	FRACTURED AND SHATTERED DOLOMITE	61										NMLC	NX	NX									
		62																					
		63																					
		64																					
		65																					
		66																					
		67																					
		68																					
		69																					
		70																					
		71																					
		72																					
		73																					
		74																					
		75																					
		76																					
	SHEAR ZONE (CRUSHED ROCK)	77																					
		78																					
		79																					
		80																					
		81																					
		82																					
		83																					
		84																					
		85																					
		86																					
		87																					
		88																					
		89																					
		90																					

ELEVATION	LITHOLOGY DESCRIPTION	DEPTH(M)	LOG	SIZE OF CORE Pcs. <10mm	10-25mm	25-75mm	75-150mm	>150mm	STRUCTURAL CONDITIONS	CORE RECOVERY (%) 20 40 60 80 100	RQD(%) 20 40 60 80 100	TYPE OF BIT	SIZE OF HOLE	SIZE OF CASING	DEPTH OF WATER LEVEL	DRILL WATER LOSS NIL	PARTIAL	FULL	PERMEABILITY TEST SECTION	EFFECTIVE PRESURE Kg/Cm.	WATER INTAKE L/M	LUGEN VALUE	SPECIAL OBSERVATIONS AND INTERPRETATIONS
	SHEAR ZONE (CRUSHED ROCK)	91																					
		92																					
	FRACTURED AND SHATTERED DOLOMITE	93										NMLC	NX	NX									
		94																					
		95																					
		96																					
		97																					
		98																					
		99																					
		100																					
		101																					
		102																					
		103																					
		104																					
		105																					
		106																					
		107																					
		108																					
		109																					
		110																					
		111																					
		112																					
		113																					
		114																					
		115																					
		116																					
		117										BX CORE BIT	BX	BX					116.00M TO 119.00M	1.00	3.40		
		118																		2.00	3.50		
		119																		3.00	3.30	3.58	
		120																		2.00	3.50		
																				1.00	3.30		

HOLE NO. SS-1
SHEET NO-5/7



HOLE NO. SS-1
SHEET NO-6/7



HOLE NO. SS-1
SHEET NO-7/7

ELEVATION	LITHOLOGY / DESCRIPTION	DEPTH(M)	LOG	SIZE OF CORE Pcs. <10mm	10-25mm	25-75mm	75-150mm	>150mm	STRUCTURAL CONDITIONS	CORE RECOVERY (%) 20 40 60 80 100	RQD(%) 20 40 60 80 100	TYPE OF BIT	SIZE OF HOLE	SIZE OF CASING	DEPTH OF WATER LEVEL	DRILL WATER LOSS NIL	PARTIAL	FULL	PERMEABILITY TEST SECTION	EFFECTIVE PRESURE Kg/Cm.	WATER INTAKE L/M	LUGEN VALUE	SPECIAL OBSERVATIONS AND INTERPRETATIONS
	SHEAR ZONE (CRUSHED ROCK)																						
	FRACTURED AND SHATTERED DOLOMITE	181										BX CORE BIT	BX						179.0 TO 182.0 m	1.00	3.50	4.22	
																				2.00	3.50		
		182																		3.00	3.90		
																				2.00	3.70		
		183																		1.00	3.50		
		183.5																					

ANNEXURE-I

ALTERNATIVE DAM SITE OF WANGCHHU HYDROELECTRIC PROJECT

Geotechnical Note on
Alternative Dam Site of Wangchhu HEP, Bhutan
Based on Reconnoitery Traverses

R. Pitchai Muthu
Director (Geological Survey of India)

The project intends to utilize the tail waters of Tala Hydro-electric Project and the catchments d/s of Tala Dam. Earlier, preliminary investigations were carried out with the layout of Dam site at Baikinza, a 4.4 km long HRT & surface Power House just u/s of the confluence of Piping River with Wangchhu. On techno-economical considerations, the height of the Dam has been reduced from 258 m to 120 m and the Dam site has been shifted u/s by about 7 Km (aerial distance). Type of the Dam has also been changed from rock fill to concrete gravity. In the revised layout, the HRT has got extended by 8 kms making it 12.5 kms long.

On the request of the Addl. General Manager, Corporate Geology Deptt., SJVN Ltd., New Shimla vide his letter no. SJVN/Bhutan/KHEP/WHEP/Exploration Work/2009, 2792-94 dated 18/06/2009, reconnoitery traverses were taken at the proposed alternative Dam site at Akom village on 15/10/2010 in the company of the following officers:

1. Er. M. S. Thakur, Sr. Manager, Infra Design, SJVN, Shimla.
2. Sh. G. S. Pundir, Manger (Geo), NM & JSHEP, Uttrakhand.
3. Er. J.S.Nayyar, Sr. Manager (C), WHEP, Bhutan.
4. Er. Ashok Kumar, Engineer, Infra Design, SJVN, Shimla.
5. Er. Ajit Singh, Engineer (C), WHEP, Bhutan.
6. Er. Tshering, A.E., SJVN (DGPC), WHEP, Bhutan.
7. Er. Ravi Kumar, Engineer Trainee, WHEP, Bhutan.
8. Er. Ramesh Kumar, J.E., WHEP, Bhutan.

Traverses were taken in the area to understand the geological setting of the region and discussions were held with the project engineers on alternative proposals. The Geotechnical Observations and the recommendations are presented here under:

Geological Setting:

Both, old and the new Dam sites fall in the same Geological Domain and are bound by MBT in South and MCT in North, but, the new site is nearer to MCT. The Wangchhu River flows from north-west to south-east in general and it forms several sharp bends. It appears to be controlled by a strong NW-SE trending structural feature,

probably a fault sympathetic to MCT. The meandering of the river appears to be due to several cross faults trending N20°E - S20°W.

The bulk lithology of the Valley constitutes phyllite and quartzite of Buxa Group. Minor bands of dolomite and meta- basalt are also noticed within phyllite. The Wangchhu River flows from NW to NE between two loops located 1.5 km apart. The U/s loop is at 27°49' 00" N - 89°37'40" E and the D/s loop is at 27°48' 42" N- 89°38'20" E. The gorge formed is deep with 40°-50° slope on the right flank and 60°-70° on the left flank. Massive outcrop of closely jointed quartzite is exposed from river bed to a height of over 300m in left flank due to removal of thin overburden after planar slides and erosion. Geological interpretations indicate that quartzite would extend for considerable distance towards north-east. However, its depth persistence in river bed has to be ascertained by drilling. The bedding of quartzite is not clear but appears to be striking NE – SW and dipping at about 30° towards NW.

The quartzite is massive, milky white and closely jointed. A N20°E-S20°W trend (across river) with vertical deep is perceptible for foliation. Foliation joints are the master joints here. A few shears of 30cm – 50 cm width are noticed on the left bank along foliation. These observations were made from the right bank as the left bank was not accessible due to considerable flow in the river. Besides the foliation joints, a set of vertical joints running parallel to the river (NW-SE) and a low dip joint with 15° dip towards SW are noticed.

The right flank is comparatively gentle. The thickness of overburden appears to be in the range of 10m-15m. The observations indicate that the right flank is predominately made up of phyllite with thin bands of quartzite, dolomite and metabasalt. However, the bulk of lithology is phyllite. The rock outcrops in the right flank are few. A quartzite band extending along the river for about 200m is noticed on the right flank at about 80m above the river bed, where right abutment of alternative axis B-B' is proposed (map). It is understood (but not established) that the river Wangchhu follows the lithological contact between the quartzite and phyllite with the former on the left flank and latter on the right with local deviations.

At the D/s loop, the river takes a 90° turn towards left (NE). Massive milky white quartzite is exposed in the vertical section on either banks of the river starting 50m U/s of the bend to a distance beyond the bend for a height of about 300m.

Geotechnical Evaluation:

In the stretch between the two loops extending for about 1.5km, the river course is straight. It forms a narrow deep gorge with massive quartzite exposed all along the left flank in the D/s half. Quartzite is a hard and compact rock suitable for founding and abutting the concrete dam. In the U/s half of the left bank, rock may be available at a shallow depth of about 5m. The river bed is occupied by boulders, cobbles and pebbles. The river may have a drop of about 8-10m between the loops. Along right bank between the loops rock exposures are scanty. A quartzite band exposed on the right flank at about 300m U/s of the D/s loop appears to be in situ. Hence, the dam axis in NE-SW direction connecting this outcrop and the exposed rock in left bank (marked as B-B' in the map) is proposed for detailed study. U/s and D/s of this outcrop, the right bank is covered with debris and scree material.

As the left bank consists massive quartzite for considerable length and height, it would be suitable for butting of the dam and for locating the intake of HRT. The thickness of quartzite and its attitude indicates that the HRT would have the medium of quartzite for considerable length. The right flank is largely occupied by phyllite which is soft and susceptible to weathering compared to quartzite. However, these observations are to be confirmed by mapping of the dam site and sub surface exploration.

Locating the dam within a range of 250m from the D/s bend may not be suitable as energy dissipation would be a problem. Though, the quartzite is hard, it is highly jointed and foliated. Fixing the axis closer to the bend may cause bank erosion and may trigger land slide. It is also interpreted that the NW-SE orientation of the river is due to faults sympathetic to MCT. Hence, the kinks/ bends of the river are probably located at the intersection points of cross faults and the MCT. Avoiding such site for locating the dam is suggested from geological point of view.

Conclusion and Recommendations

1. The proposed dam site is located in the Buxa Group of rocks consisting mainly of quartzite and phyllite. The quartzite is hard & compact and forms massive outcrops along the left flank of the river. The phyllite is relatively soft and has undergone weathering. It occupies right flank at the dam site.
2. The river flows from NW to SE in 1.5 Km long stretch between two loops at the dam site. Orientation of the river appears to be controlled by sympathetic faults of MCT and sinistral shifts in the river course may be due cross faults. Hence, it is opined that the kinks of the river are not suitable for locating the dam.

3. Five no. of observed cross sections between the two loops of the river as marked in the enclosed map may be prepared for study.
4. Geological mapping on 1:5000 scale may be carried out for the 1.5 km stretch of the river and flanks between loops. Geological sections have to be prepared for the five cross-sections as mentioned above.
5. Exploration of the site can be taken up after the study of cross-sections and choosing an optimum one.
6. A detailed report will be submitted separately by the undersigned.

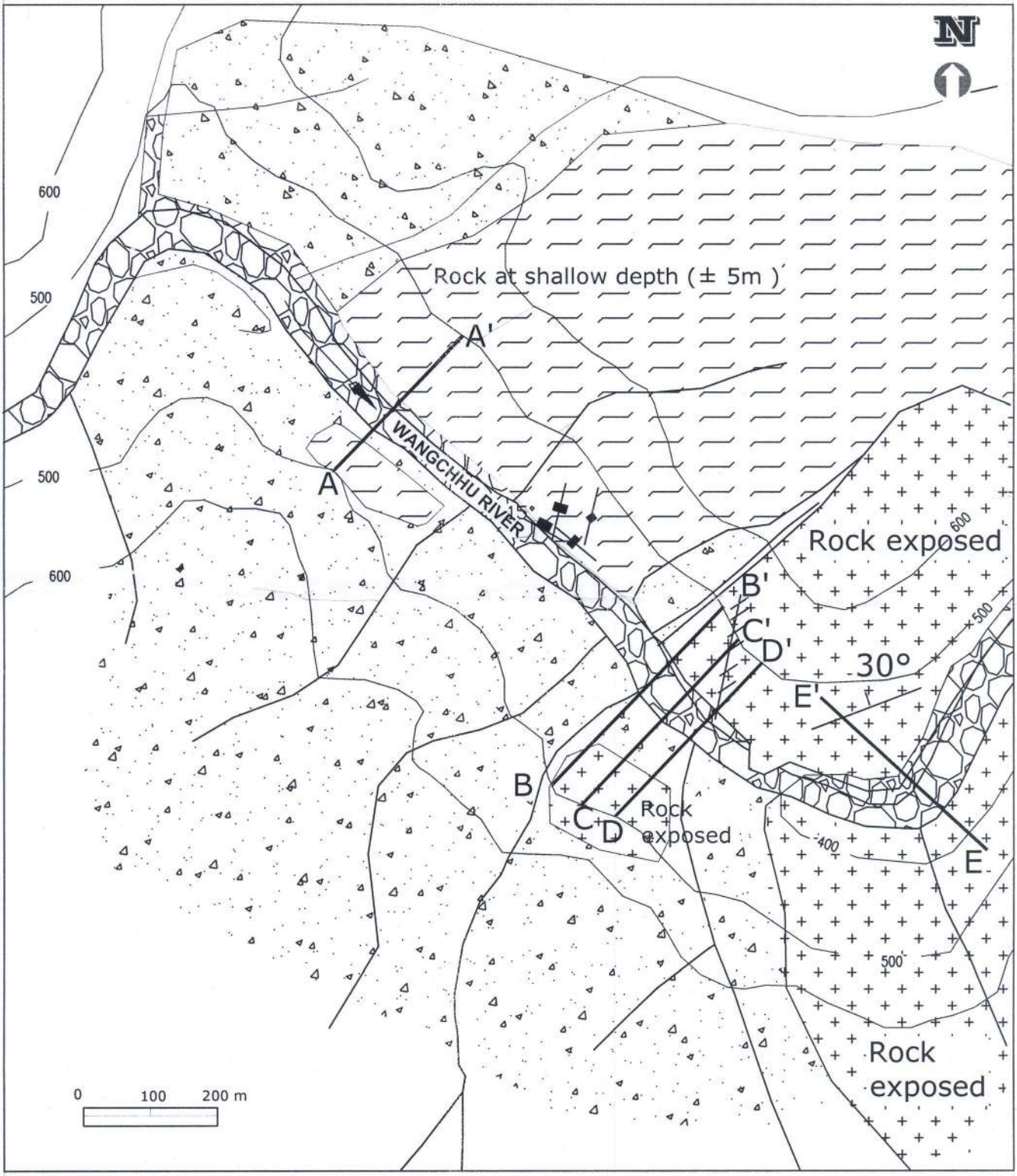
Encl: Tentative geological map of the dam site.

26.10.10

Chennai
Dated: 26.10.2010.

(R. Pitchai Muthu),
Director, GSI.

Tentative Geological Map of the Alternative dam site at Akom for Wangchhu H.E. Project, Bhutan (Based on reconnoitery traverse)



INDEX

- Riverine material mainly Boulders, cobbles and pebbles
- Overburden consisting of boulders, scree, weathered rock (Phyllite, Quartzites etc.) with occasional outcrops
- Moderately weathered rock (mainly quartzies) exposed in patches
- Fairly fresh quartzite exposed
- AA', BB', CC', DD', EE' — Recommended alignments for preparation of X-section
- Shear
- 30° — Bedding
- Vertical joint
- 15° — Inclined joint
- Vertical foliation
- 500 — Contour with value in m

R. Pitchai Muthu
Director, GSI
26.10.2010

ANNEXURE-II

LUGOEN TEST VALUES

Project Wangchu H.E.Project (Bhutan)
Location River bed, right bank
Feature Dam Site
Bore Hole DH-1

Collar Elevation 407.794 m
Total depth of hole : 50 m
Type of drilling : Rotory

Sl. No.	Test Section		Length of test section	Ground water level	Swivel Height	Casing size	Dia of hole	Dia of hole	Water discharge (q)	Gravity Head (h1)	Water pressure at collar (h2)	Water pressure at collar (h2)	Total water head (h)=h1+h2	Lugeon Value
	From	To												
	(m)	(m)	(m)	(m)	(m)		(mm)	(m)	lit/min	(m)	(Kg/cm2)	(m)	(m)	Lt/m/minute
1	15	18	3	2.90	2.90	NX	76.2	0.0762	10.80	5.80	1.00	10	15.80	22.78
	15	18	3	2.90	2.90	NX	76.2	0.0762	11.60	5.80	2.00	20	25.80	14.99
	15	18	3	2.90	2.90	NX	76.2	0.0762	12.40	5.80	3.00	30	35.80	11.55
	15	18	3	2.90	2.90	NX	76.2	0.0762	11.40	5.80	2.00	20	25.80	14.73
	15	18	3	2.90	2.90	NX	76.2	0.0762	10.60	5.80	1.00	10	15.80	22.36
2	18	21	3	3.05	2.45	NX	76.2	0.0762	13.80	5.50	1.00	10	15.50	29.68
	18	21	3	3.05	2.45	NX	76.2	0.0762	14.40	5.50	2.00	20	25.50	18.82
	18	21	3	3.05	2.45	NX	76.2	0.0762	14.90	5.50	3.00	30	35.50	13.99
	18	21	3	3.05	2.45	NX	76.2	0.0762	14.60	5.50	2.00	20	25.50	19.08
	18	21	3	3.05	2.45	NX	76.2	0.0762	14.10	5.50	1.00	10	15.50	30.32
3	21	24	3	3.75	2.65	NX	76.2	0.0762	14.80	6.40	1.00	10	16.40	30.08
	21	24	3	3.75	2.65	NX	76.2	0.0762	15.10	6.40	2.00	20	26.40	19.07
	21	24	3	3.75	2.65	NX	76.2	0.0762	15.60	6.40	3.00	30	36.40	14.29
	21	24	3	3.75	2.65	NX	76.2	0.0762	15.30	6.40	2.00	20	26.40	19.32
	21	24	3	3.75	2.65	NX	76.2	0.0762	15.10	6.40	1.00	10	16.40	30.69
4	24	27	3	4.10	2.35	NX	76.2	0.0762	13.90	6.45	1.00	10	16.45	28.17
	24	27	3	4.10	2.35	NX	76.2	0.0762	14.40	6.45	2.00	20	26.45	18.15
	24	27	3	4.10	2.35	NX	76.2	0.0762	14.90	6.45	3.00	30	36.45	13.63
	24	27	3	4.10	2.35	NX	76.2	0.0762	14.70	6.45	2.00	20	26.45	18.53
	24	27	3	4.10	2.35	NX	76.2	0.0762	14.50	6.45	1.00	10	16.45	29.38
5	27	30	3	2.96	2.25	NX	76.2	0.0762	12.80	5.21	1.00	10	15.21	28.05
	27	30	3	2.96	2.25	NX	76.2	0.0762	13.30	5.21	2.00	20	25.21	17.59
	27	30	3	2.96	2.25	NX	76.2	0.0762	14.10	5.21	3.00	30	35.21	13.35
	27	30	3	2.96	2.25	NX	76.2	0.0762	13.40	5.21	2.00	20	25.21	17.72
	27	30	3	2.96	2.25	NX	76.2	0.0762	12.60	5.21	1.00	10	15.21	27.61
6	30	33	3	3.20	2.92	NX	76.2	0.0762	16.00	6.12	1.00	10	16.12	33.09
	30	33	3	3.20	2.92	NX	76.2	0.0762	16.70	6.12	2.00	20	26.12	21.31
	30	33	3	3.00	2.92	NX	76.2	0.0762	17.80	5.92	3.00	30	35.92	16.52
	30	33	3	3.20	2.92	NX	76.2	0.0762	16.50	6.12	2.00	20	26.12	21.06
	30	33	3	3.20	2.92	NX	76.2	0.0762	15.70	6.12	1.00	10	16.12	32.46
7	33	36	3	3.80	2.35	NX	76.2	0.0762	14.40	6.15	1.00	10	16.15	29.72
	33	36	3	3.80	2.35	NX	76.2	0.0762	14.50	6.15	2.00	20	26.15	18.48
	33	36	3	3.80	2.35	NX	76.2	0.0762	15.10	6.15	3.00	30	36.15	13.92
	33	36	3	3.80	2.35	NX	76.2	0.0762	14.70	6.15	2.00	20	26.15	18.74
	33	36	3	3.80	2.35	NX	76.2	0.0762	14.20	6.15	1.00	10	16.15	29.31
8	36	39	3	3.70	2.25	NX	76.2	0.0762	15.70	5.95	1.00	10	15.95	32.81
	36	39	3	3.70	2.25	NX	76.2	0.0762	16.10	5.95	2.00	20	25.95	20.68
	36	39	3	3.70	2.25	NX	76.2	0.0762	16.40	5.95	3.00	30	35.95	15.21
	36	39	3	3.70	2.25	NX	76.2	0.0762	16.30	5.95	2.00	20	25.95	20.94
	36	39	3	3.70	2.25	NX	76.2	0.0762	15.90	5.95	1.00	10	15.95	33.23
9	39	42	3	3.95	3.05	NX	76.2	0.0762	15.50	7.00	1.00	10	17.00	30.39
	39	42	3	3.95	3.05	NX	76.2	0.0762	16.50	7.00	2.00	20	27.00	20.37
	39	42	3	3.95	3.05	NX	76.2	0.0762	17.30	7.00	3.00	30	37.00	15.59
	39	42	3	3.95	3.05	NX	76.2	0.0762	16.20	7.00	2.00	20	27.00	20.00
	39	42	3	3.95	3.05	NX	76.2	0.0762	15.50	7.00	1.00	10	17.00	30.39
10	42	45	3	3.65	2.90	NX	76.2	0.0762	14.10	6.55	1.00	10	16.55	28.40
	42	45	3	3.65	2.90	NX	76.2	0.0762	14.50	6.55	2.00	20	26.55	18.20
	42	45	3	3.65	2.90	NX	76.2	0.0762	15.50	6.55	3.00	30	36.55	14.14
	42	45	3	3.65	2.90	NX	76.2	0.0762	14.30	6.55	2.00	20	26.55	17.95
	42	45	3	3.65	2.90	NX	76.2	0.0762	13.90	6.55	1.00	10	16.55	28.00
11	45	48	3	4.05	2.65	NX	76.2	0.0762	13.90	6.70	1.00	10	16.70	27.74
	45	48	3	4.05	2.65	NX	76.2	0.0762	14.40	6.70	2.00	20	26.70	17.98
	45	48	3	4.05	2.65	NX	76.2	0.0762	15.10	6.70	3.00	30	36.70	13.71
	45	48	3	4.05	2.65	NX	76.2	0.0762	14.50	6.70	2.00	20	26.70	18.10
	45	48	3	4.05	2.65	NX	76.2	0.0762	14.40	6.70	1.00	10	16.70	28.74

Project Wangchu Hydro Project
Location River Bed, center of river
Feature Dam Axis
Bore Hole DH-2

Collar Elevation : 403.199 m
Total depth of hole : 80.0 m
Type of drilling Rotory

Sl.No.	Test Section		Length of test section	Ground water level	Swivel Height	Casing size	Dia of hole	Dia of hole	Water discharge (q)	Water discharge (q)	Gravity Head(h1)	Water pressure at collar(h2)	Water pressure at collar(h2)	Total water head (h)=h1+h	Lugeon Value
	From	To													
	(m)	(m)	(m)	(m)	(m)		(mm)	(m)	lit/min	m3/sec	(m)	(Kg/cm2)	(m)	(m)	Lt/m/minute
1	39	42	3	1.76	2.90	BX	60.3	0.0603	11.60	0.0002	4.66	1.00	10	14.66	26.38
	39	42	3	1.76	2.90	BX	60.3	0.0603	12.10	0.0002	4.66	2.00	20	24.66	16.36
	39	42	3	1.76	2.90	BX	60.3	0.0603	12.90	0.0002	4.66	3.00	30	34.66	12.41
	39	42	3	1.76	2.90	BX	60.3	0.0603	12.40	0.0002	4.66	2.00	20	24.66	16.76
	39	42	3	1.76	2.90	BX	60.3	0.0603	11.90	0.0002	4.66	1.00	10	14.66	27.06
2	42	45	3	1.70	2.65	BX	60.3	0.0603	12.20	0.0002	4.35	1.00	10	14.35	28.34
	42	45	3	1.70	2.65	BX	60.3	0.0603	12.50	0.0002	4.35	2.00	20	24.35	17.11
	42	45	3	1.70	2.65	BX	60.3	0.0603	13.30	0.0002	4.35	3.00	30	34.35	12.91
	42	45	3	1.70	2.65	BX	60.3	0.0603	12.80	0.0002	4.35	2.00	20	24.35	17.52
	42	45	3	1.70	2.65	BX	60.3	0.0603	12.00	0.0002	4.35	1.00	10	14.35	27.87
3	45	48	3	1.75	2.45	NX	76.2	0.0762	12.30	0.0002	4.20	1.00	10	14.20	28.87
	45	48	3	1.75	2.45	NX	76.2	0.0762	13.00	0.0002	4.20	2.00	20	24.20	17.91
	45	48	3	1.75	2.45	NX	76.2	0.0762	13.60	0.0002	4.20	3.00	30	34.20	13.26
	45	48	3	1.75	2.45	NX	76.2	0.0762	13.10	0.0002	4.20	2.00	20	24.20	18.04
	45	48	3	1.75	2.45	NX	76.2	0.0762	12.40	0.0002	4.20	1.00	10	14.20	29.11
4	48	51	3	1.75	2.30	BX	60.3	0.0603	12.90	0.0002	4.05	1.00	10	14.05	30.60
	48	51	3	1.75	2.30	BX	60.3	0.0603	13.30	0.0002	4.05	2.00	20	24.05	18.43
	48	51	3	1.75	2.30	BX	60.3	0.0603	14.20	0.0002	4.05	3.00	30	34.05	13.90
	48	51	3	1.75	2.30	BX	60.3	0.0603	13.20	0.0002	4.05	2.00	20	24.05	18.30
	48	51	3	1.75	2.30	BX	60.3	0.0603	12.60	0.0002	4.05	1.00	10	14.05	29.89
5	51	54	3	1.75	2.15	BX	60.3	0.0603	13.70	0.0002	3.90	1.00	10	13.90	32.85
	51	54	3	1.75	2.15	BX	60.3	0.0603	14.20	0.0002	3.90	2.00	20	23.90	19.80
	51	54	3	1.75	2.15	BX	60.3	0.0603	14.90	0.0002	3.90	3.00	30	33.90	14.65
	51	54	3	1.75	2.15	BX	60.3	0.0603	14.50	0.0002	3.90	2.00	20	23.90	20.22
	51	54	3	1.75	2.15	BX	60.3	0.0603	14.00	0.0002	3.90	1.00	10	13.90	33.57
6	54	57	3	1.75	1.90	BX	60.3	0.0603	16.00	0.0003	3.65	1.00	10	13.65	39.07
	54	57	3	1.75	1.90	BX	60.3	0.0603	9.00	0.0002	3.65	2.00	20	23.65	12.68
	54	57	3	1.75	1.90	BX	60.3	0.0603	8.50	0.0001	3.65	3.00	30	33.65	8.42
	54	57	3	1.75	1.90	BX	60.3	0.0603	5.00	0.0001	3.65	2.00	20	23.65	7.05
	54	57	3	1.75	1.90	BX	60.3	0.0603	2.50	0.0000	3.65	1.00	10	13.65	6.11
7	57	60	3	1.80	2.65	BX	60.3	0.0603	16.00	0.0003	4.45	1.00	10	14.45	36.91
	57	60	3	1.80	2.65	BX	60.3	0.0603	14.50	0.0002	4.45	2.00	20	24.45	19.77
	57	60	3	1.80	2.65	BX	60.3	0.0603	11.50	0.0002	4.45	3.00	30	34.45	11.13
	57	60	3	1.80	2.65	BX	60.3	0.0603	6.80	0.0001	4.45	2.00	20	24.45	9.27
	57	60	3	1.80	2.65	BX	60.3	0.0603	4.70	0.0001	4.45	1.00	10	14.45	10.84
8	60	63	3	1.80	2.15	BX	60.3	0.0603	13.50	0.0002	3.95	1.00	10	13.95	32.26
	60	63	3	1.80	2.15	BX	60.3	0.0603	11.50	0.0002	3.95	2.00	20	23.95	16.01
	60	63	3	1.80	2.15	BX	60.3	0.0603	11.50	0.0002	3.95	3.00	30	33.95	11.29
	60	63	3	1.80	2.15	BX	60.3	0.0603	6.50	0.0001	3.95	2.00	20	23.95	9.05
	60	63	3	1.80	2.15	BX	60.3	0.0603	6.30	0.0001	3.95	1.00	10	13.95	15.05
9	63	66	3	1.85	2.95	NX	76.2	0.0762	11.50	0.0002	4.80	1.00	10	14.80	25.90
	63	66	3	1.85	2.95	NX	76.2	0.0762	12.00	0.0002	4.80	2.00	20	24.80	16.13
	63	66	3	1.85	2.95	NX	76.2	0.0762	10.50	0.0002	4.80	3.00	30	34.80	10.06
	63	66	3	1.85	2.95	NX	76.2	0.0762	7.20	0.0001	4.80	2.00	20	24.80	9.68
	63	66	3	1.85	2.95	NX	76.2	0.0762	4.10	0.0001	4.80	1.00	10	14.80	9.23
10	66	69	3	1.85	2.10	BX	60.3	0.0603	13.80	0.0002	3.95	1.00	10	13.95	32.97
	66	69	3	1.85	2.10	BX	60.3	0.0603	13.30	0.0002	3.95	2.00	20	23.95	18.51
	66	69	3	1.85	2.10	BX	60.3	0.0603	12.00	0.0002	3.95	3.00	30	33.95	11.78
	66	69	3	1.85	2.10	BX	60.3	0.0603	7.80	0.0001	3.95	2.00	20	23.95	10.86
	66	69	3	1.85	2.10	BX	60.3	0.0603	5.50	0.0001	3.95	1.00	10	13.95	13.14
11	69	72	3	1.85	2.90	BX	60.3	0.0603	11.50	0.0002	4.75	1.00	10	14.75	25.99
	69	72	3	1.85	2.90	BX	60.3	0.0603	12.00	0.0002	4.75	2.00	20	24.75	16.16
	69	72	3	1.85	2.90	BX	60.3	0.0603	10.50	0.0002	4.75	3.00	30	34.75	10.07
	69	72	3	1.85	2.90	BX	60.3	0.0603	7.20	0.0001	4.75	2.00	20	24.75	9.70
	69	72	3	1.85	2.90	BX	60.3	0.0603	4.10	0.0001	4.75	1.00	10	14.75	9.27
12	72	75	3	1.90	2.45	BX	60.3	0.0603	10.80	0.0002	4.35	1.00	10	14.35	25.09
	72	75	3	1.90	2.45	BX	60.3	0.0603	10.00	0.0002	4.35	2.00	20	24.35	13.69
	72	75	3	1.90	2.45	BX	60.3	0.0603	10.50	0.0002	4.35	3.00	30	34.35	10.19
	72	75	3	1.90	2.45	BX	60.3	0.0603	7.70	0.0001	4.35	2.00	20	24.35	10.54
	72	75	3	1.90	2.45	BX	60.3	0.0603	5.40	0.0001	4.35	1.00	10	14.35	12.54
13	75	78	3	2.05	1.90	BX	60.3	0.0603	11.00	0.0002	3.95	1.00	10	13.95	26.28
	75	78	3	2.05	1.90	BX	60.3	0.0603	9.60	0.0002	3.95	2.00	20	23.95	13.36
	75	78	3	2.05	1.90	BX	60.3	0.0603	9.50	0.0002	3.95	3.00	30	33.95	9.33
	75	78	3	2.05	1.90	BX	60.3	0.0603	8.00	0.0001	3.95	2.00	20	23.95	11.13
	75	78	3	2.05	1.90	BX	60.3	0.0603	12.80	0.0002	3.95	1.00	10	13.95	30.59

Project Wangchu Hydro Project
Location River bed, left bank
Feature Dam axis
Bore Hole DH-3

Collar Elevation : 404.483 m
Total depth of hole : 80.0 m
Type of drilling Rotory

Sl.No.	Test Section		Length of test section	Ground water level	Swivel Height	Casing size	Dia of hole	Dia of hole	Water discharge (q)	Gravity Head (h1)	Water pressure at collar (h2)	Water pressure at collar (h2)	Total water head (h)=h1+h2	Lugeon Value
	From	To												
	(m)	(m)	(m)	(m)	(m)		(mm)	(m)	lit/min	(m)	(Kg/cm2)	(m)	(m)	Lt/m/minute
1	27	30	3	0.35	2.90	BX	60.3	0.0603	10.80	3.25	1.00	10	13.25	27.17
	27	30	3	0.35	2.90	BX	60.3	0.0603	10.90	3.25	2.00	20	23.25	15.63
	27	30	3	0.35	2.90	BX	60.3	0.0603	11.50	3.25	3.00	30	33.25	11.53
	27	30	3	0.35	2.90	BX	60.3	0.0603	11.20	3.25	2.00	20	23.25	16.06
	27	30	3	0.35	2.90	BX	60.3	0.0603	10.60	3.25	1.00	10	13.25	26.67
2	30	33	3	0.40	3.10	BX	60.3	0.0603	11.20	3.50	1.00	10	13.50	27.65
	30	33	3	0.40	3.10	BX	60.3	0.0603	11.50	3.50	2.00	20	23.50	16.31
	30	33	3	0.40	3.10	BX	60.3	0.0603	12.20	3.50	3.00	30	33.50	12.14
	30	33	3	0.40	3.10	BX	60.3	0.0603	11.40	3.50	2.00	20	23.50	16.17
	30	33	3	0.40	3.10	BX	60.3	0.0603	5.00	3.50	1.00	10	13.50	12.35
3	33	36	3	0.50	2.90	NX	76.2	0.0762	11.70	3.40	1.00	10	13.40	29.10
	33	36	3	0.50	2.90	NX	76.2	0.0762	12.20	3.40	2.00	20	23.40	17.38
	33	36	3	0.50	2.90	NX	76.2	0.0762	12.90	3.40	3.00	30	33.40	12.87
	33	36	3	0.50	2.90	NX	76.2	0.0762	12.60	3.40	2.00	20	23.40	17.95
	33	36	3	0.50	2.90	NX	76.2	0.0762	12.00	3.40	1.00	10	13.40	29.85

Project Wangchu H.E.Project (Bhutan)
Location Dam Site
Feature Bucket area
Bore Hole DH-4

Collar Elevation : 403.085 m
Total depth of hole : 50.0 m
Type of drilling Rotory

Sl.No.	Test Section		Length of test section	Ground water level	Swivel Height	Casing size	Dia of hole	Dia of hole	Water discharge (q)	Gravity Head (h1)	Water pressure at collar (h2)	Water pressure at collar (h2)	Total water head (h)=h1+h2	Lugeon Value
	From	To												
	(m)	(m)	(m)	(m)	(m)		(mm)	(m)	lit/min	(m)	(Kg/cm2)	(m)	(m)	Lt/m/minute
1	27	30	3	2.30	2.90	NX	76.2	0.0762	12.20	5.20	1.00	10	15.20	26.75
	27	30	3	2.30	2.90	NX	76.2	0.0762	12.50	5.20	2.00	20	25.20	16.53
	27	30	3	2.30	2.90	NX	76.2	0.0762	13.20	5.20	3.00	30	35.20	12.50
	27	30	3	2.30	2.90	NX	76.2	0.0762	12.80	5.20	2.00	20	25.20	16.93
	27	30	3	2.30	2.90	NX	76.2	0.0762	12.30	5.20	1.00	10	15.20	26.97
2	30	33	3	2.90	2.65	NX	76.2	0.0762	12.90	5.55	1.00	10	15.55	27.65
	30	33	3	2.90	2.65	NX	76.2	0.0762	13.40	5.55	2.00	20	25.55	17.48
	30	33	3	2.90	2.65	NX	76.2	0.0762	14.00	5.55	3.00	30	35.55	13.13
	30	33	3	2.90	2.65	NX	76.2	0.0762	13.10	5.55	2.00	20	25.55	17.09
	30	33	3	2.90	2.65	NX	76.2	0.0762	12.60	5.55	1.00	10	15.55	27.01
3	33	36	3	3.70	2.45	NX	76.2	0.0762	12.40	6.15	1.00	10	16.15	25.59
	33	36	3	3.70	2.45	NX	76.2	0.0762	12.90	6.15	2.00	20	26.15	16.44
	33	36	3	3.70	2.45	NX	76.2	0.0762	13.50	6.15	3.00	30	36.15	12.45
	33	36	3	3.70	2.45	NX	76.2	0.0762	13.20	6.15	2.00	20	26.15	16.83
	33	36	3	3.70	2.45	NX	76.2	0.0762	12.30	6.15	1.00	10	16.15	25.39
4	36	39	3	3.85	2.35	NX	76.2	0.0762	13.80	6.20	1.00	10	16.20	28.40
	36	39	3	3.85	2.35	NX	76.2	0.0762	14.10	6.20	2.00	20	26.20	17.94
	36	39	3	3.85	2.35	NX	76.2	0.0762	14.80	6.20	3.00	30	36.20	13.63
	36	39	3	3.85	2.35	NX	76.2	0.0762	14.40	6.20	2.00	20	26.20	18.32
	36	39	3	3.85	2.35	NX	76.2	0.0762	14.00	6.20	1.00	10	16.20	28.81
5	39	42	3	3.05	2.25	NX	76.2	0.0762	14.20	5.30	1.00	10	15.30	30.94
	39	42	3	3.05	2.25	NX	76.2	0.0762	14.50	5.30	2.00	20	25.30	19.10
	39	42	3	3.05	2.25	NX	76.2	0.0762	15.20	5.30	3.00	30	35.30	14.35
	39	42	3	3.05	2.25	NX	76.2	0.0762	14.80	5.30	2.00	20	25.30	19.50
	39	42	3	3.05	2.25	NX	76.2	0.0762	14.30	5.30	1.00	10	15.30	31.15
6	42	45	3	3.20	2.25	NX	76.2	0.0762	14.40	5.45	1.00	10	15.45	31.07
	42	45	3	3.20	2.25	NX	76.2	0.0762	15.00	5.45	2.00	20	25.45	19.65
	42	45	3	3.20	2.25	NX	76.2	0.0762	15.70	5.45	3.00	30	35.45	14.76
	42	45	3	3.20	2.25	NX	76.2	0.0762	15.20	5.45	2.00	20	25.45	19.91
	42	45	3	3.20	2.25	NX	76.2	0.0762	14.20	5.45	1.00	10	15.45	30.64
7	45	48	3	3.65	2.10	NX	76.2	0.0762	14.70	5.75	1.00	10	15.75	31.11
	45	48	3	3.65	2.10	NX	76.2	0.0762	15.40	5.75	2.00	20	25.75	19.94
	45	48	3	3.65	2.10	NX	76.2	0.0762	16.10	5.75	3.00	30	35.75	15.01
	45	48	3	3.65	2.10	NX	76.2	0.0762	15.60	5.75	2.00	20	25.75	20.19
	45	48	3	3.65	2.10	NX	76.2	0.0762	14.40	5.75	1.00	10	15.75	30.48

Project Wangchu H.E.Project (Bhutan)
Location Dam Site
Feature Plunge pool area
Bore Hole DH-5

Collar Elevation : 402.210 m
Total depth of hole : 50.0 m
Type of drilling : Rotory

Sl. No.	Test Section		Length of test section	Ground water level	Swivel Height	Casing size	Dia of hole	Dia of hole	Water discharge (q)	Gravity Head (h1)	Water pressure at collar (h2)	Water pressure at collar (h2)	Total water head (h)=h1+h2	Lugeon Value
	From	To												
	(m)	(m)	(m)	(m)	(m)		(mm)	(m)	lit/min	(m)	(Kg/cm2)	(m)	(m)	Lt/m/minute
1	27	30	3	3.05	2.80	NX	76.2	0.0762	10.60	5.85	1.00	10	15.85	22.29
	27	30	3	3.05	2.80	NX	76.2	0.0762	11.30	5.85	2.00	20	25.85	14.57
	27	30	3	3.05	2.80	NX	76.2	0.0762	12.50	5.85	3.00	30	35.85	11.62
	27	30	3	3.05	2.80	NX	76.2	0.0762	11.00	5.85	2.00	20	25.85	14.18
	27	30	3	3.05	2.80	NX	76.2	0.0762	10.50	5.85	1.00	10	15.85	22.08
2	30	33	3	2.90	2.65	NX	76.2	0.0762	11.30	5.55	1.00	10	15.55	24.22
	30	33	3	2.90	2.65	NX	76.2	0.0762	12.40	5.55	2.00	20	25.55	16.18
	30	33	3	2.90	2.65	NX	76.2	0.0762	13.80	5.55	3.00	30	35.55	12.94
	30	33	3	2.90	2.65	NX	76.2	0.0762	12.90	5.55	2.00	20	25.55	16.83
	30	33	3	2.90	2.65	NX	76.2	0.0762	10.80	5.55	1.00	10	15.55	23.15
3	33	36	3	2.85	2.45	NX	76.2	0.0762	11.60	5.30	1.00	10	15.30	25.27
	33	36	3	2.85	2.45	NX	76.2	0.0762	12.10	5.30	2.00	20	25.30	15.94
	33	36	3	2.85	2.45	NX	76.2	0.0762	13.20	5.30	3.00	30	35.30	12.46
	33	36	3	2.85	2.45	NX	76.2	0.0762	12.20	5.30	2.00	20	25.30	16.07
	33	36	3	2.85	2.45	NX	76.2	0.0762	11.80	5.30	1.00	10	15.30	25.71
4	36	39	3	3.10	2.35	NX	76.2	0.0762	12.30	5.45	1.00	10	15.45	26.54
	36	39	3	3.10	2.35	NX	76.2	0.0762	13.00	5.45	2.00	20	25.45	17.03
	36	39	3	3.10	2.35	NX	76.2	0.0762	13.70	5.45	3.00	30	35.45	12.88
	36	39	3	3.10	2.35	NX	76.2	0.0762	12.50	5.45	2.00	20	25.45	16.37
	36	39	3	3.10	2.35	NX	76.2	0.0762	12.30	5.45	1.00	10	15.45	26.54
5	39	42	3	3.05	2.25	NX	76.2	0.0762	12.70	5.30	1.00	10	15.30	27.67
	39	42	3	3.05	2.25	NX	76.2	0.0762	13.30	5.30	2.00	20	25.30	17.52
	39	42	3	3.05	2.25	NX	76.2	0.0762	13.90	5.30	3.00	30	35.30	13.13
	39	42	3	3.05	2.25	NX	76.2	0.0762	13.20	5.30	2.00	20	25.30	17.39
	39	42	3	3.05	2.25	NX	76.2	0.0762	12.80	5.30	1.00	10	15.30	27.89
6	42	45	3	3.20	2.15	NX	76.2	0.0762	14.00	5.35	1.00	10	15.35	30.40
	42	45	3	3.20	2.15	NX	76.2	0.0762	14.50	5.35	2.00	20	25.35	19.07
	42	45	3	3.00	2.15	NX	76.2	0.0762	15.50	5.15	3.00	30	35.15	14.70
	42	45	3	3.20	2.15	NX	76.2	0.0762	15.00	5.35	2.00	20	25.35	19.72
	42	45	3	3.20	2.15	NX	76.2	0.0762	14.40	5.35	1.00	10	15.35	31.27
7	45	48	3	3.80	2.10	NX	76.2	0.0762	14.80	5.90	1.00	10	15.90	31.03
	45	48	3	3.80	2.10	NX	76.2	0.0762	15.50	5.90	2.00	20	25.90	19.95
	45	48	3	3.80	2.10	NX	76.2	0.0762	16.10	5.90	3.00	30	35.90	14.95
	45	48	3	3.80	2.10	NX	76.2	0.0762	15.40	5.90	2.00	20	25.90	19.82
	45	48	3	3.80	2.10	NX	76.2	0.0762	14.80	5.90	1.00	10	15.90	31.03

Project Name: WANGCHU HEP, BHUTAN

Water Pressure Test in bed rock

Drill Hole No.: DH-6 | **Coordinates:**

Location: Upstream coffer dam | **Collar Elevation:**

Inclination: Vertical | **Total Depth:** 50 m

Test Number	Depth of Packer (mts)		Test Section (in mts)	Water Table (Depth in mts)	Height of water swievel (H1) from NSL (in mts)	Height from NSL upto water level (H2) (in mts)	Applied Pressure (P0) in Manometer (in kg/cm2)	Pressure of water Column (P1=H1/10+H2/10) in kg/cm2	Effective Pressure at Packer (P=P0+P1)	Duration of Test (in min)	Average Water Intake (in lits)	Water Intake (Q) in Lit/min/m	Lugeon =Qx10/P
	Upper	Lower											
1	21	24	3	0	2.15	0	1	0.2	1.2	5.0	45.0	3.0	24.7
	21	24	3	0	2.15	0	2	0.2	2.2	5.0	35.0	2.3	10.5
	21	24	3	0	2.15	0	3	0.2	3.2	5.0	60.0	4.0	12.4
	21	24	3	0	2.15	0	2	0.2	2.2	5.0	35.0	2.3	10.5
	21	24	3	0	2.15	0	1	0.2	1.2	5.0	30.0	2.0	16.5
2	24	27	3	0	1.9	0	1	0.2	1.2	5.0	55.0	3.7	30.8
	24	27	3	0	1.9	0	2	0.2	2.2	5.0	65.0	4.3	19.8
	24	27	3	0	1.9	0	3	0.2	3.2	5.0	75.0	5.0	15.7
	24	27	3	0	1.9	0	2	0.2	2.2	5.0	45.0	3.0	13.7
	24	27	3	0	1.9	0	1	0.2	1.2	5.0	40.0	2.7	22.4
3	27	30	3	0	2.65	0	1	0.3	1.3	5.0	45.0	3.0	23.7
	27	30	3	0	2.65	0	2	0.3	2.3	5.0	55.0	3.7	16.2
	27	30	3	0	2.65	0	3	0.3	3.3	5.0	75.0	5.0	15.3
	27	30	3	0	2.65	0	2	0.3	2.3	5.0	40.0	2.7	11.8
	27	30	3	0	2.65	0	1	0.3	1.3	5.0	40.0	2.7	21.1
4	30	33	3	0	2.1	0	1	0.2	1.2	5.0	70.0	4.7	38.6
	30	33	3	0	2.1	0	2	0.2	2.2	5.0	60.0	4.0	18.1
	30	33	3	0	2.1	0	3	0.2	3.2	5.0	80.0	5.3	16.6
	30	33	3	0	2.1	0	2	0.2	2.2	5.0	50.0	3.3	15.1
	30	33	3	0	2.1	0	1	0.2	1.2	5.0	50.0	3.3	27.5
5	33	36	3	0	2.35	0	1	0.2	1.2	5.0	55.0	3.7	29.7
	33	36	3	0	2.35	0	2	0.2	2.2	5.0	50.0	3.3	14.9
	33	36	3	0	2.35	0	3	0.2	3.2	5.0	80.0	5.3	16.5
	33	36	3	0	2.35	0	2	0.2	2.2	5.0	50.0	3.3	14.9
	33	36	3	0	2.35	0	1	0.2	1.2	5.0	40.0	2.7	21.6
6	36	39	3	0	2.9	0	1	0.3	1.3	5.0	50.0	3.3	25.8
	36	39	3	0	2.9	0	2	0.3	2.3	5.0	65.0	4.3	18.9
	36	39	3	0	2.9	0	3	0.3	3.3	5.0	75.0	5.0	15.2
	36	39	3	0	2.9	0	2	0.3	2.3	5.0	50.0	3.3	14.6
	36	39	3	0	2.9	0	1	0.3	1.3	5.0	45.0	3.0	23.3
7	39	42	3	0	2.65	0	1	0.3	1.3	5.0	60.0	4.0	31.6
	39	42	3	0	2.65	0	2	0.3	2.3	5.0	65.0	4.3	19.1
	39	42	3	0	2.65	0	3	0.3	3.3	5.0	85.0	5.7	17.4
	39	42	3	0	2.65	0	2	0.3	2.3	5.0	60.0	4.0	17.7
	39	42	3	0	2.65	0	1	0.3	1.3	5.0	45.0	3.0	23.7
8	42	45	3	0	2.1	0	1	0.2	1.2	5.0	45.0	3.0	24.8
	42	45	3	0	2.1	0	2	0.2	2.2	5.0	50.0	3.3	15.1
	42	45	3	0	2.1	0	3	0.2	3.2	5.0	70.0	4.7	14.5
	42	45	3	0	2.1	0	2	0.2	2.2	5.0	55.0	3.7	16.6
	42	45	3	0	2.1	0	1	0.2	1.2	5.0	40.0	2.7	22
9	45	48	3	0	2.9	0	1	0.3	1.3	5.0	45.0	3.0	23.3
	45	48	3	0	2.9	0	2	0.3	2.3	5.0	55.0	3.7	16
	45	48	3	0	2.9	0	3	0.3	3.3	5.0	80.0	5.3	16.2
	45	48	3	0	2.9	0	2	0.3	2.3	5.0	50.0	3.3	14.6
	45	48	3	0	2.9	0	1	0.3	1.3	5.0	45.0	3.0	23.3
10	47	50	3	0	3.1	0	1	0.3	1.3	5.0	50.0	3.3	25.4
	47	50	3	0	3.1	0	2	0.3	2.3	5.0	40.0	2.7	11.5
	47	50	3	0	3.1	0	3	0.3	3.3	5.0	75.0	5.0	15.1
	47	50	3	0	3.1	0	2	0.3	2.3	5.0	55.0	3.7	15.9
	47	50	3	0	3.1	0	1	0.3	1.3	5.0	45.0	3.0	22.9

Project Name: WANGCHU HEP, BHUTAN													
Drill Hole No.: DH-7								**Coordinates:**					
Location: Dam axis, left bank top								**Collar Elevation:** 506.018 m					
Inclination: Vertical								**Total Depth:** 140.0 m					
Test Number	Depth of Packer (mts)		Test Section (in mts)	Water Table (Depth in mts)	Height of water swievel (H1) from NSL (in mts)	Height from NSL upto water level (H2) (in mts)	Applied Pressure (P0) (in Manometer kg/cm2)	Pressure of water Column (P1=H1/10+H2/10) in kg/cm2	Effective Pressure at Packer (P=P0+P1)	Duration of Test (in min)	Average Water Intake (in lits)	Water Intake (Q) in Lit/min/m	Lugeon =Qx10/P
	Upper	Lower											
1	3	6	3	0	2.1	0	1	0.21	1.21	5.00	22.50	1.50	12.4
	3	6	3	0	2.1	0	2	0.21	2.21	5.00	25.00	1.67	7.54
	3	6	3	0	2.1	0	3	0.21	3.21	5.00	32.50	2.17	6.75
	3	6	3	0	2.1	0	2	0.21	2.21	5.00	22.50	1.50	6.79
	3	6	3	0	2.1	0	1	0.21	1.21	5.00	20.00	1.33	11
2	6	9	3	0	2.35	0	1	0.24	1.24	5.00	36.50	2.43	19.7
	6	9	3	0	2.35	0	2	0.24	2.24	5.00	36.00	2.40	10.7
	6	9	3	0	2.35	0	3	0.24	3.24	5.00	43.50	2.90	8.96
	6	9	3	0	2.35	0	2	0.24	2.24	5.00	37.00	2.47	11
	6	9	3	0	2.35	0	1	0.24	1.24	5.00	32.50	2.17	17.5
3	9	12	3	0	2.9	0	1	0.29	1.29	5.00	31.50	2.10	16.3
	9	12	3	0	2.9	0	2	0.29	2.29	5.00	39.00	2.60	11.4
	9	12	3	0	2.9	0	3	0.29	3.29	5.00	45.00	3.00	9.12
	9	12	3	0	2.9	0	2	0.29	2.29	5.00	35.00	2.33	10.2
	9	12	3	0	2.9	0	1	0.29	1.29	5.00	32.50	2.17	16.8
4	12	15	3	0	2.65	0	1	0.27	1.27	5.00	32.50	2.17	17.1
	12	15	3	0	2.65	0	2	0.27	2.27	5.00	39.00	2.60	11.5
	12	15	3	0	2.65	0	3	0.27	3.27	5.00	62.50	4.17	12.8
	12	15	3	0	2.65	0	2	0.27	2.27	5.00	40.00	2.67	11.8
	12	15	3	0	2.65	0	1	0.27	1.27	5.00	39.50	2.63	20.8
5	15	18	3	0	2.9	0	1	0.29	1.29	5.00	36.00	2.40	18.6
	15	18	3	0	2.9	0	2	0.29	2.29	5.00	37.50	2.50	10.9
	15	18	3	0	2.9	0	3	0.29	3.29	5.00	56.00	3.73	11.3
	15	18	3	0	2.9	0	2	0.29	2.29	5.00	39.00	2.60	11.4
	15	18	3	0	2.9	0	1	0.29	1.29	5.00	35.00	2.33	18.1
6	18	21	3	0	2.35	0	1	0.24	1.24	5.00	36.00	2.40	19.4
	18	21	3	0	2.35	0	2	0.24	2.24	5.00	35.00	2.33	10.4
	18	21	3	0	2.35	0	3	0.24	3.24	5.00	57.00	3.80	11.7
	18	21	3	0	2.35	0	2	0.24	2.24	5.00	41.00	2.73	12.2
	18	21	3	0	2.35	0	1	0.24	1.24	5.00	35.00	2.33	18.9
7	21	24	3	0	2.65	0	1	0.27	1.27	5.00	39.00	2.60	20.6
	21	24	3	0	2.65	0	2	0.27	2.27	5.00	40.00	2.67	11.8
	21	24	3	0	2.65	0	3	0.27	3.27	5.00	58.50	3.90	11.9
	21	24	3	0	2.65	0	2	0.27	2.27	5.00	39.00	2.60	11.5
	21	24	3	0	2.65	0	1	0.27	1.27	5.00	35.00	2.33	18.4
8	24	27	3	0	2.1	0	1	0.21	1.21	5.00	38.00	2.53	20.9
	24	27	3	0	2.1	0	2	0.21	2.21	5.00	30.00	2.00	9.05
	24	27	3	0	2.1	0	3	0.21	3.21	5.00	45.00	3.00	9.35
	24	27	3	0	2.1	0	2	0.21	2.21	5.00	36.50	2.43	11
	24	27	3	0	2.1	0	1	0.21	1.21	5.00	30.00	2.00	16.5
9	27	30	3	0	2.35	0	1	0.24	1.24	5.00	40.00	2.67	21.6
	27	30	3	0	2.35	0	2	0.24	2.24	5.00	44.00	2.93	13.1
	27	30	3	0	2.35	0	3	0.24	3.24	5.00	54.00	3.60	11.1
	27	30	3	0	2.35	0	2	0.24	2.24	5.00	40.00	2.67	11.9

	27	30	3	0	2.35	0	1	0.24	1.24	5.00	35.00	2.33	18.9
10	30	33	3	0	2.6	0	1	0.26	1.26	5.00	34.00	2.27	18
	30	33	3	0	2.6	0	2	0.26	2.26	5.00	41.00	2.73	12.1
	30	33	3	0	2.6	0	3	0.26	3.26	5.00	51.00	3.40	10.4
	30	33	3	0	2.6	0	2	0.26	2.26	5.00	37.50	2.50	11.1
	30	33	3	0	2.6	0	1	0.26	1.26	5.00	27.50	1.83	14.6
11	33	36	3	0	2.8	0	1	0.28	1.28	5.00	44.00	2.93	22.9
	33	36	3	0	2.8	0	2	0.28	2.28	5.00	47.50	3.17	13.9
	33	36	3	0	2.8	0	3	0.28	3.28	5.00	52.50	3.50	10.7
	33	36	3	0	2.8	0	2	0.28	2.28	5.00	43.50	2.90	12.7
	33	36	3	0	2.8	0	1	0.28	1.28	5.00	40.50	2.70	21.1
12	36	39	3	0	2.25	0	1	0.23	1.23	5.00	34.00	2.27	18.5
	36	39	3	0	2.25	0	2	0.23	2.23	5.00	37.50	2.50	11.2
	36	39	3	0	2.25	0	3	0.23	3.23	5.00	57.50	3.83	11.9
	36	39	3	0	2.25	0	2	0.23	2.23	5.00	39.00	2.60	11.7
	36	39	3	0	2.25	0	1	0.23	1.23	5.00	33.50	2.23	18.2
13	39	42	3	0	2.1	0	1	0.21	1.21	5.00	32.50	2.17	17.9
	39	42	3	0	2.1	0	2	0.21	2.21	5.00	36.50	2.43	11
	39	42	3	0	2.1	0	3	0.21	3.21	5.00	47.50	3.17	9.87
	39	42	3	0	2.1	0	2	0.21	2.21	5.00	52.50	3.50	15.8
	39	42	3	0	2.1	0	1	0.21	1.21	5.00	41.00	2.73	22.6
14	42	45	3	0	2.65	0	1	0.27	1.27	5.00	38.00	2.53	20
	42	45	3	0	2.65	0	2	0.27	2.27	5.00	57.50	3.83	16.9
	42	45	3	0	2.65	0	3	0.27	3.27	5.00	56.00	3.73	11.4
	42	45	3	0	2.65	0	2	0.27	2.27	5.00	43.50	2.90	12.8
	42	45	3	0	2.65	0	1	0.27	1.27	5.00	41.00	2.73	21.6
15	45	48	3	0	2.35	0	1	0.24	1.24	5.00	40.00	2.67	21.6
	45	48	3	0	2.35	0	2	0.24	2.24	5.00	45.00	3.00	13.4
	45	48	3	0	2.35	0	3	0.24	3.24	5.00	53.50	3.57	11
	45	48	3	0	2.35	0	2	0.24	2.24	5.00	42.50	2.83	12.7
	45	48	3	0	2.35	0	1	0.24	1.24	5.00	36.00	2.40	19.4
16	48	51	3	0	2.65	0	1	0.27	1.27	5.00	39.00	2.60	20.6
	48	51	3	0	2.65	0	2	0.27	2.27	5.00	42.50	2.83	12.5
	48	51	3	0	2.65	0	3	0.27	3.27	5.00	52.50	3.50	10.7
	48	51	3	0	2.65	0	2	0.27	2.27	5.00	40.00	2.67	11.8
	48	51	3	0	2.65	0	1	0.27	1.27	5.00	40.00	2.67	21.1
17	51	54	3	0	2.8	0	1	0.28	1.28	5.00	37.00	2.47	19.3
	51	54	3	0	2.8	0	2	0.28	2.28	5.00	49.00	3.27	14.3
	51	54	3	0	2.8	0	3	0.28	3.28	5.00	57.50	3.83	11.7
	51	54	3	0	2.8	0	2	0.28	2.28	5.00	42.50	2.83	12.4
	51	54	3	0	2.8	0	1	0.28	1.28	5.00	35.00	2.33	18.2
18	54	57	3	0	2.25	0	1	0.23	1.23	5.00	38.00	2.53	20.7
	54	57	3	0	2.25	0	2	0.23	2.23	5.00	49.00	3.27	14.7
	54	57	3	0	2.25	0	3	0.23	3.23	5.00	62.50	4.17	12.9
	54	57	3	0	2.25	0	2	0.23	2.23	5.00	43.50	2.90	13
	54	57	3	0	2.25	0	1	0.23	1.23	5.00	37.50	2.50	20.4
19	57	60	3	0	2.55	0	1	0.26	1.26	5.00	45.00	3.00	23.9
	57	60	3	0	2.55	0	2	0.26	2.26	5.00	42.50	2.83	12.6
	57	60	3	0	2.55	0	3	0.26	3.26	5.00	58.50	3.90	12
	57	60	3	0	2.55	0	2	0.26	2.26	5.00	37.00	2.47	10.9
	57	60	3	0	2.55	0	1	0.26	1.26	5.00	35.00	2.33	18.6
20	60	63	3	0	2.65	0	1	0.27	1.27	5.00	37.50	2.50	19.8
	60	63	3	0	2.65	0	2	0.27	2.27	5.00	43.50	2.90	12.8
	60	63	3	0	2.65	0	3	0.27	3.27	5.00	57.50	3.83	11.7
	60	63	3	0	2.65	0	2	0.27	2.27	5.00	40.00	2.67	11.8
	60	63	3	0	2.65	0	1	0.27	1.27	5.00	35.00	2.33	18.4

21	63	66	3	0	2.65	0	1	0.27	1.27	5.00	37.50	2.50	19.8
	63	66	3	0	2.65	0	2	0.27	2.27	5.00	40.50	2.70	11.9
	63	66	3	0	2.65	0	3	0.27	3.27	5.00	46.00	3.07	9.39
	63	66	3	0	2.65	0	2	0.27	2.27	5.00	45.00	3.00	13.2
	63	66	3	0	2.65	0	1	0.27	1.27	5.00	35.00	2.33	18.4
22	66	69	3	0	2.25	0	1	0.23	1.23	5.00	35.00	2.33	19
	66	69	3	0	2.25	0	2	0.23	2.23	5.00	40.00	2.67	12
	66	69	3	0	2.25	0	3	0.23	3.23	5.00	50.00	3.33	10.3
	66	69	3	0	2.25	0	2	0.23	2.23	5.00	37.50	2.50	11.2
	66	69	3	0	2.25	0	1	0.23	1.23	5.00	29.00	1.93	15.8
23	69	72	3	0	2.55	0	1	0.26	1.26	5.00	36.50	2.43	19.4
	69	72	3	0	2.55	0	2	0.26	2.26	5.00	42.00	2.80	12.4
	69	72	3	0	2.55	0	3	0.26	3.26	5.00	54.00	3.60	11.1
	69	72	3	0	2.55	0	2	0.26	2.26	5.00	40.00	2.67	11.8
	69	72	3	0	2.55	0	1	0.26	1.26	5.00	30.00	2.00	15.9
24	72	75	3	0	2.8	0	1	0.28	1.28	5.00	40.00	2.67	20.8
	72	75	3	0	2.8	0	2	0.28	2.28	5.00	57.00	3.80	16.7
	72	75	3	0	2.8	0	3	0.28	3.28	5.00	55.00	3.67	11.2
	72	75	3	0	2.8	0	2	0.28	2.28	5.00	39.00	2.60	11.4
	72	75	3	0	2.8	0	1	0.28	1.28	5.00	35.00	2.33	18.2
25	75	78	3	0	2.1	0	1	0.21	1.21	5.00	35.00	2.33	19.3
	75	78	3	0	2.1	0	2	0.21	2.21	5.00	43.50	2.90	13.1
	75	78	3	0	2.1	0	3	0.21	3.21	5.00	55.00	3.67	11.4
	75	78	3	0	2.1	0	2	0.21	2.21	5.00	40.00	2.67	12.1
	75	78	3	0	2.1	0	1	0.21	1.21	5.00	33.50	2.23	18.5
26	78	81	3	0	2.1	0	1	0.21	1.21	5.00	49.00	3.27	27
	78	81	3	0	2.1	0	2	0.21	2.21	5.00	40.00	2.67	12.1
	78	81	3	0	2.1	0	3	0.21	3.21	5.00	64.00	4.27	13.3
	78	81	3	0	2.1	0	2	0.21	2.21	5.00	50.00	3.33	15.1
	78	81	3	0	2.1	0	1	0.21	1.21	5.00	38.50	2.57	21.2
27	81	84	3	0	2.65	0	1	0.27	1.27	5.00	40.00	2.67	21.1
	81	84	3	0	2.65	0	2	0.27	2.27	5.00	46.50	3.10	13.7
	81	84	3	0	2.65	0	3	0.27	3.27	5.00	60.00	4.00	12.3
	81	84	3	0	2.65	0	2	0.27	2.27	5.00	43.50	2.90	12.8
	81	84	3	0	2.65	0	1	0.27	1.27	5.00	36.50	2.43	19.2
28	84	87	3	0	2.25	0	1	0.23	1.23	5.00	38.00	2.53	20.7
	84	87	3	0	2.25	0	2	0.23	2.23	5.00	50.00	3.33	15
	84	87	3	0	2.25	0	3	0.23	3.23	5.00	54.00	3.60	11.2
	84	87	3	0	2.25	0	2	0.23	2.23	5.00	39.00	2.60	11.7
	84	87	3	0	2.25	0	1	0.23	1.23	5.00	35.00	2.33	19

Project Name: WANGCHU HEP, BHUTAN

Drill Hole No.: DH-8 | **Coordinates:**

Location: Dam axis, right bank top | **Collar Elevation:** 486.0 m

Inclination: Vertical | **Total Depth:** 130.0 m

Test Number	Depth of Packer (mts)		Test Section (in mts)	Water Table (Depth in mts)	Height of water swievel (H1) from NSL (in mts)	Height from NSL upto water level (H2) (in mts)	Applied Pressure (P0) (in Manometer kg/cm2)	Pressure of water Column (P1=H1/10+H2/10) in kg/cm2	Effective Pressure at Packer (P=P0+P1)	Duration of Test (in min)	Average Water Intake (in lits)	Water Intake (Q) in Lit/min/m	Lugeon =Qx10/P
	Upper	Lower											
1	81	84	3	0	2.9	0	1	0.29	1.29	5	60	4.00	31
	81	84	3	0	2.9	0	2	0.29	2.29	5	64.5	4.30	18.8
	81	84	3	0	2.9	0	3	0.29	3.29	5	70	4.67	14.2
	81	84	3	0	2.9	0	2	0.29	2.29	5	60.5	4.03	17.6
	81	84	3	0	2.9	0	1	0.29	1.29	5	56.5	3.77	29.2
2	84	87	3	0	2.45	0	1	0.25	1.25	5	34	2.27	18.2
	84	87	3	0	2.45	0	2	0.25	2.25	5	45.5	3.03	13.5
	84	87	3	0	2.45	0	3	0.25	3.25	5	54.1	3.61	11.1
	84	87	3	0	2.45	0	2	0.25	2.25	5	35.3	2.35	10.5
	84	87	3	0	2.45	0	1	0.25	1.25	5	40	2.67	21.4
3	87	90	3	0	2.45	0	1	0.25	1.25	5	62.5	4.17	33.5
	87	90	3	0	2.45	0	2	0.25	2.25	5	64	4.27	19
	87	90	3	0	2.45	0	3	0.25	3.25	5	78	5.20	16
	87	90	3	0	2.45	0	2	0.25	2.25	5	65	4.33	19.3
	87	90	3	0	2.45	0	1	0.25	1.25	5	58	3.87	31.1
4	90	93	3	0	2.45	0	1	0.25	1.25	5	55.5	3.70	29.7
	90	93	3	0	2.45	0	2	0.25	2.25	5	57	3.80	16.9
	90	93	3	0	2.45	0	3	0.25	3.25	5	70	4.67	14.4
	90	93	3	0	2.45	0	2	0.25	2.25	5	57	3.80	16.9
	90	93	3	0	2.45	0	1	0.25	1.25	5	55	3.67	29.5
5	93	96	3	0	2.95	0	1	0.30	1.30	5	40	2.67	20.6
	93	96	3	0	2.95	0	2	0.30	2.30	5	43	2.87	12.5
	93	96	3	0	2.95	0	3	0.30	3.30	5	50	3.33	10.1
	93	96	3	0	2.95	0	2	0.30	2.30	5	46	3.07	13.4
	93	96	3	0	2.95	0	1	0.30	1.30	5	41.5	2.77	21.4
6	96	99	3	0	2.15	0	1	0.22	1.22	5	54.5	3.63	29.9
	96	99	3	0	2.15	0	2	0.22	2.22	5	63	4.20	19
	96	99	3	0	2.15	0	3	0.22	3.22	5	70	4.67	14.5
	96	99	3	0	2.15	0	2	0.22	2.22	5	60	4.00	18.1
	96	99	3	0	2.15	0	1	0.22	1.22	5	44	2.93	24.1
7	99	102	3	0	3.1	0	1	0.31	1.31	5	86	5.73	43.8
	99	102	3	0	3.1	0	2	0.31	2.31	5	92.5	6.17	26.7
	99	102	3	0	3.1	0	3	0.31	3.31	5	101	6.73	20.3
	99	102	3	0	3.1	0	2	0.31	2.31	5	86	5.73	24.8
	99	102	3	0	3.1	0	1	0.31	1.31	5	78	5.20	39.7
8	102	105	3	0	3.05	0	1	0.31	1.31	5	50	3.33	25.5
	102	105	3	0	3.05	0	2	0.31	2.31	5	65	4.33	18.8
	102	105	3	0	3.05	0	3	0.31	3.31	5	74	4.93	14.9
	102	105	3	0	3.05	0	2	0.31	2.31	5	55	3.67	15.9
	102	105	3	0	3.05	0	1	0.31	1.31	5	46	3.07	23.5
9	105	108	3	0	3.12	0	1	0.31	1.31	5	77.5	5.17	39.4
	105	108	3	0	3.12	0	2	0.31	2.31	5	79.5	5.30	22.9
	105	108	3	0	3.12	0	3	0.31	3.31	5	78	5.20	15.7
	105	108	3	0	3.12	0	2	0.31	2.31	5	76.5	5.10	22.1

	105	108	3	0	3.12	0	1	0.31	1.31	5	73.5	4.90	37.3
10	108	111	3	0	3.1	0	1	0.31	1.31	5	78	5.20	39.7
	108	111	3	0	3.1	0	2	0.31	2.31	5	82.5	5.50	23.8
	108	111	3	0	3.1	0	3	0.31	3.31	5	89	5.93	17.9
	108	111	3	0	3.1	0	2	0.31	2.31	5	95.5	6.37	27.6
	108	111	3	0	3.1	0	1	0.31	1.31	5	74.5	4.97	37.9
11	111	114	3	0	2.96	0	1	0.30	1.30	5	60	4.00	30.9
	111	114	3	0	2.96	0	2	0.30	2.30	5	75	5.00	21.8
	111	114	3	0	2.96	0	3	0.30	3.30	5	85	5.67	17.2
	111	114	3	0	2.96	0	2	0.30	2.30	5	65	4.33	18.9
	111	114	3	0	2.96	0	1	0.30	1.30	5	61	4.07	31.4
12	114	117	3	0	2.9	0	1	0.29	1.29	5	53	3.53	27.4
	114	117	3	0	2.9	0	2	0.29	2.29	5	62.5	4.17	18.2
	114	117	3	0	2.9	0	3	0.29	3.29	5	67.5	4.50	13.7
	114	117	3	0	2.9	0	2	0.29	2.29	5	61	4.07	17.8
	114	117	3	0	2.9	0	1	0.29	1.29	5	51	3.40	26.4
13	117	120	3	0	3.25	0	1	0.33	1.33	5	48.5	3.23	24.4
	117	120	3	0	3.25	0	2	0.33	2.33	5	52	3.47	14.9
	117	120	3	0	3.25	0	3	0.33	3.33	5	61	4.07	12.2
	117	120	3	0	3.25	0	2	0.33	2.33	5	52	3.47	14.9
	117	120	3	0	3.25	0	1	0.33	1.33	5	47	3.13	23.6
14	120	123	3	0	2.8	0	1	0.28	1.28	5	75	5.00	39.1
	120	123	3	0	2.8	0	2	0.28	2.28	5	80	5.33	23.4
	120	123	3	0	2.8	0	3	0.28	3.28	5	91	6.07	18.5
	120	123	3	0	2.8	0	2	0.28	2.28	5	84.5	5.63	24.7
	120	123	3	0	2.8	0	1	0.28	1.28	5	71.5	4.77	37.2
15	123	126	3	0	3.1	0	1	0.31	1.31	5	55	3.67	28
	123	126	3	0	3.1	0	2	0.31	2.31	5	65	4.33	18.8
	123	126	3	0	3.1	0	3	0.31	3.31	5	80	5.33	16.1
	123	126	3	0	3.1	0	2	0.31	2.31	5	62	4.13	17.9
	123	126	3	0	3.1	0	1	0.31	1.31	5	53	3.53	27
16	126	129	3	0	2.9	0	1	0.29	1.29	5	65	4.33	33.6
	126	129	3	0	2.9	0	2	0.29	2.29	5	75	5.00	21.8
	126	129	3	0	2.9	0	3	0.29	3.29	5	94	6.27	19
	126	129	3	0	2.9	0	2	0.29	2.29	5	72	4.80	21
	126	129	3	0	2.9	0	1	0.29	1.29	5	65	4.33	33.6

Project Name: WANGCHU HEP, BHUTAN

Drill Hole No.: DH-9 | **Coordinates:**

Location: Diversion tunnel, outlet | **Collar Elevation:** 455.0 m

Inclination: Vertical | **Total Depth:** 50 m

Test Number	Depth of Packer (mts)		Test Section (in mts)	Water Table (Depth in mts)	Height of water swievel (H1) from NSL (in mts)	Height from NSL upto water level (H2) (in mts)	Applied Pressure (P0) (in in Manometer kg/cm2)	Pressure of water Column (P1=H1/10+H2/10) in kg/cm2	Effective Pressure at Packer (P=P0+P1)	Duration of Test (in min)	Average Water Intake (in lits)	Water Intake (Q) in Lit/min/m	Lugeon =Qx10/P
	Upper	Lower											
1	36	39	3	1.55	2.55	1.55	1	0.41	1.41	5	18.66	1.24	8.82
	36	39	3	1.55	2.55	1.55	2	0.41	2.41	5	26	1.73	7.19
	36	39	3	1.55	2.55	1.55	3	0.41	3.41	5	33.66	2.24	6.58
	36	39	3	1.55	2.55	1.55	2	0.41	2.41	5	36	2.40	9.96
	36	39	3	1.55	2.55	1.55	1	0.41	1.41	5	32.33	2.16	15.29
2	21	24	3	0	2.55	0	1	0.26	1.26	5	40	2.67	21.2
	21	24	3	0	2.55	0	2	0.26	2.26	5	50	3.33	14.8
	21	24	3	0	2.55	0	3	0.26	3.26	5	57.5	3.83	11.8
	21	24	3	0	2.55	0	2	0.26	2.26	5	47.5	3.17	14
	21	24	3	0	2.55	0	1	0.26	1.26	5	40	2.67	21.2
3	24	27	3	0	2.9	0	1	0.29	1.29	5	35	2.33	18.1
	24	27	3	0	2.9	0	2	0.29	2.29	5	45	3.00	13.1
	24	27	3	0	2.9	0	3	0.29	3.29	5	50	3.33	10.1
	24	27	3	0	2.9	0	2	0.29	2.29	5	45	3.00	13.1
	24	27	3	0	2.9	0	1	0.29	1.29	5	40	2.67	20.7
4	27	30	3	0	2.1	0	1	0.21	1.21	5	50	3.33	27.5
	27	30	3	0	2.1	0	2	0.21	2.21	5	55	3.67	16.6
	27	30	3	0	2.1	0	3	0.21	3.21	5	60	4.00	12.5
	27	30	3	0	2.1	0	2	0.21	2.21	5	45	3.00	13.6
	27	30	3	0	2.1	0	1	0.21	1.21	5	40	2.67	22
5	30	33	3	0	2.45	0	1	0.25	1.25	5	40	2.67	21.4
	30	33	3	0	2.45	0	2	0.25	2.25	5	50	3.33	14.8
	30	33	3	0	2.45	0	3	0.25	3.25	5	55	3.67	11.3
	30	33	3	0	2.45	0	2	0.25	2.25	5	45	3.00	13.4
	30	33	3	0	2.45	0	1	0.25	1.25	5	45	3.00	24.1
6	33	36	3	0	2.65	0	1	0.27	1.27	5	50	3.33	26.4
	33	36	3	0	2.65	0	2	0.27	2.27	5	55	3.67	16.2
	33	36	3	0	2.65	0	3	0.27	3.27	5	65	4.33	13.3
	33	36	3	0	2.65	0	2	0.27	2.27	5	45	3.00	13.2
	33	36	3	0	2.65	0	1	0.27	1.27	5	40	2.67	21.1
7	36	39	3	0	2.9	0	1	0.29	1.29	5	45	3.00	23.3
	36	39	3	0	2.9	0	2	0.29	2.29	5	60	4.00	17.5
	36	39	3	0	2.9	0	3	0.29	3.29	5	80	5.33	16.2
	36	39	3	0	2.9	0	2	0.29	2.29	5	50	3.33	14.6
	36	39	3	0	2.9	0	1	0.29	1.29	5	40	2.67	20.7
8	39	42	3	0	2.1	0	1	0.21	1.21	5	40	2.67	22
	39	42	3	0	2.1	0	2	0.21	2.21	5	47.5	3.17	14.3
	39	42	3	0	2.1	0	3	0.21	3.21	5	77.5	5.17	16.1
	39	42	3	0	2.1	0	2	0.21	2.21	5	47.5	3.17	14.3
	39	42	3	0	2.1	0	1	0.21	1.21	5	37.5	2.50	20.7
9	42	45	3	0	2.35	0	1	0.24	1.24	5	45	3.00	24.3
	42	45	3	0	2.35	0	2	0.24	2.24	5	45	3.00	13.4
	42	45	3	0	2.35	0	3	0.24	3.24	5	70	4.67	14.4
	42	45	3	0	2.35	0	2	0.24	2.24	5	47.5	3.17	14.2
	42	45	3	0	2.35	0	1	0.24	1.24	5	37.5	2.50	20.2
10	45	48	3	0	2.65	0	1	0.27	1.27	5	47.5	3.17	25
	45	48	3	0	2.65	0	2	0.27	2.27	5	52.5	3.50	15.5
	45	48	3	0	2.65	0	3	0.27	3.27	5	64	4.27	13.1
	45	48	3	0	2.65	0	2	0.27	2.27	5	45	3.00	13.2
	45	48	3	0	2.65	0	1	0.27	1.27	5	40	2.67	21.1
11	24	27	3	0	2.55	0	1	0.26	1.26	5	36	2.40	19.1
	24	27	3	0	2.55	0	2	0.26	2.26	5	43.5	2.90	12.9
	24	27	3	0	2.55	0	3	0.26	3.26	5	50.5	3.37	10.3
	24	27	3	0	2.55	0	2	0.26	2.26	5	40.5	2.70	12
	24	27	3	0	2.55	0	1	0.26	1.26	5	31	2.07	16.5
12	47	50	3	0	2.1	0	1	0.21	1.21	5	40.5	2.70	22.3
	47	50	3	0	2.1	0	2	0.21	2.21	5	75	5.00	22.6
	47	50	3	0	2.1	0	3	0.21	3.21	5	54.5	3.63	11.3
	47	50	3	0	2.1	0	2	0.21	2.21	5	32.5	2.17	9.8
	47	50	3	0	2.1	0	1	0.21	1.21	5	40.5	2.70	22.3

Project Name: WANGCHU HEP, BHUTAN

Drill Hole No.: HRT-1 | **Coordinates:**

Location: Zilung nallah-HRT crossing | **Collar Elevation:** 450.0 m

Inclination: Vertical | **Total Depth:** 75.0 m

Test Number	Depth of Packer (mts)		Test Section (in mts)	Water Table (Depth in mts)	Height of water swievel (H1) from NSL (in mts)	Height from NSL upto water level (H2) (in mts)	Applied Pressure (P0) in Manometer (in kg/cm2)	Pressure of water Column (P1=H1/10+H2/10) in kg/cm2	Effective Pressure at Packer (P=P0+P1)	Duration of Test (in min)	Average Water Intake (in lits)	Water Intake (Q) in Lit/min/m	Lugeon =Qx10/P
	Upper	Lower											
1	27	30	3	3.2	1.9	3.2	1	0.5	1.5	5	16	1.07	7.06
	27	30	3	3.2	1.9	3.2	2	0.5	2.5	5	19	1.27	5.05
	27	30	3	3.2	1.9	3.2	3	0.5	3.5	5	22.5	1.50	4.27
	27	30	3	3.2	1.9	3.2	2	0.5	2.5	5	16.5	1.10	4.38
	27	30	3	3.2	1.9	3.2	1	0.5	1.5	5	14	0.93	6.18
2	30	33	3	3.4	2.6	3.4	1	0.6	1.6	5	19	1.27	7.95
	30	33	3	3.4	2.6	3.4	2	0.6	2.6	5	22.5	1.50	5.79
	30	33	3	3.4	2.6	3.4	3	0.6	3.6	5	28.5	1.90	5.29
	30	33	3	3.4	2.6	3.4	2	0.6	2.6	5	21.5	1.43	5.53
	30	33	3	3.4	2.6	3.4	1	0.6	1.6	5	18	1.20	7.54
3	33	36	3	3.6	2.2	3.6	1	0.6	1.6	5	13.5	0.90	5.71
	33	36	3	3.6	2.2	3.6	2	0.6	2.6	5	19	1.27	4.91
	33	36	3	3.6	2.2	3.6	3	0.6	3.6	5	26	1.73	4.85
	33	36	3	3.6	2.2	3.6	2	0.6	2.6	5	16.5	1.10	4.27
	33	36	3	3.6	2.2	3.6	1	0.6	1.6	5	13	0.87	5.49
4	36	39	3	3.7	2.7	3.7	1	0.6	1.6	5	17	1.13	6.92
	36	39	3	3.7	2.7	3.7	2	0.6	2.6	5	25	1.67	6.32
	36	39	3	3.7	2.7	3.7	3	0.6	3.6	5	28.5	1.90	5.22
	36	39	3	3.7	2.7	3.7	2	0.6	2.6	5	22.5	1.50	5.69
	36	39	3	3.7	2.7	3.7	1	0.6	1.6	5	15.5	1.03	6.31
5	39	42	3	3.9	2.9	3.9	1	0.7	1.7	5	14	0.93	5.55
	39	42	3	3.9	2.9	3.9	2	0.7	2.7	5	19.5	1.30	4.85
	39	42	3	3.9	2.9	3.9	3	0.7	3.7	5	25.5	1.70	4.62
	39	42	3	3.9	2.9	3.9	2	0.7	2.7	5	19	1.27	4.72
	39	42	3	3.9	2.9	3.9	1	0.7	1.7	5	14.5	0.97	5.75
6	42	45	3	4.0	2.7	4.0	1	0.7	1.7	5	18.5	1.23	7.40
	42	45	3	4.0	2.7	4.0	2	0.7	2.7	5	25	1.67	6.25
	42	45	3	4.0	2.7	4.0	3	0.7	3.7	5	30.5	2.03	5.54
	42	45	3	4.0	2.7	4.0	2	0.7	2.7	5	23.5	1.57	5.87
	42	45	3	4.0	2.7	4.0	1	0.7	1.7	5	16	1.07	6.40
7	45	48	3	4.2	2.5	4.2	1	0.7	1.7	5	18	1.20	7.21
	45	48	3	4.2	2.5	4.2	2	0.7	2.7	5	20.5	1.37	5.13
	45	48	3	4.2	2.5	4.2	3	0.7	3.7	5	21	1.40	3.82
	45	48	3	4.2	2.5	4.2	2	0.7	2.7	5	19.5	1.30	4.88
	45	48	3	4.2	2.5	4.2	1	0.7	1.7	5	17.5	1.17	7.01
8	48	51	3	4.4	2.1	4.4	1	0.7	1.7	5	15.5	1.03	6.26
	48	51	3	4.4	2.1	4.4	2	0.7	2.7	5	18.5	1.23	4.65
	48	51	3	4.4	2.1	4.4	3	0.7	3.7	5	26	1.73	4.75
	48	51	3	4.4	2.1	4.4	2	0.7	2.7	5	15.5	1.03	3.90
	48	51	3	4.4	2.1	4.4	1	0.7	1.7	5	13.5	0.90	5.45
9	51	54	3	4.4	2.7	4.4	1	0.7	1.7	5	18	1.20	7.04
	51	54	3	4.4	2.7	4.4	2	0.7	2.7	5	21.5	1.43	5.30
	51	54	3	4.4	2.7	4.4	3	0.7	3.7	5	27.5	1.83	4.95
	51	54	3	4.4	2.7	4.4	2	0.7	2.7	5	20.5	1.37	5.05
	51	54	3	4.4	2.7	4.4	1	0.7	1.7	5	15	1.00	5.87
10	54	57	3	4.4	2.9	4.4	1	0.7	1.7	5	9.5	0.63	3.66
	54	57	3	4.4	2.9	4.4	2	0.7	2.7	5	12.5	0.83	3.05
	54	57	3	4.4	2.9	4.4	3	0.7	3.7	5	16.5	1.10	2.95
	54	57	3	4.4	2.9	4.4	2	0.7	2.7	5	11	0.73	2.69
	54	57	3	4.4	2.9	4.4	1	0.7	1.7	5	7.5	0.50	2.89
11	57	60	3	4.4	3.1	4.4	1	0.8	1.8	5	11.5	0.77	4.38
	57	60	3	4.4	3.1	4.4	2	0.8	2.8	5	14.5	0.97	3.52
	57	60	3	4.4	3.1	4.4	3	0.8	3.8	5	19	1.27	3.38
	57	60	3	4.4	3.1	4.4	2	0.8	2.8	5	12.5	0.83	3.03
	57	60	3	4.4	3.1	4.4	1	0.8	1.8	5	11	0.73	4.19
12	60	63	3	4.4	3.4	4.4	1	0.8	1.8	5	13	0.87	4.86
	60	63	3	4.4	3.4	4.4	2	0.8	2.8	5	17.5	1.17	4.19
	60	63	3	4.4	3.4	4.4	3	0.8	3.8	5	21	1.40	3.70
	60	63	3	4.4	3.4	4.4	2	0.8	2.8	5	17	1.13	4.07
	60	63	3	4.4	3.4	4.4	1	0.8	1.8	5	11	0.73	4.11
13	63	66	3	4.4	3.5	4.4	1	0.8	1.8	5	13	0.87	4.87
	63	66	3	4.4	3.5	4.4	2	0.8	2.8	5	15.5	1.03	3.72
	63	66	3	4.4	3.5	4.4	3	0.8	3.8	5	20.5	1.37	3.62
	63	66	3	4.4	3.5	4.4	2	0.8	2.8	5	14.5	0.97	3.48
	63	66	3	4.4	3.5	4.4	1	0.8	1.8	5	11.5	0.77	4.31
14	66	69	3	4.4	3.4	4.4	1	0.8	1.8	5	13.5	0.90	5.07
	66	69	3	4.4	3.4	4.4	2	0.8	2.8	5	16.5	1.10	3.96
	66	69	3	4.4	3.4	4.4	3	0.8	3.8	5	22.5	1.50	3.97
	66	69	3	4.4	3.4	4.4	2	0.8	2.8	5	15.5	1.03	3.72
	66	69	3	4.4	3.4	4.4	1	0.8	1.8	5	12.5	0.83	4.69
15	69	72	3	4.4	3.5	4.4	1	0.8	1.8	5	10.5	0.70	3.92
	69	72	3	4.4	3.5	4.4	2	0.8	2.8	5	13.5	0.90	3.23
	69	72	3	4.4	3.5	4.4	3	0.8	3.8	5	18.5	1.23	3.26
	69	72	3	4.4	3.5	4.4	2	0.8	2.8	5	12.5	0.83	2.99
	69	72	3	4.4	3.5	4.4	1	0.8	1.8	5	10	0.67	3.73

Project Wangchu H.E.Project (Bhutan)
Location Power House
Feature Centre of power house
Bore Hole PH-5

Collar Elevation : 179.20 m
Total depth of hole : 50.0 m
Type of drilling : Rotory

Sl. No.	Test Section		Length of test section	Ground water level	Swivel Height	Casing size	Dia of hole	Dia of hole	Water discharge (q)	Gravity Head (h1)	Water pressure at collar (h2)	Water pressure at collar (h2)	Total water head (h)=h1+h2	Lugeon Value
	From	To												
	(m)	(m)	(m)	(m)	(m)		(mm)	(m)	lit/min	(m)	(Kg/cm2)	(m)	(m)	Lt/m/minute
1	47	50	3	9.90	2.60	NX	76.2	0.0762	0.77	12.50	1.00	10	22.50	1.14
	47	50	3	9.90	2.60	NX	76.2	0.0762	1.35	12.50	2.00	20	32.50	1.38
	47	50	3	9.90	2.60	NX	76.2	0.0762	1.70	12.50	3.00	30	42.50	1.33
	47	50	3	9.90	2.60	NX	76.2	0.0762	1.05	12.50	2.00	20	32.50	1.08
	47	50	3	9.90	2.60	NX	76.2	0.0762	0.40	12.50	1.00	10	22.50	0.59
2	44	47	3	9.80	2.65	NX	76.2	0.0762	1.30	12.45	1.00	10	22.45	1.93
	44	47	3	9.80	2.65	NX	76.2	0.0762	1.50	12.45	2.00	20	32.45	1.54
	44	47	3	9.80	2.65	NX	76.2	0.0762	2.30	12.45	3.00	30	42.45	1.81
	44	47	3	9.80	2.65	NX	76.2	0.0762	1.30	12.45	2.00	20	32.45	1.34
	44	47	3	9.80	2.65	NX	76.2	0.0762	1.00	12.45	1.00	10	22.45	1.48
3	41	44	3	9.70	2.70	NX	76.2	0.0762	0.70	12.40	0.50	5	17.40	1.34
	41	44	3	9.70	2.70	NX	76.2	0.0762	1.10	12.40	1.00	10	22.40	1.64
	41	44	3	9.70	2.70	NX	76.2	0.0762	1.30	12.40	1.50	15	27.40	1.58
	41	44	3	9.70	2.70	NX	76.2	0.0762	0.80	12.40	1.00	10	22.40	1.19
	41	44	3	9.70	2.70	NX	76.2	0.0762	0.50	12.40	0.50	5	17.40	0.96
4	38	41	3	8.85	2.60	NX	76.2	0.0762	0.70	11.45	1.00	10	21.45	1.09
	38	41	3	8.85	2.60	NX	76.2	0.0762	1.50	11.45	2.00	20	31.45	1.59
	38	41	3	8.85	2.60	NX	76.2	0.0762	2.10	11.45	3.00	30	41.45	1.69
	38	41	3	8.85	2.60	NX	76.2	0.0762	0.70	11.45	2.00	20	31.45	0.74
	38	41	3	8.85	2.60	NX	76.2	0.0762	0.40	11.45	1.00	10	21.45	0.62
5	35	38	3	9.85	2.60	NX	76.2	0.0762	0.90	12.45	1.00	10	22.45	1.34
	35	38	3	9.85	2.60	NX	76.2	0.0762	1.40	12.45	2.00	20	32.45	1.44
	35	38	3	9.85	2.60	NX	76.2	0.0762	1.90	12.45	3.00	30	42.45	1.49
	35	38	3	9.85	2.60	NX	76.2	0.0762	0.80	12.45	2.00	20	32.45	0.82
	35	38	3	9.85	2.60	NX	76.2	0.0762	0.50	12.45	1.00	10	22.45	0.74
6	32	35	3	9.80	2.70	NX	76.2	0.0762	1.50	12.50	1.00	10	22.50	2.22
	32	35	3	9.80	2.70	NX	76.2	0.0762	2.10	12.50	2.00	20	32.50	2.15
	32	35	3	9.80	2.70	NX	76.2	0.0762	2.30	12.50	3.00	30	42.50	1.80
	32	35	3	9.80	2.70	NX	76.2	0.0762	1.10	12.50	2.00	20	32.50	1.13
	32	35	3	9.80	2.70	NX	76.2	0.0762	1.10	12.50	1.00	10	22.50	1.63
7	29	32	3	9.80	2.75	NX	76.2	0.0762	0.60	12.55	1.00	10	22.55	0.89
	29	32	3	9.80	2.75	NX	76.2	0.0762	1.30	12.55	2.00	20	32.55	1.33
	29	32	3	9.80	2.75	NX	76.2	0.0762	2.10	12.55	3.00	30	42.55	1.65
	29	32	3	9.80	2.75	NX	76.2	0.0762	0.90	12.55	2.00	20	32.55	0.92
	29	32	3	9.80	2.75	NX	76.2	0.0762	0.60	12.55	1.00	10	22.55	0.89
8	26	29	3	8.80	2.70	NX	76.2	0.0762	0.30	11.50	1.00	10	21.50	0.47
	26	29	3	8.80	2.70	NX	76.2	0.0762	0.70	11.50	2.00	20	31.50	0.74
	26	29	3	8.80	2.70	NX	76.2	0.0762	1.90	11.50	3.00	30	41.50	1.53
	26	29	3	8.80	2.70	NX	76.2	0.0762	0.40	11.50	2.00	20	31.50	0.42
	26	29	3	8.80	2.70	NX	76.2	0.0762	0.20	11.50	1.00	10	21.50	0.31
9	23	26	3	8.70	2.75	NX	76.2	0.0762	0.50	11.45	0.50	5	16.45	1.01
	23	26	3	8.70	2.75	NX	76.2	0.0762	1.00	11.45	1.00	10	21.45	1.55
	23	26	3	8.70	2.75	NX	76.2	0.0762	1.20	11.45	1.50	15	26.45	1.51
	23	26	3	8.70	2.75	NX	76.2	0.0762	0.40	11.45	1.00	10	21.45	0.62
	23	26	3	8.70	2.75	NX	76.2	0.0762	0.30	11.45	0.50	5	16.45	0.61

ANNEXURE-III

GEO-MECHANICAL PROPERTIES OF BOREHOLE SAMPLES

GEO-MECHANICAL PROPERTIES OF BOREHOLE SAMPLES

Submitted to

Wangchhu Hydro-Electrical Project

Bhutan

Prof. T.N. Singh

DEPARTMENT OF EARTH SCIENCES,

INDIAN INSTITUTE OF TECHNOLOGY, BOMBAY

POWAI, MUMBAI – 400 076

2011

GEO-MECHANICAL PROPERTIES OF BORE HOLE SAMPLES PROVIDED

The core boxes with various lengths of cores were sent by the client to Department of Earth Sciences, Indian Institute of Technology Bombay, Powai, Mumbai, Maharashtra-400076. The test was performed as per code provided.

The studies of provided samples are tested and observed by three ways 1) Laboratory testing of geomechanical characterization of rock core samples, 2) Physical properties of rocks and 3) Petrography of some selected core samples.

First, the testing methodology for each test has been given, followed by the tabulated test results for the bore hole samples.

1. PHYSICAL PROPERTIES AND GEO-MECHANICAL CHARACTERISTICSATION OF ROCKS

The following laboratory tests have been performed for estimation of the strength of rocks and physical properties of rocks of different core samples:

Physical Properties of Rocks:

1) Bulk Density
2) Porosity
3) Grain desnity

Geo-mechanical Properties of Rocks:

1) Uniaxial compressive strength (UCS) dry and saturated condition
2) Tensile strength (Brazilian Test)
3) Shear Strength of Triaxial C.
4) Deformability characteristic
5) Slake Durability
6) P-wave and S-wave velocity under dry and saturated condition

1. Physical Properties of Rocks:

1.1 Density

The density is defined the mass per unit volume of a material. Since a rock contains both grains (solid matrix material) and voids, it is necessary to distinguish between different densities which are related to different parts or components of the rock. The density of rocks has been determined using the method suggested by ISRM (1979c). The instrumental setup for the density and porosity has been illustrated in figure 1. The bulk density and grain density have been evaluated using equation 1.1 and equation 1.2.

$$\rho = \frac{M}{V} \tag{1.1}$$

$$\rho_s = \frac{M_s}{V_s} \tag{1.2}$$

Where,

ρ = Bulk density (gram/cc)

ρ_S = Grain density (gram/cc)

M = Bulk mass of Sample

V = Bulk Volume of sample

M_s = Mass of grains

V_s =Volume of grains

Figure 1: Setup for determination of density of rock samples and selected samples for determination of density.

1.2 Porosity

The porosity ϕ, is defined as the ratio of void or pore volume, V_v, to the total volume, V, of the rock samples.

$$\phi = \frac{V_v}{V} \tag{1.3}$$

Porosity is dimensionless and given as a percentage or as a decimal fraction. The porosity of rocks has been determined using the method suggested by ISRM (1979c).

2. Geomechanical Characterization of Rocks

2.1 Uniaxial Compressive Strength (UCS)

The uniaxial compression test is most direct means of determining rock strength. In this test, cylindrical rock specimens are tested in compression without lateral confinement. The test specimen should be a rock cylinder of length-to-width ratio (H/D) in the range of 2 to 2.5 with flat, smooth, and parallel ends cut perpendicular to the cylinder axis. The specimen is kept between two loading platens of a compression testing machine (UTM). The specimen must maintain full contact with the loading platens. If full contact is not there then the application of load will be on a lesser area and the sample will fail at an early load. The load should be applied at the rate of 0.5-1.0 MPa/sec for uniform distribution of zero stress in the sample. Strength depends upon the rate of loading also.

The samples are immersed in water for 24 hour to get 100% saturation. The uniaxial compression test has been performed on saturated condition to evaluate the strength of rock in saturated condition.

The unconfined compressive strength of the specimen, in dry and wet condition, has calculated by dividing the maximum load at failure by the sample cross-sectional area:

$$\boldsymbol{\sigma_c = F/A}$$

Where,

$\boldsymbol{\sigma_c}$ = Unconfined Compressive Strength (MPa),

F = Maximum Failure Load (kN), and

A = Cross-sectional area of the core sample (cm^2).

Figure 2: Universal Testing Machine and loading platens

2.2 Tensile Strength Estimation Using Brazilian Test

The tensile strength of a material is defined as the maximum tensile stress which a material is capable of developing. In nature, rock mass is rarely subjected to direct tension, but it undergoes tensile stress. Rocks become weaker under the tension. It has been found that the rock possess tensile strength which is about 10% of its compressive strength.

The direct tensile strength testing is difficult to perform and generally expensive for routine applications. Also it often is prone to giving low results due to the effects of existing micro-fractures and other rock defects. Therefore, an indirect method, the Brazilian disk test, is most commonly used to determine the tensile strength of rocks as per **ISRM (1978)** suggested method.

In the Brazilian test, a circular disk specimen is used with a thickness to diameter ratio (L/D) of between 0.5 and 0.75. The load is applied across the sample diameter as shown in figure

3. This specimen is placed in loading platens of the UTM. The rate of loading is normally 220 Kgf/sec. The test may be stress controlled or strain controlled. The tensile strength is calculated by the following formula:

$$\sigma_t = \frac{2P \times 10}{\pi dt}$$

Where,

σ_t = Tensile strength (MPa),

P = Failure load (kN),

d = Diameter of the specimen (cm), and

t = Thickness of the specimen (cm).

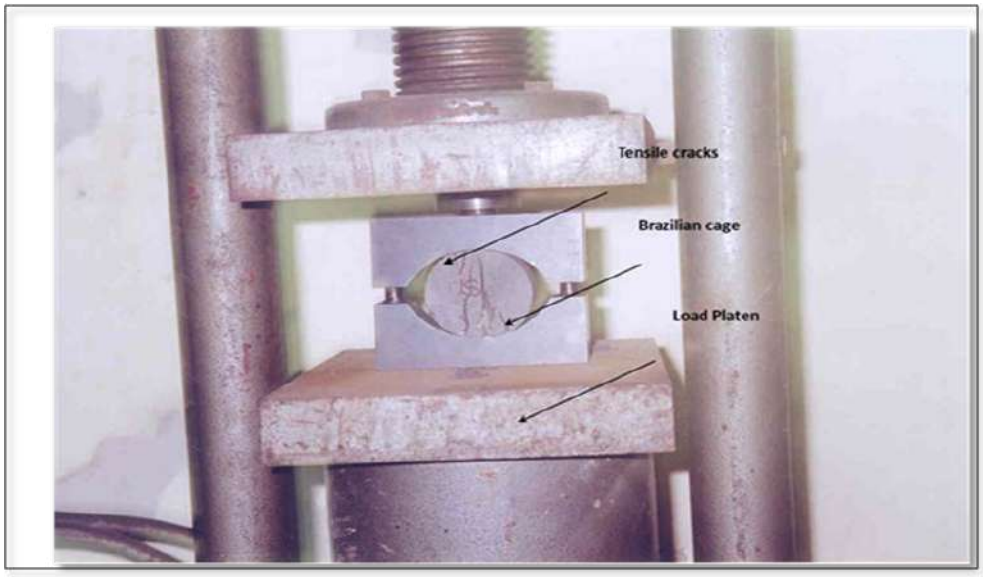


Figure 3: Brazilian cage inside the UTM.

2.3 Cohesion and Angle of Internal Friction Triaxial Test

The rock specimen for conducting triaxial shear test is prepared as per the specifications. The test may be conducted in dry, saturated or at any water content as per the requirement. The standard method for triaxial test from American Society for Testing Materials (ASTM) is given by **ASTM D2664**. The specimen is enclosed in a flexible impervious sleeve and sealed at the top with the cap and at the bottom with the pedestal. The cap will have spherical seating. The axial load is applied to the specimen at a constant rate of deformation or loading in a loading machine. At least three specimen tests

under different confining pressure are conducted to provide values of shear strength parameter. An schematic diagram of triaxial testing machine is shown in Figure 4.

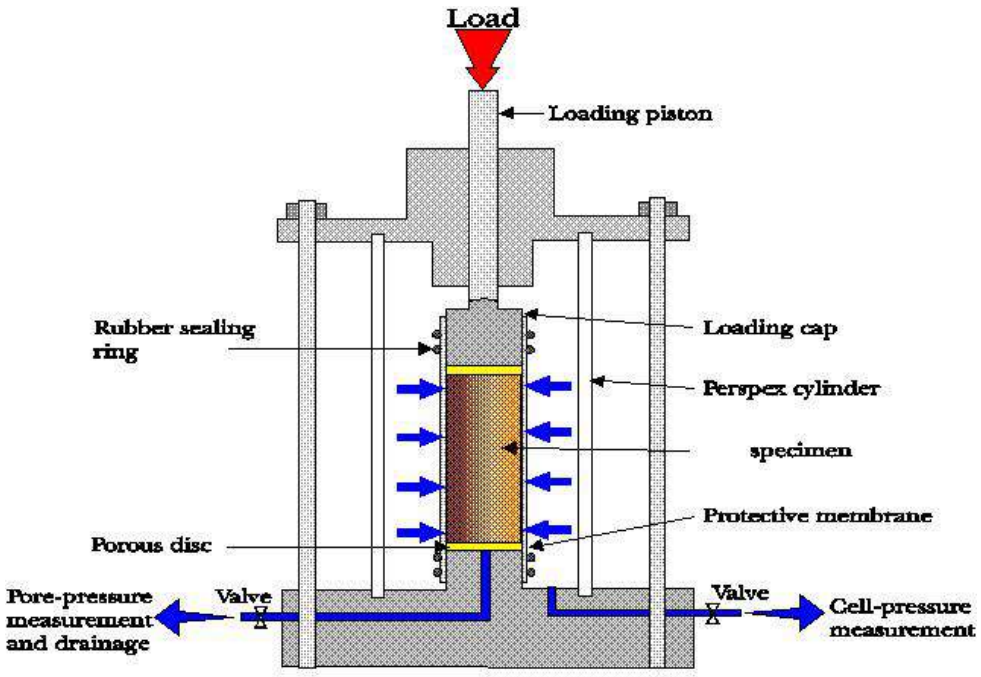


Figure 4: A schematic diagram of triaxial apparatus

2.4 Determination of Slake durability index

The Slake Durability Index (SDI) experiment was performed to estimate the strength reduction of sample under fluid action. The slake durability of rock depends upon the porosity and permeability as they control the fluid flow through the rock. The slake durability index instrument is shown in Figure 5. Dry sample with no sharp edges and corners was taken and weighed. Then sample was rotated with 20 rpm for 30 minute in brass in presence of fluid. After this, sample was taken out from brass drum and dried in over at 105ºC for 24 hour. Now sample was again weighed after 24 hour. The same process was repeated and weight after second cycle is noted. The ratio of final and initial weight of the sample is the slake durability index of the sample.

Figure 5: Slake durability test instrument

2.5 Determination of P-wave velocity

The velocity of ultrasonic pulses travelling in solid material depends on the density and elastic properties of the material. PUNDIT (Portable Ultrasonic Non-destructive Digital Indicating Tester) instrument was used to determine the P-wave velocity (Figure 6). The Instrument displayed the P-wave velocity on basis of transit time (instrument calculate), density of rock, length of core and Young's modulus or Poisson's ratio.

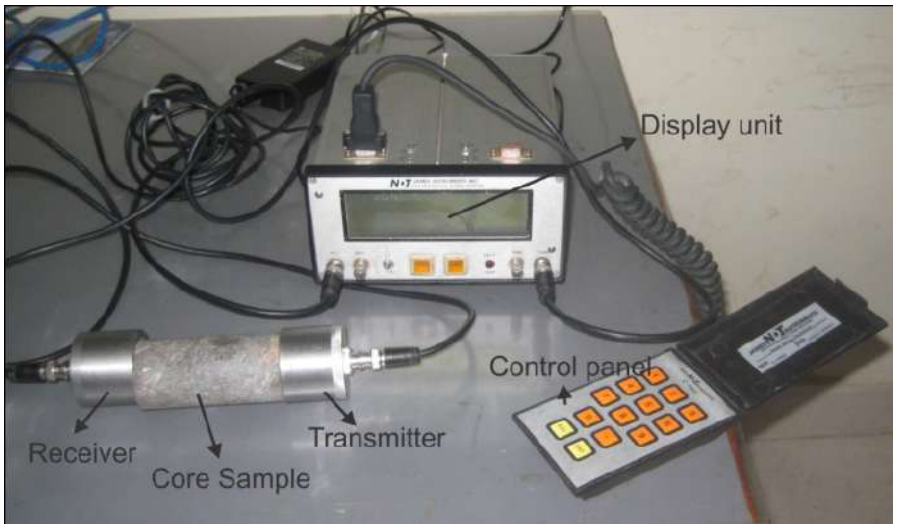


Figure 6: Portable Ultrasonic Non-destructive Digital Indicating Tester for P-wave velocity.

2.6 Deformability Characteristic

Elastic properties of intact rock are measured during uniaxial compression test by measuring deformation as a function of load. Load deformation curve obtained from UTM is used to calculate Young's modulus and Poisson's ratio. Further Young's modulus is used to calculate various elastic parameters like Bulk modulus, Shear modulus etc. In this experiment strain gauges were pasted on the core sample vertically and laterally. These gauges were soldered to the circuit wire to complete the Wheatstone bridge. The gauges were connected to a digital multiplier which records the vertical and horizontal strain in two channels. The multiplier is calibrated such that the gauge factor is set to be 2.1 and the resistance is taken to be 102 Ω.

Young's modulus (E) is a measure of the stiffness of an isotropic elastic material. It is defined as the ratio of the uniaxial stress over the uniaxial strain in the range of stress in which Hook's Law holds.

$$E = \frac{Stress}{Strain}$$

Poisson's ratio (ν) of a material is defined as the negative ratio of the strain in the transverse direction to the strain in the axial direction. In this experiment, the UTM setup was used. Strain gauges were pasted on the sample core vertically and horizontally before applying the pressure. The vertical and horizontal strain gauges give strain values in axial and perpendicular directions respectively at the same time the corresponding load applied was also noted. Using the Stress-Strain curves the Young's Modulus was calculated and using the horizontal and vertical strain gauge readings the Poisson's ratio was calculated.

$$\nu = \frac{AS}{LS}$$

Where,

υ= poison's ratio

AS = Axial Strain

LS = Lateral Strain

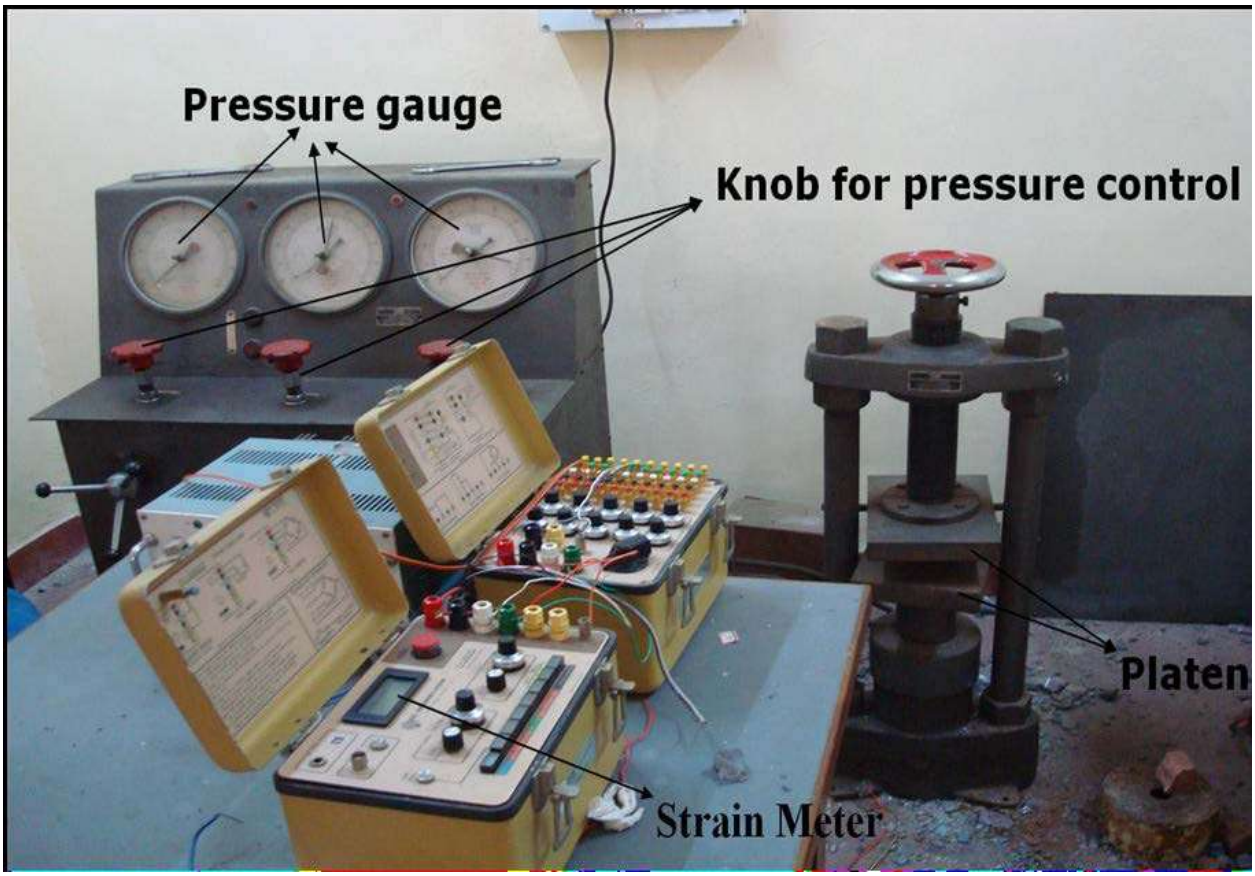


Figure.7: Wheat stone bridge arrangement for strain calculation

Table No. 1 Physical Properties of Core samples

Sample No.	Rock Type	Bulk Density (g/cc)	Grain Density (g/cc)	Porosity (%)	Ultrasonic Wave Velocity (m/sec) Dry		Ultrasonic Wave Velocity (m/sec) Wet	
					P-wave	S-wave	P-wave	S-wave
Dam Site								
DH-1(1)	Quartzite	2.64	2.67	0.15	4157	2512	-	-
DH-1(2)	-do-	-	-	0.14	-	-	4011	2487
DH-1(3)	-do-	2.63	2.64		-	-	-	-
DH-2(1)	-do-	2.62	2.63	0.21	4434	2560	-	-
DH-2(2)	-do-	-	-	0.18	-	-	4079	2456
DH-2(3)	-do-	-	-		-	-	-	-
DH-3(1)	-do-	-	-		4277	2419	3819	2389
DH-3(2)	-do-	2.64	2.68	0.18	-	-	-	-
DH-3(3)	-do-	-	-		-	-	3912	2367
DH-4(1)	-do-	2.67	2.69	0.20	4512	2711	-	-
DH-4(2)	-do-	-	-		-	-	4012	2481
DH-4(3)	-do-	-	-	0.17	-	-	-	-
DH-5(1)	-do-	2.61	2.67	0.15	4534	2689	-	-
DH-5(2)	-do-	-	-	0.18	-	-	4121	2467
DH-6(1)	-do-	-	-		4476	2617	-	-
DH-6(2)	-do-	2.68	2.69	0.19	-	-	3817	2341
DH-6(3)	-do-	-	-		-	-	-	-
DH-7(1)	-do-	-	-	0.15	4226	2513	3978	2351
DH-7(2)	-do-	2.65	2.67		-	-	-	-
DH-7(3)	-do-	-	-	0.22	4234	2555	3998	2456
DH-7(4)	-do-	-	-		-	-	-	-
DH-7(5)	-do-	2.66	2.67	0.20	-	-	-	-
DT outlet (1)	-do-	2.60	2.65	0.15	4410	2589	4012	2481
DT outlet (2)	-do-	2.61	2.66	0.14	-	-	-	-
Power House Piping								
PH-1	Phyllite	2.78	2.70	1.76	3346	2412	2596	1623

PH-2	Quartzite	2.64	2.69	0.16	-	-	-	-
PH-3	-do-	2.62	2.65	0.15	4782	2812	4245	2567
PH-4	Phyllite	2.79	2.69	1.98	3426	2317	2613	1734
PH-5	Quartzite	2.65	2.64	0.17	4723	2893	4213	2492
PH-6	-do-	2.66	2.63	0.21	-	-	4014	2315
PH-7	-do-	2.65	2.62	0.12	-	-	-	-
PH-8	Dolomite	2.72	2.78	-	3527	2245	-	-
PH-9	-do-	-	-	2.12	-	-	3012	1992
PH-10	-do-	2.70	2.66	1.92	4241	2617	3412	2189
PH-11	-do-	-	-	-	-	-	-	-
HRT								
HRT-1	Slate	2.62	2.71	1.86	-	-	5535	2816
HRT-2	-do-	2.63	2.74	1.93	6158	3395	-	-
HRT-3	Dolomite	2.59	2.64	2.13	-		3125	1934
HRT-4	-do-	-	-	-	3690	2341	3094	1925
HRT-5	-do-	-	2.61	2.03	3586	2258	-	-
HRT-6	Quartzite	2.58	2.61	0.16	4334	2721	3817	2489
HRT-7	-do-	2.63	2.67		-	-	-	-
HRT-8	-do-	2.59	2.65	0.20	-	-	3796	2376
HRT-9	-do-	-	-		4504	2819	-	-
HRT-10	Slate	2.68	2.78	0.11	6145	3356	5516	2713
HRT-11	-do-	-	-	0.17	-	-	-	-
HRT-12	Quartzite	2.66	2.63		-	-	-	-
HRT-13	-do-	2.67	2.62	0.21	4487	2413	-	-
HRT-14	-do-	2.63	2.59		-	-	3872	2367
HRT-15	-do-	-	-		4158	2612	3765	2017
HRT-16	-do-	2.62	2.58	0.18	-	-	-	-
HRT-17	-do-	2.5	2.61	0.13	4120	2448	3821	2314
HRT-18	Micaceous Phyllite (Hard)	2.52	2.79	1.75	3678	2334	3214	1989
HRT-19	-do-	-	-	-	3517	2219	3345	2112
HRT-20	-do-	2.68	2.83	1.83	-	-	-	-

Table No.2 Geomechanical Properties of Core samples

Sample No.	Rock Type	Poisson's Ratio	Elastic Modulus (E) (GPa)	Tensile Strength (MPa)	UCS (MPa)		Triaxial Test	
					Dry	Wet	Cohesion (MPa)	Angle of Internal Friction (^{0})
Dam Site								
DH-1(1)	Quartzite	0.24	21.5	21.35	166.27	-	34.12	39.5
DH-1(2)	-do-		-	-	-	157.76	-	-
DH-1(3)	-do-	0.24	21.98	20.84	169.38	-	-	-
DH-2(1)	-do-	0.23	21.24	-	164.43	-	34.24	39.5
DH-2(2)	-do-	-	-	20.78	163.98	-	-	-
DH-2(3)	-do-	-	-	-	-	154.94	34.35	41
DH-3(1)	-do-	-	-	22.07	-	-	36.37	41
DH-3(2)	-do-	0.24	22.65	-	171.95	-	-	-
DH-3(3)	-do-	-	-	21.34	-	159.67	-	-
DH-4(1)	-do-	-	2.69	21.94	171.84	-	-	-
DH-4(2)	-do-	0.24	22.57	-	-	160.87	36.25	42
DH-4(3)	-do-	-	-	22.03	-	-	-	-
DH-5(1)	-do-	-	-	20.85	-	158.07	35.97	42
DH-5(2)	-do-	0.23	22.68	-	170.37	-	-	-
DH-6(1)	-do-	-	-	20.98	171.42	-	-	-
DH-6(2)	-do-	0.23	22.75	-	-	-	35.36	41
DH-6(3)	-do-	-	-	21.08	-	161.06	-	-
DH-7(1)	-do-	0.24	21.35	-	165.35	-	-	-
DH-7(2)	-do-	-	-	19.98	-	153.97	-	-
DH-7(3)	-do-		-	-	164.67	-	34.86	41.5
DH-7(4)	-do-	0.24	21.54	-	-	156.08		
DH-7(5)	-do-	-	2.67	20.05	166.08	-	35.27	42
DT outlet (1)	-do-	0.24	22.64	22.18	170.45	-	36.43	42
DT outlet (2)	-do-		-	-	-	159.16	-	-
PH-1	Phyllite	0.22	12.34	6.67	45.54	30.27	8.56	38
PH-2	Quartzite	0.23	21.23	19.64	159.05	151.02		
PH-3	-do-		2.65	17.58	157.98	148.56	33.99	39

PH-4	Phyllite	0.22	12.22	5.96	42.96	28.94	7.89	39
PH-5	Quartzite	0.23	22.46	18.78	158.96	149.96	-	-
PH-6	-do-	0.24	22.45	19.02	161.58	150.97	34.35	40
PH-7	-do-		-	-	-	-	34.67	40
PH-8	Dolomite	0.23	16.54	6.65	62.89	-	-	-
PH-9	-do-		-	-	-	26.67	16.25	39
PH-10	-do-		-	8.27	64.67	-	-	-
PH-11	-do-	0.23	17.12	12.4	80.78	67.15	18.45	40
HRT-1	Slate	0.23	19.45	10.08	82.81	75.93	20.24	38
HRT-2	-do-	-	-	9.84	-	76.12	-	-
HRT-3	Dolomite		-	6.76	65.12	-	15.12	39
HRT-4	-do-	0.23	16.67	-	-	55.35	-	-
HRT-5	-do-		-	7.93	66.03	-	-	-
HRT-6	Quartzite	0.24	22.13	15.67	-	-	35.65	41
HRT-7	-do-	-	-	-	167.92	153.95	-	-
HRT-8	-do-	-	-		168.09	159.47	35.47	41
HRT-9	-do-	0.24	22.43	19.86	166.98	-	-	-
HRT-10	Slate	0.23	19.47	13.54	64.87	-	15.37	37
HRT-11	-do-		-		65.19	47.96		
HRT-12	Quartzite	0.23	20.43	16.42	-	47.82	29.45	38
HRT-13	-do-	-	-	16.46	94.36	-	-	
HRT-14	-do-	0.23	19.98	10.67	-	79.34	-	-
HRT-15	-do-	-	-	-	96.24	81.34	28.87	38
HRT-16	-do-		2.58	-	159.62	-	34.76	41
HRT-17	-do-	0.24	21.34	17.34	-	148.56		
HRT-18	Micaceous Phyllite (Hard)	0.22	11.56	6.23	39.18	14.69	7.46	38
HRT-19	-do-	-	-	-	40.12	-	-	-
HRT-20	-do-	11.68/0.22	2.83	5.97	-	13.95	-	-

Petrography of Borehole core Samples

From the given bore hole core samples, it is observed that there are four types of rocks present. The rock types are quartzite, phyllite, slate and impure dolomitic rock. The details of rock types in every core samples are given in the Tables.**3.1, 3.2** and **3.3**.

For the petrography of these core samples, the thin sections were prepared of 0.03 mm thickness. The study has been performed under Leica microscope and studied in transmitted light. The macroscopic and microscopic study of these samples is given as follows:

3.1: Sample No. DH-1- DH-7 and DT-Outlet (Dam Site)

Rock Type- Quartzite

Mineralogy: Quartz + Opaque

Description:

Macroscopic Observation: The felsic, light coloured, almost uniform composition through the length of core shows the quartz dominant rock. The maximum percentage of aligned quartz mineral and non-foliated nature rock represent the metamorphosed rock. The origin of rocks are orthoquartzite marked by dominant presence of quartz and white coloured rocks (**Fig. 3.6 and 3.7**).

Microscopic Study: The inequigranular, medium to coarse grained metamorphic rock composed of mainly quartz (more than 95%) and very few opaque minerals. The quartz shows the alignment in particular direction and grains are inequigranular. Non-foliated and granoblastic mosaic textures are identified. Contact between adjacent quartz grains is sutured and deformational bands are frequent (**Fig. 3.10**).

3.2: Sample No. PH-2, PH-3, PH-5 and PH-6 (Power House Piping)

Rock Type- Quartzite

Mineralogy: Quartz + Opaque

Macroscopic Observation: The light green coloured, medium to coarse grained metamorphic rock predominantly composed of quartz. The grains of quartz show the alignment and sutured contact between them. These rocks are little bit different from the dam site quartzites which having all are white in coloure and also textural differences as these samples show more alignment than dam site samples.

Microscopic Study: Under the microscope it consists of dominantly quartz and few opaque grains in minor amount. The grains are coarse (maximum diameter of quartz grain is 0.15 mm) and anhedral and show granoblastic mosaic texture. Contact between adjacent quartz grains is sutured (**Fig 3.10**). Deformational bands are frequent. A few polygonal aggregates of quartz are also seen in this thin section. A modal composition is visually estimated as 95% quartz and 5% others.

3.3: Sample No. PH-1and PH-4 (Power House Piping)

Rock Type: Phyllite

Mineralogy: Mica + Chlorite (?) + Opaque

Macroscopic Observations: Greenish coloured fine grained rock shows phyllitic texture. The rock composed primarily micas and clay minerals. Platy texture and can easily break along the foliation. The strength of rock is less parallel to the foliation direction but other than foliation direction strength is comparatively high (**Fig. 3.5**)

Microscopic Study: The fine to medium grained foliated rock composed of mainly micaseous minerals and clay minerals. Micas flakes and alignments are observed through the section. The foliation shows the initial stage which indicate the low grade of metamorphism (**Fig. 3.11**).

3.4: Sample No. PH-7 to PH-11 (Power House Piping)

Rock Type: Dolomite with impurities

Mineralogy: Carbonate minerals

Macroscopic Observations: The fine to medium grained dark grey coloured sedimentary rock shows the carbonate minerals with carbonatic layering in between all the samples. The minerals could not identified in hand specimen due to dark grey colour and fine grain minerals except some minerals show calcite and white coloured carbonate layer in between grey dolomitic layer. The dolomitic layer is not pure but having impurities.

Microscopic Study: Under the microscope the rock shows fine to medium grained minerals, to identify the minerals are very difficult, muscovite and carbonate minerals have been identified in the samples. Carbonate layer shows the rhombohedral cleavage.

3.5: Sample No. HRT-1, HRT-2, HRT-10 and HRT-11 (HRT)

Rock Type: Slate (black in colour) with carbonate layer

Mineralogy: Biotite+ Mafic minerals+ Carbonate minerals

Macroscopic Observations: The rock consists of predominantly mafic minerals, mica and lithic fragments as minor amounts. The rock is very fine-grained. The platy texture and slaty cleavage indicate the low grade of metamorphism. Carbonate layers having discordant relationship with slate (**Fig. 3.4 and 3.9**). Sample no. HRT-10 also having phyllitic rock contact with slate.

3.6: Sample No. HRT-18- HRT-20 (HRT)

Rock Type: Phyllite (Micaceous)

Mineralogy: Biotite + Muscovite + Quartz + Chlorite + Opaque

Microscopic Study: The rock consists of predominantly muscovite and followed in the order of abundance are quartz, chlorite, and opaque minerals. The minerals are fine grained and show a well developed foliation. Three sets of foliation trends are observed as indicated by the alignment of fine grained muscovite, chlorite and quartz. Minor amounts of opaque minerals are seen associated with later recrystallized quartz probably indicating mobilized ore minerals. Opaque minerals do follow the trend of foliation (**Fig.3.11**).

Table. 3.1: Rock Types of Dam Site

Serial No.	Sample No.	Rock Type	Remarks
1	DH-1	Quartzite	White in colour
2	DH-2	-do-	-do-
3	DH-3	-do-	-do-
4	DH-4	-do-	-do-
5	DH-5	-do-	-do-
6	DH-6	-do-	-do-
7	DH-7	-do-	Last two samples show the light grey colour with minor amounts of pyrite minerals
8	DT-Outlet	-do-	Pure White colour

Table. 3.2: Rock Types of Power House Piping

Serial No.	Sample No.	Rock Type	Remarks
1	PH-1	Phyllite	Greenish foliated
2	PH-2	Quartzite	Light grey in colour
3	PH-3	Quartzite	-do-
4	PH-4	Phyllite	Greenish foliated
5	PH-5	Quartzite	
6	PH-6	Quartzite	
7	PH-7	Quartzite	
8	PH-8	Dolomite with impurities	Dark Grey Colour Rock with carbonate layers in between
9	PH-9	-do-	-do-
10	PH-10	-do-	-do-
11	PH-11	-do-	-do-

Table. 3.3: Rock Types of HRT

Serial No.	Sample No.	Rock Type	Remarks
1	HRT-1	Slate	Blach coloured with Platy texture
2	HRT-2	-do-	-do-
3	HRT-3	Dolomite with impurities	Dark Grey Colour Rock with carbonate layers in between
4	HRT-4	-do-	-do-
5	HRT-5	-do-	-do-
6	HRT-6	Quartzite	Light Green quartzite
7	HRT-7	-do-	-do-
8	HRT-8	-do-	-do-
9	HRT-9	-do-	-do-
10	HRT-10	Slate	Black colour with slaty cleavage
11	HRT-11	-do-	-do-
12	HRT-12	Quartzite	Light green quartzite
13	HRT-13	-do-	-do-
14	HRT-14	-do-	-do-
15	HRT-15	-do-	-do-
16	HRT-16	-do-	-do-
17	HRT-17	-do-	Grey quartzite with pyrite minerals
18	HRT-18	Micaceous Phyllite	comparatively dark green colour phyllite with foliation
19	HRT-19	-do-	-do-
20	HRT-20	-do-	-do-

Fig. 3.1: Sample No. HRT-16 in hand specimen, shows light greenish colour, non-foliated quartzite

Fig. 3.2: Sample No. HRT-15 in hand specimen, shows light greenish colour, non-foliated quartzite

Fig. 3.3: Sample No. PH-11 in hand specimen, shows dark grey colour dolomitic rock with white coloured carbonate layering in between the dolomitic rock

Fig. 3.4: Sample No. HRT-10, this sample has contact between slate rock and phyllite. **A)** Right portion shows the slate **B)** Now right portion shows phyllitic rock.

Fig. 3.5: Sample No. PH-1, A green colour foliated phyllite (Low grade metamorphism).

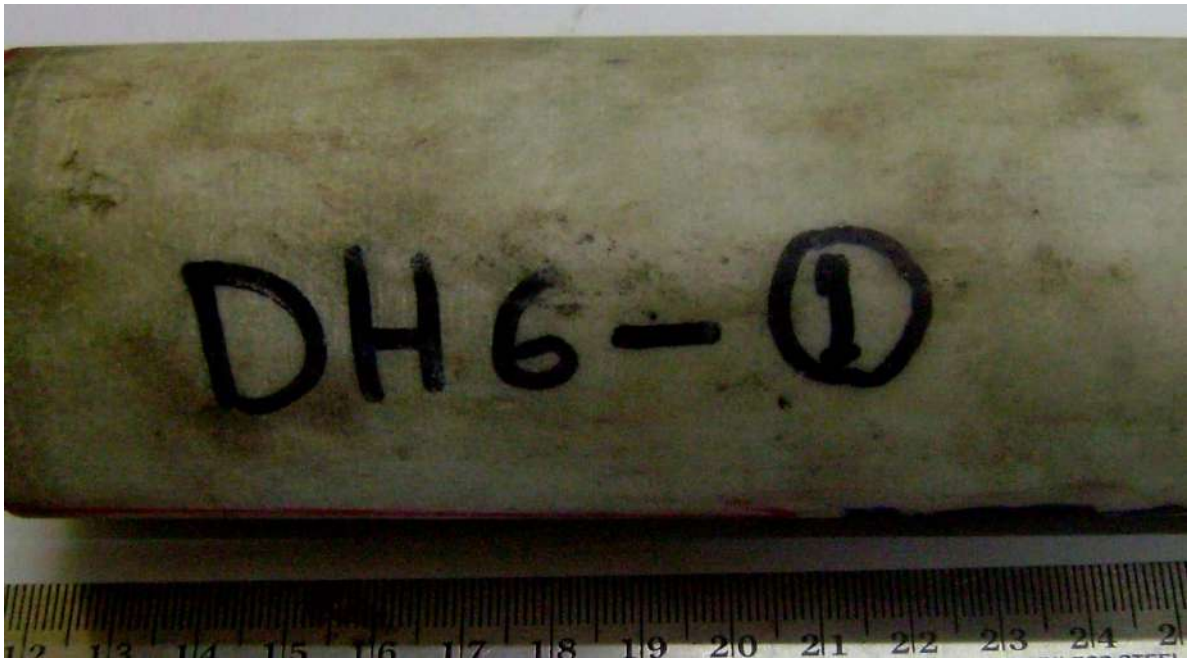


Fig. 3.6: Sample No. DH-6, A white coloured quartzite having more than 95% quartz

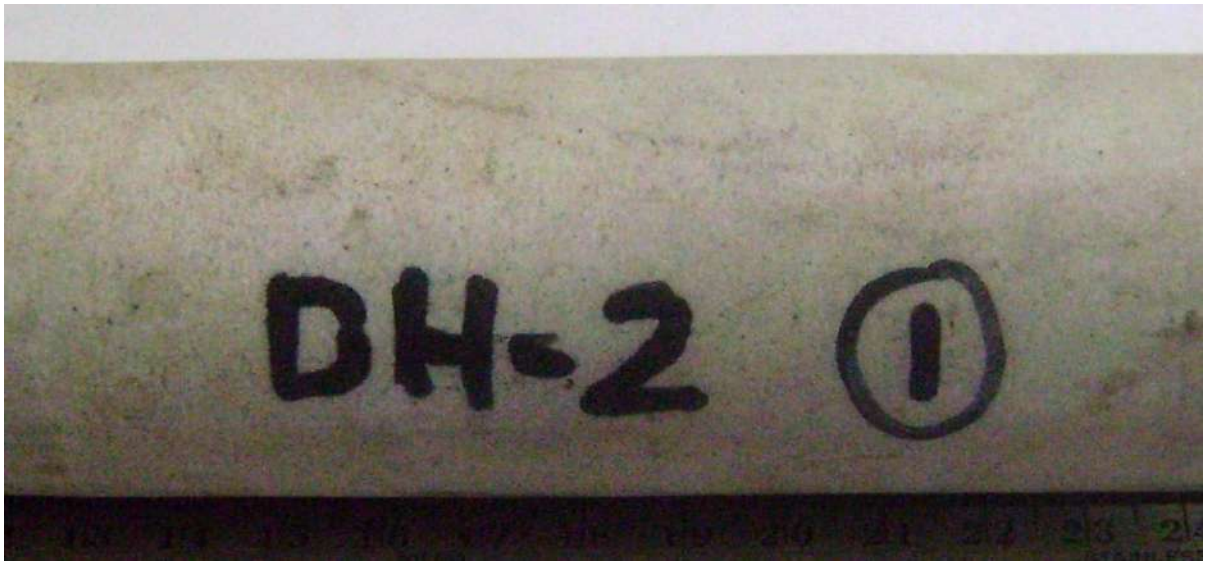


Fig. 3.7: Sample No. DH-2, A white coloured quartzite having more than 95% quartz

Fig. 3.8: Sample No. HRT-17 shows aligned quartz crystals of quartzite rock

Fig. 3.9: Sample No. HRT-2 (Slate), black coloured rock with platy texture and carbonate layer between the rock.

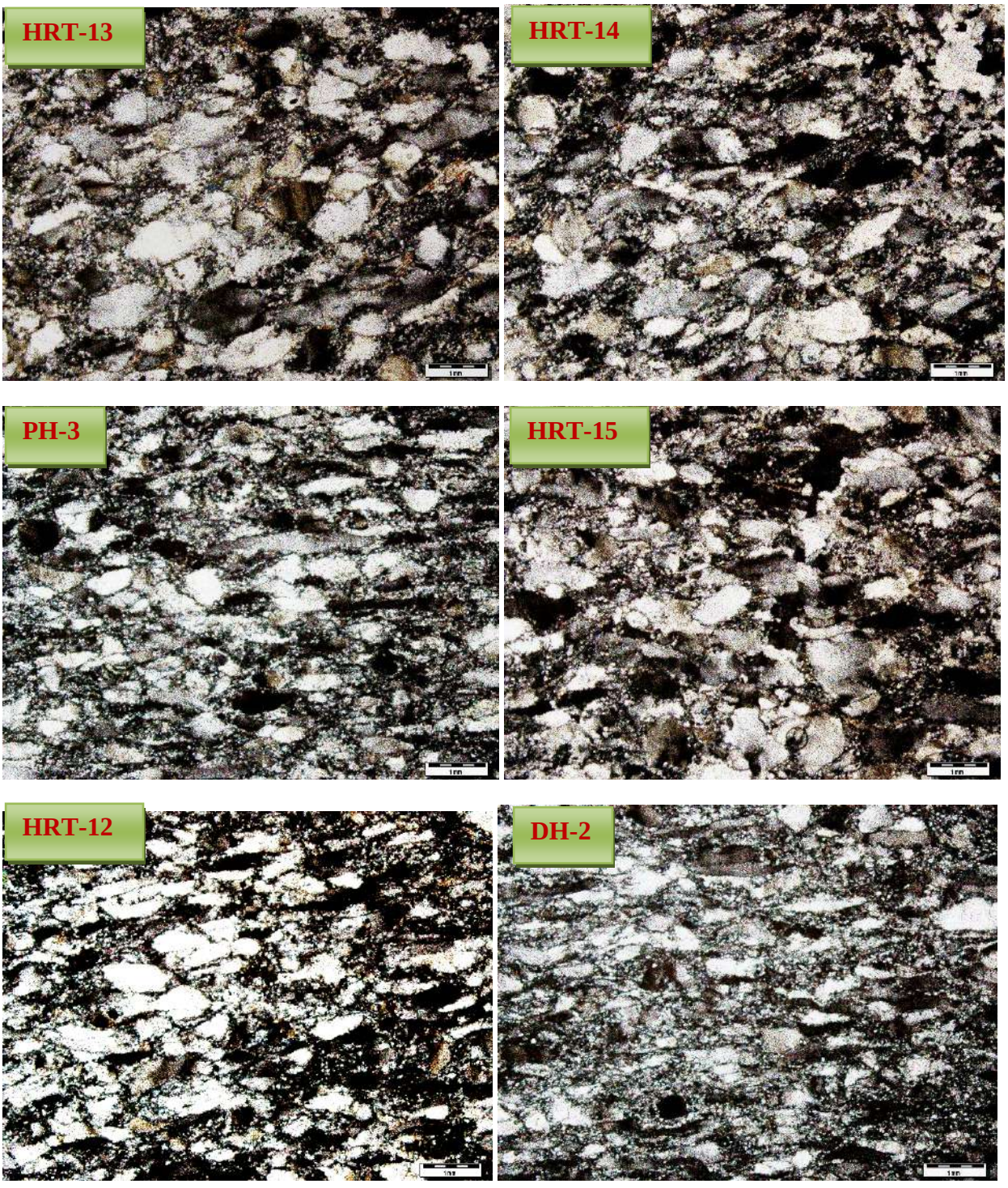


Fig. 3.10: Quartzite Rocks, Thin Sections of different core samples show the quartzite rock with quartz alignments in a particular direction. Sample nos. are marked at every photographs (All photographs have been taken under cross nicole).

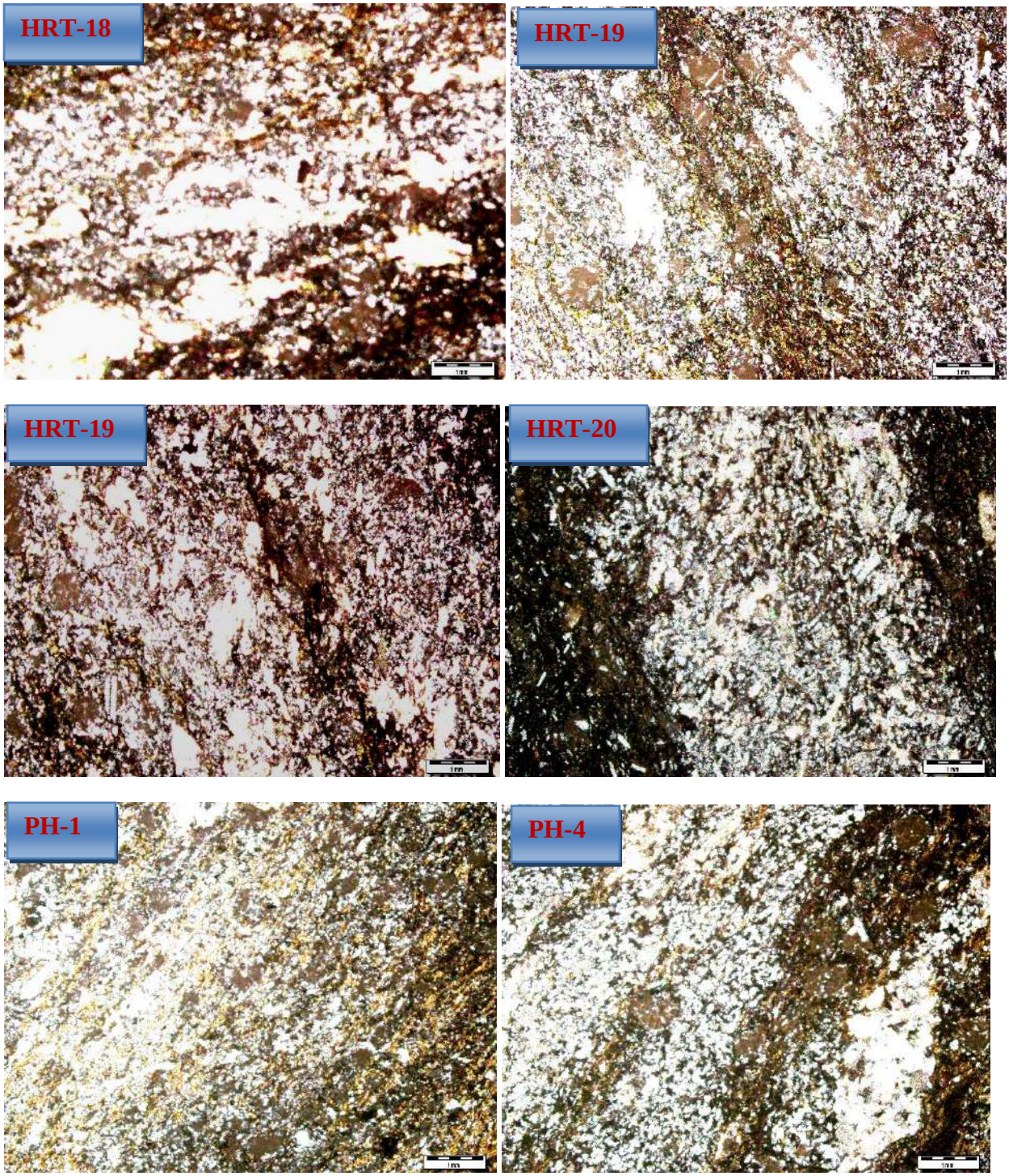


Fig. 3.11: Phyllite Rocks, Photographs of thin sections of core samples show the foliation of mica minerals. Minerals are aligned and foliated which are clearly visible in every photograph of thin sections. The sample nos. are marked in every photographs (All photographs have been taken under cross nicole).

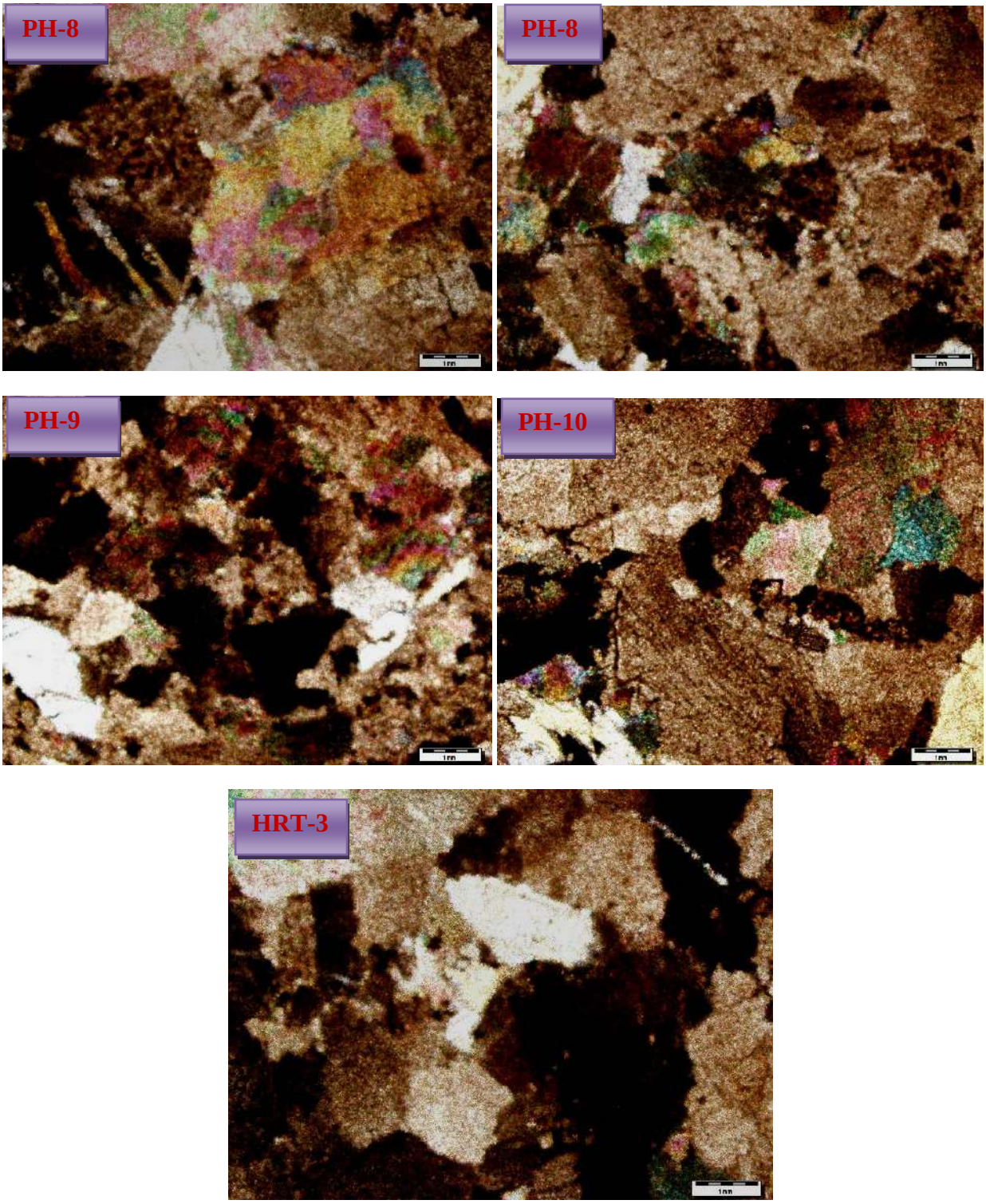


Fig. 3.12: Dolomite (Impure), Photographs show the medium dolomitic rocks with white coloured carbonate layers in between (Cross nicole).

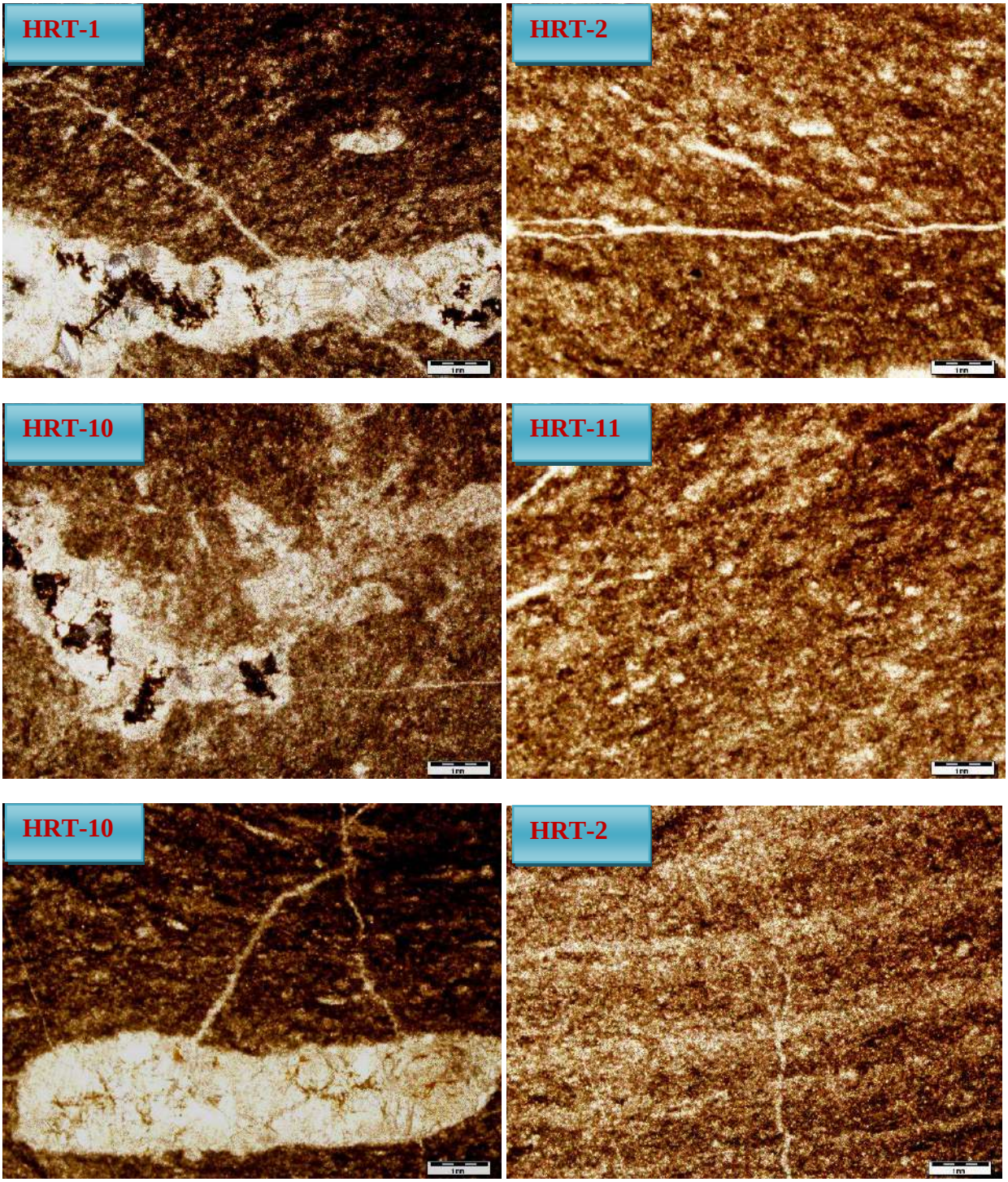


Fig. 3.13: Slate, Photographs show the fine grained mineral with white carbonate layers. The mineral composition is clayey and micaceous which show the alignment in particular directions and low grade foliation effects (cross nicole).

ANNEXURE-IV

GEOPHYSICAL SURVEY REPORT

Draft Report
On
Seismic Refraction Survey for Wangchhu Hydro Power Project (600MW) Phuentsholing: Bhutan.

October, 2011

Submitted to:

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Fig. C: The ABC Method (Horizontal Refractor)

Fig D: The ABC Method (Dipping Refractor)

CHAPTER-1

1. INTRODUCTION

The Wangchu hydroelectric project envisages construction of a 120m high concrete gravity dam across river Wangchu in Bhutan near Silli village (N:26046' – E:89038'02"). The water is proposed to be conducted through a 12.50 km long, circular, headrace tunnel of 8.5 m diameter to a surface powerhouse located just upstream of Wangchu - Piping river confluence (26046': 89044'; 78F/9). The scheme would utilize a net design head of 285.0m available below the Tala Hydroelectric Project up to Piping confluence and would generate 600 MW (installed capacity) of power.

The dam site of the Wangchu hydroelectric project is approachable by road from Phuentsholing via Geddu up to Devrali. Thereafter, a 7 km traverse is to be taken along a footpath on a ridge via village Gammna to reach the dam site. The power house site is approachable from Phuentsholing via Hasimara and Alipurduar through state road (between Phuentsholing and Hasimara and Alipurduar and Rajabhatkhawa) and NH-31 between Hasimara and Alipurduar. From Rajabhatkhawa, a fair weather road leads up to Bhutanghat (26046': 89051'; 78F/9) on Indo-Bhutan border. From Bhutanghat, an 8Km long purely temporary road made every year after monsoon, joins Piping which may be treated as the last road head. The powerhouse site is just on the other bank of the river. The distance between Phuentsholing and Bhutanghat is 82 Km.

Satluj Jal Vidyut Nigam Limited (SJVN Ltd) mandated Advanced Technology & Engineering Services (ATES) a Division of Aimil Ltd. to conduct Refraction Seismic Survey along the TRT, TRT out fall and Dam for Wangchhu Hydro Electric Power Project (600MW) in Bhutan. The purpose of the survey was to determine and estimate the thickness of overburden, underlying fractured and sound (compact) rock system based on the seismic waves through these layers generated by the Seismic Refraction Technique.

The Refraction Seismic survey was conducted from 16th October, 2011 to 23rd October,2011 . In all Six (06) Seismic lines were conducted using 24 channel Seismograph (RAS-24) with 24 geophones and inter Geophone spacing of 5m & 6m interval have been kept according to the field condition and on the basis of available ground stretch with an overlapping of 12 geophones. The lines were laid on the ground as per the plan of Power House,TRT and Dam Axis of the Project area. Site representative and Geologist of SJVN Ltd., provided the locations of seismic lines Total Station survey team of SJVN Ltd also marked the seismic lines on the ground provided with pegs at every 5m interval. The total length covered Six (06) Seismic lines are of 887m.

This report covers the field investigations concerning seismic refraction tests carried out at the project site, the results of the field studies and conclusions drawn there from.

1.1 REGIONAL GEOLOGY

Physiographic & Regional Geology

i) Physiography

Physiographically, the Bhutan Himalaya can be divided roughly in to three zones from south to north; **(i)** Sub-Himalaya or Foot-hill zone; **(ii)** Lesser Himalaya and **(iii)** Great Himalaya.

The Sub-Himalayan zone consists of the Siwalik sediments of Tertiary period, lying to the south of the Main Boundary Fault (MBF) and is characterised by low lying hills generally below an altitude of 1500m. Because of a gap in the Siwalik exposures between the Teesta and Torsa rivers in this part of Himalaya, the Sub-Himalayan zone is missing and Lesser Himalaya starts immediately after the alluvial plains of North Bengal, as seen near Phuentsholing.

The Lesser Himalaya consists of chains of ranges of hills, rising to 1500 to 4925m in altitude, which radiate southward from the Great Himalayan Range, forming the watersheds between the main rivers. The terrain is rouged, characterized by deep valleys with precipitous slopes and thick cover of vegetation. This zone includes rocks of all three belts, i.e., the Frontal belt (excluding the Siwalik Sediments), Central Crystalline Belt

and the Tethyan Sedimentary Belt of the Black Mountain Region. The highest peak in this zone in Central Bhutan is the Black Mountain (4925m above the mean sea level.

The Great Himalayan Zone, lying to the north of the Lesser Himalaya, is characterized by a chain of snow-covered high peaks along Tibetan border. The main peaks along the Great Himalayan Range in Bhutan, from west to east, are Chomolhari (7314 m), Kungphu (6797 m), Takaphu(6532 m) and Kula kangri (7516 m) among many others. The Great Himalayan Zone in Bhutan comprises rocks of the Central Crystalline Belt, Tethyan Sedimentary Belt and younger 'Chomolhari Granites'.

ii) Geological Structure

Major thrusts/faults of the Bhutan Himalaya, from south to north, are:

(i) The Main Boundary Fault / Thrust (MBF);

(ii) The thrust between Damuda Group and Buxa Group;

(iii) The Shumar Thrust between the rocks of Shumar formation and the Buxa Group;

(iv) The Main Central Thrust (M.C.T) between the Frontal Belt and the Central Crystalline Belt.

Main Boundary Fault / Thrust separating the Siwalik sediments from the rocks of the Buxa/Gondwana Groups, is the most important tectonic feature. It has been mapped between the Pana River and Sarbhang in the west for strike distance of about 40 Km, and again between Kakulong and the Dhansiri River in the Eastern Bhutan for a strike distance of about 140 Km with two gaps in between. It is a moderate to steep northerly dipping fault/thrust plane with vertical dips (southerly at places).

In Eastern Bhutan, two prominent thrusts have been recognized, viz.,

(i) Separating Buxa Group of rocks represented by Duiry pebbly phyllite of the Phuentsholing Formation and the Damuda Group (Gondwana)

(ii) Thrust separating the rocks of Shumar Formation from those of the Buxa Group.

The contact between the frontal Belt and Central Crystalline Belt has been regarded as the Main Central Thrust (M.C.T) in other sectors of the Himalaya.

However in Bhutan Himalaya, this contact is regarded as the thrusted by some workers and as a gradational metamorphic contact by the others.

A number of major fold structures have been recognized in Bhutan Himalaya. Folds within the Buxa Group have a general axial trace in E-W direction. Overturned regional anticline and syncline are seen in Mangde chu and the Sankosh river sections, where various formations of the Buxa Group are repeated due to the folding. The dolomites of the Manas Formation occupy the core of the syncline whereas the quartzite's belonging to Thungsing Formation occupy the core of the anticlinal structure.

Geology of the dam site:

The dam site is located approx. 25 km upstream of Wangchu-Piping river confluence (26°46′-89°44', 78F/9).

General Geology & Tectonic Setup:

The dam site area lies in the south-western region of Bhutan and falls within the rocks of Shumar Formation of the Lesser Himalayan Belt of Bhutan Himalayas. Broadly, the Shumar Formation of rocks comprises of an alternating sequence of quartzite and phyllitic quartzite/mica schist interbands. The phyllitic quartzite interbands is fine grained, commonly grey to greyish green and well foliated. However, sporadically due to enrichment of carbonaceous matter it attains dark grey hues. Locally, laminations, defined by alternating quartzose, phyllosilicate rich layers are well preserved. Essential mineral constituents of pelites are muscovite/sericite, quartz, chlorite and opaques. Quartz veins are wide spread in the sequence. The quartzite is commonly fine grained, white to greyish white, thin to medium bedded and well jointed. Colour banding defining the bedding is conspicuous and is invariably associated with a bedding joint. The concentration of phyllosilicate minerals along layers as well as the bedding joints imparts a flaggy look to the rock. Locally, the quartzite is almost devoid of phyllosilicate minerals with inconspicuously developed bedding imparting a massive look to the litho-unit. The dominant minerals in the quartzite are quartz, muscovite, sericite with rare chlorite and biotite. The quartzite grades into phyllitic quartzite/micaceous quartzite with increase in proportion of phyllosilicate

minerals. The tectono-stratigraphy of the Bhutan Himalayas worked out by GSI (1995) is as under:

Tectono-Stratigraphic order of superposition

Tethyan	Conglomerate, schist, siltstone, sandstone, limestone & volcanic.
…… Contact Unconformity……	
Thimphu Group	Gneiss, migmatite, amphibolite & high grade metasediments
……Thimpu Thrust (MCT) ……	
Jaishidanda Formation	Biotite, garnet, staurolite with tectonic slivers of granite gneiss schist
…… Jaishidanda thrust ……	
Shumar Formation	Quartzite, phyllite, chlorite mica schist with tectonic slivers of granite gneiss.
…… Shumar Thrust ……	
Diuri Formation	Diamictite, phyllite, quartzite
…… Unconformity /Faulted……	
Baxa Group	Gritty feldspathic quartzite, limestone, dolomite, quartzite, conglomerate slate, phyllite &tectonic slices of Permian Setikhola Formation
…… Baxa Thrust ……	
Damuda Subgroup	Sandstone, siltstone, shale. clay and conglomerate
…… Main Boundary Thrust (MBT)……	
Siwalik Group	Sandstone, siltstone. shale, clay and conglomerate
…… Fault ……	
Quaternary	Sand, conglomerate, silt and clay

The left abutment in general has massive outcrop of closely jointed quartzite from river bed to a height of over 300 m due to the removal of thin overburden after planer slides and erosion. The bedding of quartzite is not clear but appears to be striking in NE – SW direction and dipping 300 towards NW. The quartzite rock is traversed by vertical fissures

(shears) striking across the river, i.e. in N300-450E – S300-450W direction which could be the foliations. Besides the foliation joints, a set of vertical joints running parallel to the river (NW-SE) and a low dipping joint with 150-300 dip towards S15-30W was also observed.

The right abutment which is comparatively gentle in nature is dominated by overburden, mainly in the form of slope debris (ranging in thickness from 5 to 15 m) along with a thick vegetation cover. Rock exposures are scanty on the right flank. Blocky quartzite is exposed at the river bed (with open joints) traversed by three or more sets of joints, i.e 450-600/N25-40W dipping into the valley in upstream direction, 500-700/S50-75W dipping into the hill, 450-600/S50-60E and 750-800/N30E dipping into the valley (strike parallel to river flow). A quartzite band extending along the river for about 150 m is noticed on the right abutment above 500 meter elevation, upstream of the dam axis. The right flank is supposed to be dominated by phyllite rock which has undergone weathering due to its soft nature.

On the right abutment quartzite rock (ledge) extending along the river is exposed at the river bed level for 4 to 5 m in height, extending 50 m in the downstream direction and some 75 m in the upstream direction. This upstream extension of the rock exposure is broken along a NE-SW, gently flowing nala, having rocky abutments formed of sub-vertically to vertically dipping joint planes. The quartzites are further exposed in the upstream of this nala. Similarly, a quartzite band extending along the river for about 150 m is noticed on the right abutment at about 70-80 m, above the river bed at the dam axis.

CHAPTER-2

METHODOLOGY

2.1 Seismic Refraction Method

The main objective of seismic prospecting is the mapping of geological structures in the uppermost part of the earth's crust. The methods for generating seismic waves are weight dropping techniques, mechanical hammer, mechanical vibrator etc. Any impact-source should ideally provide a pulse of duration of not more than a few milliseconds with large amplitude; the waves are of very short wavelength with periods ranging from 0.002 to 0.15 seconds, the corresponding frequencies being in the range of 5 to 500 Hz at depths of interest for engineering applications. In an elastically homogeneous ground, the source inducts instantaneous deformation which causes elastic deformation in the vicinity of the source point. By virtue of elastic behavior of rocks, the elastic deformation propagates in all directions as spherical fronts. In view of, restriction on use of explosives in the project area, the hammer was used as the energy source in this survey.

2.2 Propagation of Waves

The application of shock force to the ground surface generates four principal types of waves. Two propagate within the ground and are known as body waves (or Compression P-wave and Shear S-wave). The other two propagate along the surface and are called surface waves (or Raleigh and Love waves). The surface waves are used for the SASW (Spectral Analysis of Surface Waves) method while refraction and reflection methods use either P or S waves or in some cases both.

2.2.1 Body Waves

(i) Compressional Wave

The body wave, having the highest velocity among seismic waves, is known as the longitudinal, compressional, dilatational, primary or P-wave. The rock particle motion caused by the P-wave is to and fro in a straight line parallel to the direction of propagation. The media is alternately

compressed and stretched. P-waves correspond to ordinary sound waves. It is primarily the velocity of longitudinal or compressional waves, which is utilized also in the seismic reflection method of exploration.

(ii) Shear Wave

The other body wave is known as the transverse, shear, secondary or S-wave. The S- wave causes motion of particles in a plane at right angle to the direction of propagation. Shear wave velocity is generally just a little more than half of longitudinal wave velocity.

2.2.2 Surface Waves

(i) Love Wave

The surface wave with the higher velocity is known as Love or L-Wave or Q wave or SL wave. The wave motion is perpendicular to the propagation direction of the waves and in a plane parallel to the contact surface.

(ii) Raleigh Wave

The second surface wave is known as the Raleigh or R-wave or LR wave. In R-wave motion, the rock particles vibrate in vertical ellipses in such a way that when at the top of the ellipse, they are moving opposite to the direction of the wave travel. The velocity of the Raleigh waves is generally about 10% less than that of the shear waves.

2.3 Three Basic Concepts

The seismic waves are considered to be transmitted according to the same laws as for ray optics. The three basic concepts, namely Huygen's principle, Fermat's principle and Snell's law are vital and relevant in this context.

2.3.1 Huygen's Principle

This principle states that each point on a wave surface acts as a source for an expanding spherical wave and after a certain time lapse, the envelope of all the wavelets defines the new wave front. The principle is used for the construction of wave fronts, provided that the location of a wave front at a particular time and the velocity in the medium are known.

2.3.2 Fermat's Principle

This principle states that an elastic disturbance travels from one point to another along a path that requires the minimum amount of time. The statement implies that the shortest travel time does not necessarily refer to a straight line between the points, if the points are located in different media with different physical properties.

2.3.3 Snell's Law

Snell's law is a consequence of Fermat's principle – it states that the sine of the angle of incidence is to the sine of the angle of refraction as the velocity of wave in the first medium is to the velocity in the second medium.

2.4 Principle of Seismic Refraction Method

The seismic refraction method is well suited for determination of the depth of rock and other strata substantially different from the surface materials. It can also be used on water-covered areas.

Seismic waves when pass through the various media having different velocities, get refracted according to the law of refraction which means that if the ray incident on the interface between the two media makes an angle i1 with the normal to the interface, the refracted ray in the adjoining medium makes an angle i2 with the normal such that

$$\frac{sini_2}{sini_1} = \frac{V_2}{V_1}$$

Where V1 and V2 are the seismic velocities in the two media respectively.

Referring to Fig. A, it follows that if V2 is greater than V1, we have Sin i2 >Sin i1 and therefore, i2 > i1. Thus, the refracted ray makes a larger angle with the normal, i.e. smaller angle with the interface than the incident ray.

If the incident ray makes a particular angle Ic such that i2 = 90°, then

$$\frac{Sin90^{\circ}}{Sin\ i_c} = \frac{V_2}{V_1}$$

OR

$$\sin i_c = \frac{V_2}{V_1}$$

In this case, the refracted ray travels along the interface and the angle of incidence is called the critical angle.

In seismic refraction method, the radiating shock waves are picked up by the vibration detector (geophone), where the time of travel gets recorded. If a number of geophones are arranged in straight line from the shot point, the first ray to arrive at the nearer geophones will be the direct ray traveling along the surface. However, at the distant geophones, the first ray to arrive will be the refracted ray because it travels along part of the path with higher velocity V2 and overtakes the direct ray. Therefore, if first arrival times are plotted against the distance from the shot point, the first few arrival times will fall on one straight line and the rest on the other, and the slopes of these lines will depend on the velocities V1 and V2 respectively.

In fact, the slopes (distance over travel time) are equal to the respective velocities as indicated in Fig. B (a). The main purpose of the seismic refraction equipment is to detect the time taken by the wave front to reach the various geophones. The raw data consists of travel times and distances. This time distance information is then processed to obtain an interpretation in the form of velocities of wave propagation layer wise and structure of the sub-surface strata.

2.5 Field Work

This section presents briefly the field procedures, problems encountered, constraints and equipment used. Personnel of Advance Technology & Engineering Services (a division of AIMIL Ltd.) carried out the fieldwork from 16th October, 2011 to 23rd October 2011. The Specification of the Seismograph Seistronix make RAS-24 deployed at site for this work is given in Table 2.

2.5.1 Data Acquisition

A seismic spread consists of a group of geophones connected to the recording system at regular interval along a line. In this study, spreads of

24 geophones with an overlapping of 12 channels were used with a RAS-24 Seismic Survey system, A seismic unit consists basically of amplifiers, geophones, seismic cables, seismic energy source (Mechanical Hammer or other source) and recording device. The amplifier's function is to boost the signal detected by the geophones to a level suitable for input to the recording device. The choice of seismic unit involves factors such as frequency response of geophones, length of seismic lines, required spacing between geophones, number of channels and required recording parameters (record length, sampling frequency, etc.). In total Five (5) seismic lines as per the plan were covered. All spreads were performed with 5m-geophone spacing and 24 geophones were used in each spread.

Sledge Hammer was used as seismic source to generate the seismic waves. For each spread of 24 geophones In total and for all spreads maximum 15 shots were executed: 5 shots (2 end shots and 11 intermediate shots, 1 mid shot) within the profile to obtain the lateral velocity variation in the top layer(s) and 2 far shots on either side of the spread, to provide the true seismic velocity of the weathered, fractured or "sound" rock surface. The seismic record from each shot was verified in the field, as a first step of quality control. Several criteria were adopted:

- The first arrival times on each seismic record must be clean and precise.
- No more than two traces should be absent.

No end trace should be absent, so as to obtain a good time – distance curve closure.

If any of these criteria were not respected, the shot was then repeated to obtain the desired accuracy. Site Photographs during data acquisition are given. Investigation Plan of the Project refer the drawing Dwg No:- SJVN/ATES/SEISMICPLAN/001. In total, Six (06) seismic lines were completed using nine (09) Seismic spreads.

2.5.2 Constraints for Data Acquisition

There were serious field constraints for data acquisition that impacted the quality and coverage of the results.

The first constraint was the limitation in using dynamite (explosive) as a seismic energy source for all profiles. Numerous profiles or sections of profiles were located close to housing and farming making the hammer as the only possible seismic energy source. In particular, it prevented many profiles to locate the « offset shot » past the critical distance to allow the mapping of bedrock along the whole seismic spread. In the type of overburden material present at the site, the maximum source-receiver distance to record a clear first break arrival was in the order of 50 to 100 metres while the « offset shot » had to be located up to 25 metres away from the last geophone to map the bed rock in many cases.

2.6 Interpretation Technique

The following are the various methods of interpretation used in this survey:

(i) Intercept Time Method
(ii) Wave Front Method
(iii) Plus Minus or ABC Method (Hawkin's Method)

A brief description of the above methods is detailed below. However, interpretation of seismic data was done using the time intercept & Hawkin's method. Rayfract software has been used for interpretation and it was cross-checked by manual interpretation using Time Intercept & plus minus method. The time intercept method allows the computation of rock depth at shot points. This method provides information on thickness of the various layers, depth to bedrock and rock quality. However, plus minus method provides the same information at each geophone location and with greater accuracy

2.6.1 Intercept Time Method

Refer to Fig. B (a) for the two-layer case.

The intercept time, marked T_{2i} on the ordinate, is the intersection between the prolongation of the time – distance segment corresponding to the second medium & the time axis through the impact point B. In

order to obtain the intercept time, we need the time –distance-depth equation for the segment corresponding to the second layer.

The equation for the arrival time T1 of the direct surface waves is

$$T_1 = \frac{x}{V_1}$$

Which is the equation of a straight line through the impact point with slope 1/V1For the arrival time T_2 of the refracted wave,

We have,

$$T_2 = \frac{x}{V_2} + 2\frac{h_1}{V_1} Cosi_{12}$$

This is the equation of a straight line with slope 1/V2 and an intercept on the time axis through the impact point (i.e. the time for x = 0) equal to

$$T_{2i} = \frac{2h_1}{V1} \cos\ i_{12}$$

From this, we get

$$h_1 = \frac{T_{2i}V_1}{2COSi_{12}}$$

In terms of velocities V1 & V2,

$$h_1 = \frac{\langle T_{2i}|V_1|V_2\rangle}{\left(2\left|\sqrt{\langle V_2^2|-|V_1^2\rangle}\right|\right)}$$

$$\text{Cos}i_{12} = \sqrt{\left(1 - \left|\frac{v_1^2}{v_2^2}\right|\right)}$$

The intercept time T2i is the total time T2 minus the time x/V2, x being the distance BO. The real travel path in the V2 layer is, however, not equal to x but to x – 2h1 tan i12 because of the slant ray paths in the upper medium. We have, therefore, the delay time (concept introduced by Gardner in 1939), which is defined as the travel time for any slant ray path between the ground surface (reference level) & a refractor minus the time required to travel the horizontal projection of the ray path at the velocity of the refractor. There are two delay times, one at the impact point and another at the receiving station, in the intercept time due to which only an average depth and not a unique solution can be obtained. A true intercept time can, however, be obtained if the refractor velocity segment from an impact point is extrapolated back to the point parallel to a covering refractor velocity curve from a distance impact point.

2.6.2 Wave Front Method

Unlike the other methods discussed here that use a analytical approach to solving the travel times, the wavefront inversion allows to migrate the combined forward and reverse traveltimes into depth using a Finite Difference approximation of the eikonal equation. The eikonal equation can simply be written as:

$$|\nabla_x T| = s(x)$$

where T is travel time and s(x) is slowness as a function of position x.

The use of computer allows to solve the equation numerically given a set of measured travel time.

This method has gained in popularity since the development of softwares for PC such as RAYFRACT that overcame the critics concerning the complicated graphical construction of wave fronts and the unreliable results from such complex constructions. This approach is now commonly used in the industry for engineering application of seismology.

2.6.3 Plus Minus or ABC Method (Hawkin's Method)

This method belongs to the interpretation group where two emergence points on the refractor and a common point on the ground surface are considered. The time terms on which it is based were introduced by Edge and Laby in 1931. The interpretation technique was described by Heiland (1940) & Jackosky (1950) under the name 'ABC System' and 'Method of Differences' respectively. The method was further analyzed and developed by Hagedoorn (1959) as the plus part of the plus minus method & by Hawkins (1961) as the reciprocal method.. In the Encyclopedic Dictionary of Exploration Geophysics, Sheriff (1973) has called the interpretation technique as the 'ABC Method'.

It makes use of reversal refraction survey data to obtain depths to the refractor at intermediate geophone positions. It is very useful for determining the complete profile of refractor. A typical time distance plot for two layers case is shown in Fig. C.

The method involves summation of arrival times of critically refracted waves at a common surface point, B in Fig.C from two impact points A & C minus the reciprocal time (R.T.) i.e. the total time from impact point to impact point for waves propagated via the refractor. It is absolutely necessary that the times summed at B & the reciprocal time refers to the same refractor. Inherent in the ABC Method are the assumptions that the refractor is plane between the emergence points D & E and that the refractor velocity is constant.

With reference to Fig. C., let us consider three points A, B and C on the surface. For direct refraction survey, the source is at A while B & C are receivers. For reverse survey, the source is at C while B & A are receivers.

Let T_{AB} = Travel time from source A to receiver B,

TCB = Travel time from source C to receiver B,

TAC = Travel time from source A to receiver C,

TDB = Travel time from D to B,

TEB = Travel time from E to B,

TDE = Travel time from D to E,

V1 = Velocity of wave in first layer,

V2 = Velocity of wave in second layer,

& h1 = Depth to the refractor beneath the receiver.

Then,

$$T_{AB} + T_{CB} - T_{AC} = T_{DB} + T_{EB} - T_{DE}$$

$$= \frac{2 h_1}{V_1 \cos i_{12}} - \frac{2 h_1 \tan i_{12}}{V_2}$$

$$= \frac{2 h_1}{V_1 \cos i_{12}} - \frac{2 h_1 \sin^2 i_{12}}{V_1 \cos i_{12}}$$

$$\frac{V_1}{V_2} = Sini_{12}$$

for critically refracted wave

$$= \frac{2 h_1 \cos i_{12}}{V_1}$$

$$\text{Thus } h_1 = \frac{(T_{AB} + T_{CB} - T_{AC}) V_1}{2 \cos i_{12}}$$

If $T_{AB} + T_{CB} - T_{AC} = T$, where T is the delay time,

In term of velocities,

$$h_1 = \frac{T V_1 V_2}{2\sqrt{V_2^2 - V_1^2}}$$

From the time distance curve, we know the values of T_{AB}, T_{CB}, T_{AC}, V_1 and V_2. Substituting these values in the above equation, we can get the depth of refractor at every receiver position.

Figure.D pertains to the case when the refractor is inclined. The derivation of the depth formula is restricted to the region DBG since terms outside the triangle are common to the travel times from the impact point to point B and in the reciprocal time but occur with different signs so that they cancel each other.

In this case, $h_1 = \dfrac{T \; V_1}{2 \cos i_{12} \cos \phi_2}$

2.7 Representative Seismic Velocities In Various Materials

There is no unique value of longitudinal wave velocity for any material in the substrata on account of inherent variations therein from site to site and even within the same site at best it can be range of longitudinal wave velocities. Different investigators have also proposed slightly varying criteria. To serve as a guide, the following four criteria are presented in Tables 3 to 6:

(i) Criteria suggested by BIS (Table 3).
(ii) Criteria listed in Manual of Rock Mechanics, CBI&P, May 1988 (Table 4)
(iii) Criteria proposed by Rzhevsky & Novik, 1971 (Table 5)
(iv) Criteria proposed by M.B.Dobrin, 1976 (Table 6)

RESULTS

Presentation of Results

Investigation plan for seismic survey of the project area as Dwg No:-SJVN/ATES/SEISMICPLAN/001. The seismic results are presented in the form of seismic sections for each of Six (06) seismic lines (WSP-PH01(355M), WSP-PH02(115M), WSP-PH03(115M), WSP-PH04(115M), WSP-DAM05(115M), WSP-DAM05(72M)). The seismic results are presented in the form of seismic sections defining the subsurface status in terms of compressional wave velocities for each of Six(06) seismic lines. All the seismic spreads were implanted within pre-defined position of each seismic line axis as per the practical feasibility of seismic line.

The results are given for each of the Six(06) seismic lines. Every line has been presented as a seismic tomogram showing the chainage at X-axis and Depth at Y-axis. Different layers have been shown presenting different seismic velocities with velocity contours. All tomograms are prepared into seismic sections with Horizontal scale 1:500 and vertical scale 1:500 have been presented in natural scale of 1:1000 on A3 size papers depending upon the length of section.

Particular Use of Terms

The term weathered is used in following paragraphs. It includes both the mechanical and chemical weathering conditions of the rock. The mechanical weathering includes broken up rock. No distinction has been made between the two.

The term bedrock and rock relates to the rock in its massive state.

Analysis of Seismic Data

The analysis of seismic data has been carried out on the basis of seismic velocities recorded at each Spread and the depths derived adopting these recoded velocities using RAYFRACT software/Wave front method..

Calibration of Seismic Velocities

400 to 800 m/s : Unconsolidated overburden material Top soil

800m/s to 1500 m/s: consolidated soil,clay,sandy matrix.

1500m/s to 2000m/s: Pebbles, Cobbles & Boulders in sandy matrix.

2000 to 3000 m/s: Weathered rock layer.

3000 to 4000 : Sound bed Rock.

Bedrock consists mainly in Quartzite with various degrees of weathering and fracturing.

Interpretation of Seismic Data along different Seismic Lines.

Six(06) Seismic Lines as WSP-PH01(355M), WSP-PH02(115M), WSP-PH03(115M), WSP-PH04(115M), WSP-DAM05(115M), WSP-DAM05(72M)were surveyed at Power house site,TRT outfall.along the TRT alignment and Dam site area the summary results of the lines are discussed in the following paragraphs based on the velocities calculated from Seismic Surveys. The seismic profiles given show the seismic velocities for each seismic unit detected by the survey. All profiles WSP-PH01(355M), WSP-PH02(115M), WSP-PH03(115M), WSP-PH04(115M), WSP-DAM05(115M), show only three layers Overburden Weathered zone and Sound Rock layer. Whereas seismic profile WSP-DAM06(72M) show only Two layers it is due the small spread length.

All Geo-Seismic Depth sections are

Geo-Seismic Line AA1 (Refer Fig:1, Tomogram as WSP-PH01(355 M))

Seismic line AA1 covering 355m length involved laying of 71 geophones with Five(05) number of seismic spreads with an overlapping of 12 geophones in each and every seismic spread. A total of 24 shots were taken using Hammer as source (2, Far shots, 2 end shots and 19 intermediate shots and 1 mid shot all intermediate shots are taken at every geophone all along the seismic spread). The seismic velocities are observed in the tomograms using Rayfract software with the type of sub-surface material. In absence of Borehole data However, it is expected that the first layer with compressional velocities in the range of 400 m/s to 1500m/sec could be related to unconsolidated overburden materials as clayey humus rich soil, Silt, Clay and Sand. The second layer with recorded P-wave velocity in the range of 1500 m/sec to 3000m/sec indicates the presence of Boulders of Quartize with high degree of weathering and the Third layer with recorded velocity 3000m/s to 4000m/s indicates the presence of medium to fine grained Quartize with various degrees of weathering and fracturing.

The depth at every geo phone positions is given below.

Geophone	Natural Soil Level	Weathered Layer	Rock Line
1	180.389	159.889	135.389
2	180.254	160.254	133.754
3	180.129	161.629	130.129
4	180.065	162.565	129.065
5	180.069	162.569	128.569
6	179.985	163.485	128.485
7	179.931	163.931	128.431
8	179.914	164.414	127.914
9	179.853	163.853	127.353
10	179.754	163.254	127.254
11	179.717	163.217	127.717
12	179.639	162.639	127.639
13	179.524	162.024	128.024
14	179.452	161.952	127.952
15	179.383	161.383	128.883
16	179.343	161.843	130.343
17	179.359	161.859	131.359
18	179.271	162.271	132.271
19	179.256	161.756	133.256
20	179.264	162.264	134.264
21	179.254	162.254	134.254
22	179.325	161.825	135.325
23	179.155	160.655	134.655

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24	179.143	160.143	135.143
25	179.103	159.103	134.103
26	179.066	158.566	133.566
27	179.027	158.527	133.527
28	178.988	158.488	133.988
29	178.975	158.475	132.475
30	178.932	160.432	131.432
31	178.894	160.394	130.894
32	178.853	161.853	130.353
33	178.778	161.278	129.778
34	178.72	161.72	129.22
35	178.676	160.176	129.176
36	178.611	160.611	129.611
37	178.575	160.075	130.075
38	178.544	160.544	130.544
39	178.519	160.519	131.519
40	178.477	161.977	132.477
41	178.408	161.908	133.408
42	178.369	162.369	135.869
43	178.34	162.34	135.84
44	178.311	162.311	133.311
45	178.227	161.727	133.227
46	178.201	161.201	132.201
47	178.141	160.641	131.641

48	178.148	160.148	130.648
49	178.076	159.576	130.076
50	178.085	158.585	129.585
51	178.055	158.555	129.555
52	178.019	158.519	129.019
53	177.988	159.488	129.488
54	177.931	159.431	129.431
55	177.908	159.908	129.408
56	177.853	159.853	129.353
57	177.714	160.214	129.214
58	177.742	160.242	129.742
59	177.985	160.985	130.485
60	178.063	161.063	131.563
61	178.264	161.764	132.264
62	178.305	161.805	133.805
63	178.288	161.788	134.288
64	178.325	162.325	135.325
65	178.295	162.295	135.795
66	178.267	161.767	136.267
67	178.329	161.829	135.829
68	178.345	163.345	137.345
69	178.376	163.376	137.376
70	178.456	163.456	137.456
71	178.476	163.476	137.476

Geo-Seismic Line BB1 (Refer Fig: 02, Tomogram as WSP-PH02(115 M))

Seismic line BB1 covering 115 m length involved laying of 24 Geophones. A total of 22 shots were taken using Hammer (2, Far shots, 2 end shots and 10 intermediate shots and 1 mid shot all intermediate shots are taken at every even geophone all along the seismic spread). The seismic velocities are observed in the tomograms using Rayfract software with the type of sub-surface material in absence of Borehole data. However, it is expected that the first layer with compressional velocities in the range of 400 m/s to 1500m/sec could be related to unconsolidated overburden materials as clayey humus rich soil, sand and silt. The second layer with recorded P-wave velocity in the range of 1500 m/sec to 3000m/sec indicates the presence of admixture of fine sand with pieces of rock fragments partially to highly weathered, Quartz and Amphiboles and the Third layer with recorded velocity 3000m/s to 4000m/s indicates the presence of Quartzite with various degrees of weathering and fracturing.
The depth at every geo phone positions is given below.

Geophone	Natural Soil Level	Weathered Rock Level	Rock Line
1	181.501	160.001	130.501
2	180.951	158.451	128.951
3	180.626	157.126	127.626
4	180.324	155.824	126.824
5	180.163	155.163	125.663
6	180.068	154.568	126.068
7	180.006	154.006	126.006
8	180.028	154.028	126.028
9	180.026	154.026	126.026
10	180.014	154.014	126.014
11	180.001	154.001	125.501
12	180.022	154.022	125.022
13	180.008	154.008	124.008
14	180.019	153.519	124.019
15	180.006	153.506	124.006
16	180.012	153.512	124.012
17	180.012	153.512	124.012
18	179.983	153.483	123.983
19	179.983	153.483	123.983
20	179.986	153.486	123.986
21	179.955	153.955	123.955
22	179.83	153.83	123.33
23	179.385	153.885	122.885
24	178.131	153.131	123.131

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Geo-Seismic Line CC1 (Refer Fig: 03, Tomogram as WSP-PH03(115 M))

Seismic line CC1 covering 115 m length involved laying of 24 Geophones. A total of 27 shots were taken using Hammer (2, Far shots, 2 end shots and 22 intermediate shots and 1 mid shot all intermediate shots are taken at every even geophone all along the seismic spread). The seismic velocities are observed in the tomograms using Rayfract software with the type of sub-surface material in absence of Borehole data. However, it is expected that the first layer with compressional velocities in the range of 400 m/s to1500m/sec could be related to unconsolidated overburden materials as Clay and Sand. The second layer with recorded P-wave velocity in the range of 1500 m/sec to 3000m/sec could be the mixture of weathered mass, rock fragments and Boulders of Quartzite, phyllites mixed with soil and clay and the Third layer with recorded velocity 3000m/s to 4000m/s indicates the presence of sound bed rock consisting of Quartzite with various degrees of weathering and fracturing.

The depth at every geo phone positions is given below.

Geophone	Natural Soil Level	Weathered Soil Level	Rock Line
1	178.497	156.497	128.497
2	178.474	155.974	127.474
3	178.545	156.045	127.545
4	178.465	155.965	126.965
5	178.414	155.914	125.914
6	178.444	156.444	124.944
7	178.446	156.946	124.446
8	178.481	157.481	124.481
9	178.616	158.616	124.616
10	178.555	160.055	124.555
11	178.521	160.021	124.521
12	178.344	157.844	124.344
13	178.197	156.197	124.197
14	178.099	156.099	124.099
15	178.063	156.063	124.563
16	178.114	156.114	124.614
17	178.129	157.629	124.629
18	178.131	157.631	125.131
19	178.17	158.17	125.17
20	178.095	158.595	125.595
21	178.027	159.527	126.027
22	177.984	159.484	126.484
23	177.911	159.411	127.911
24	177.236	158.236	127.236

Geo-Seismic Line DD1 (Refer Fig:04, Tomogram as WSP-PH04(115 M))

Seismic line DD1 covering 115 m length involved laying of 24 Geophones. A total of 27 shots were taken using Hammer (2, Far shots, 2 end shots and 22 intermediate shots and 1 mid shot all intermediate shots are taken at every even geophone all along the seismic spread). The seismic velocities are observed in the tomograms using Rayfract software with the type of sub-surface material in absence of Borehole data. However, it is expected that the first layer with compressional velocities in the range of 400 m/s to1500m/sec could be related to unconsolidated overburden materials as Clay, silt and Sand. The second layer with recorded P-wave velocity in the range of 1500 m/sec to 3000m/sec could be the mixture of weathered mass, rock fragments and Boulders of Quartzite,phyllites mixed with soil and clay and the Third layer with recorded velocity 3000m/s to 4000m/s indicates the presence of sound bed rock consisting of Quartzite with various degrees of weathering and fracturing.

The depth at every geo phone positions is given below.

Geophone	Natural Soil Level	Weathered Soil Level	Rock Line
1	177.512	153.512	126.012
2	177.498	153.498	125.498
3	177.488	154.988	125.488
4	177.453	155.453	124.453
5	177.368	156.368	123.868
6	177.29	156.29	123.79
7	177.529	156.529	124.029
8	178.032	157.532	124.032
9	178.209	158.209	124.209
10	178.278	158.778	124.278
11	178.29	159.79	124.79
12	178.257	160.257	124.757
13	178.239	161.239	124.739
14	178.175	161.175	124.675
15	178.121	161.121	124.621
16	178.056	161.056	126.056
17	177.95	161.45	125.95
18	177.868	161.368	125.868
19	177.712	160.212	125.712
20	177.583	158.583	125.583
21	177.426	155.426	125.426
22	177.298	155.298	124.298
23	177.283	155.283	123.783
24	177.229	155.229	123.729

Geo-Seismic Line EE1 (Refer Fig:05, Tomogram as WSP-DAM05(115 M))

Seismic line EE1 covering 115 m length involved laying of 24 Geophones. A total of 27 shots were taken using Hammer (2, Far shots, 2 end shots and 22 intermediate shots and 1 mid shot all intermediate shots are taken at every even geophone all along the seismic spread). The seismic velocities are observed in the tomograms using Rayfract software with the type of sub-surface material in absence of Borehole data. However, it is expected that the first layer with compressional velocities in the range of 400 m/s to1500m/sec could be related to unconsolidated overburden materials as Clay,Silt and Sand The second layer with recorded P-wave velocity in the range of 1500 m/sec to 3000m/sec could be the mixture of weathered mass, rock fragments and Boulders of Quartzite,phyllites mixed with soil and clay and the Third layer with recorded velocity 3000m/s to 4000m/s indicates the presence of sound bed rock consisting of Quartzite with various degrees of weathering and fracturing.

The depth at every geo phone positions is given below.

Geophone	Natural Soil Level	Weathered Layer	Rock Line
1	404.084	383.584	370.084
2	404.299	385.299	371.799
3	404.431	387.931	372.431
4	404.474	390.474	371.974
5	404.397	393.397	372.897
6	404.289	395.289	372.789
7	403.687	398.687	374.187
8	404.062	397.562	373.062
9	405.056	397.556	374.556
10	405.354	397.854	374.354
11	405.917	398.417	374.917
12	405.659	398.659	374.659
13	405.41	399.41	374.41
14	404.909	399.909	372.409
15	404.858	400.358	371.358
16	405.3	400.3	370.8
17	405.442	400.442	368.942
18	406.182	400.182	368.182
19	406.321	398.821	367.821
20	406.15	399.15	366.15
21	405.97	397.97	365.47
22	405.942	397.442	364.942
23	406.108	397.108	364.108
24	405.459	396.459	363.459

Geo-Seismic Line FF1 (Refer Fig:06, Tomogram as WSP-DAM06(72M))

Seismic line EE1 covering 72 m length involved laying of 12 Geophones. A total of 15 shots were taken using Hammer (2, Far shots, 2 end shots and 10 intermediate shots and 1 mid shot all intermediate shots are taken at every even geophone all along the seismic spread).

Only two layers are deciphered due to its small length of the Seismic spread. The seismic velocities are observed in the tomograms using Rayfract software with the type of sub-surface material in absence of borehole data. However, it is expected that the first layer with compressional velocities in the range of 400 m/s to1500m/sec could be related to unconsolidated overburden materials as Clay ,Silt and Sand. The second layer with recorded P-wave velocity in the range of 1500 m/sec to 3000m/sec could be the mixture of weathered mass, rock fragments and Boulders of Quartzite,phyllites mixed with soil and clay and the Third layer with recorded velocity 3000m/s to 4000m/s indicates the presence of sound bed rock consisting of Quartzite with various degrees of weathering and fracturing.

The depth at every geo phone positions is given below.

Geophone	Natural Soil Level	Weathered Layer
1	405.345	393.345
2	405.209	392.209
3	405.246	393.246
4	405.162	395.162
5	405.217	397.217
6	405.294	399.294
7	405.277	399.277
8	404.892	398.892
9	405.594	398.594
10	405.76	398.26
11	405.934	397.934
12	405.73	396.73

Field data acquisition setup.

Laying seismic cable:

Clipping Geophones with the seismic cable along the spread

Geophone and Seismic cable in a spread.

Hammer shot

Table:1 Coordinates of Seismic Lines

LINE No.	START POINT				END POINT			
	EASTING	NORTHING	ELEVATION	GEOPHONE POSITION	EASTING	NORTHING	ELEVATION	GEOPHONE POSITION
WSP-PH001	49687.634	44715.954	180.389	A	50047.432	44674.269	178.476	A1
WSP-PH002	49723.377	44753.984	181.651	B	49689.609	44644.850	178.131	B1
WSP-PH003	49903.193	44750.144	178.497	C	49949.433	44644.850	177.236	C1
WSP-PH004	50012.462	44619.884	177.512	D1	50021.174	44734.548	177.229	D
WSP-DAM005	39987.476	49960.789	404.084	E	39999.120	50075.198	406.459	E1
WSP-DAM006	40001.052	50112.298	405.345	F1	40003.654	50040.345	405.73	F

Table 2 - TECHNICAL SPECIFICATIONS OF RAS-24

GENERAL	
Number of Channels:	12 or 24 per RAS module, up to 240 channels per system (10 modules)
Sample Intervals:	.125, .25, .5, 1, 2 and 4 ms
Record Length:	4 ms - 64 sec, 2 ms - 32 sec, 1 ms - 16 sec, .5 ms - 8 sec,.25 ms - 4 sec, .125 ms - 2 sec
Multiline Operation:	10 lines
CDP Operation:	2D: Automatic or manual roll of entire spread 3D: Managed by RAS-24 script editor
Stacking:	Vertical stack
Cable:	One 12 takeout cable for 12-channel system. Two for 24 channel system
Laptop to RAS Interval:	1200ft maximum 3 pair wire
RAS to RAS Interval:	5000ft maximum 2 pair wire
Recording Format:	SEG-2, SEG-D 8038, SEG-D 8058

RAS-24 MODULE	
Channels:	12 or 24
A/D Resolution:	24 bits using Delta-Sigma A/D converters - one per channel
Preamp Gain (PG):	12db, 24db, 36db or 48db, remotely selectable
Frequency Response:	.125 ms: 2 - 3300Hz, .25 ms: 2 - 1650 Hz, .5 ms: 2 - 825 Hz, 1 ms: 2 - 412 Hz, 2 ms: 2 - 206 Hz, 4 ms: 2 - 103 Hz
Dynamic Range:	112db @ 2 ms PG=36db, 117db @ 2 ms PG=12db (typ)
Distortion (THD):	.005% at 25 Hz, 2 ms sample interval (typ)
Crosstalk:	Greater than 90db
CMR:	Greater than 90db @ 60 Hz
Max Input Signal:	880 mVRMS @ 12db, 55 mVRMS @ 36db
Input Noise:	.21 mVRMS @ 2ms PG=36db, 1.6 mVRMS @ 2ms PG=12db (typ)
Anti-Alias Filters:	4 ms 103 Hz, 2 ms 206 Hz, 1 ms 412 Hz, .5 ms 825 Hz, .25ms 1650 Hz, .125ms 3300 Hz
Test Oscillator:	10, 25, 50, 60, 100, 125, 200, 250 Hz Amplitude adjustable in 10 mV steps
Instrument Tests:	Internal digital tests, battery voltage, internal voltage, crosstalk, amplifier pulse, CMR, amplifier noise, dynamic range, gain & phase similarity, system timing, communications, trigger verification
Line Tests:	Geophone pulse, geophone similarity, geophone resistance, cable leakage
Connectors:	Two 27-pin NK-27-21C connectors for geophone spread cable, 3-pin Bendix for trigger, two 6-pin Bendix for data, 3-pin Cannon for power
Power:	12 volts nominal. Standby: 60ma / Acquisition:12 Chs: 1A, 24 Chs: 2A
Physical:	10.5” x 13.5” x 6”, 10 lb

Table 3: Representative Seismic Wave Velocities in Various Materials as per IS: 1892 –1979 'Code of Practice for Subsurface Investigation for Foundations'. (First Revision)

Sr.No.	Material	Longitudinal Velocity (m/s)
1.	Sand and top soil	180 to 365
2.	Sandy clay	365 to 580
3.	Gravel	490 to 790
4.	Glacial till	550 to 2135
5.	Rock talus	400 to 760
6.	Water in loose material	1400 to 1830
7.	Shale	790 to 3350
8.	Sandstone	915 to 2740
9.	Granite	3050 to 6100
10.	Limestone	1830 to 6100

Table 4: Representative Seismic Wave Velocities in Various Materials (Reference: Manual on Rock Mechanics, C B I & P, May 1988)

Sr. No.	Type of Materials	Longitudinal Velocity (m/s)
	a) Unconsolidated Materials	
1.	Most unconsolidated materials	Below 980
2.	Normal soil	240-450
3.	Hard packed soil	450-600
4.	Loose sand, above water table	240-600
5.	Loose sand, below water table	450-1200
6.	Loose mixed sand and gravels wet	450-1050
7.	Loose gravel, wet	450-900
	b) Consolidated Materials	
1.	Most hard rocks	Above 2400
2.	Coal	900 – 1500
3.	Clay	900 – 1800
4.	Soft Shale	1200 – 2100
5.	Hard shale	1800 – 3000
6.	Soft sandstone	1500 – 2100
7.	Hard sandstone	1800 – 3000
8.	Weathered limestone	As low as 1200
9.	Hard limestone	2400 – 5400
10.	Basalt	2400-3900
11.	Granite and unweathered gneiss	3000-6000
12.	Compacted glacial tills, hardpan, cemented gravels	1200-2100
13.	Frozen soil	1200-2100
14.	Rock salt	4000-5500
15.	Glacial moraine	1500-2700

Table 5: Velocities of Longitudinal Waves in Constituent Phases of Rocks (After Rzhevsky and Novik, 1971)

Phase	Apparent Density (kg/m^3)	Longitudinal Velocity (m/s)
Water	1000	1485
Air	129	339
Ice	918	3200-3300

Table 6: Representative P& S – Wave Velocities for Some Rocks
(Ref: Dobrin, M.B. (1976), "Introduction to Geophysical Prospecting", Third Edition, McGraw-Hill Book Company)

S.No.	Material	P -Wave Velocity (m/s)	S - Wave Velocity (m/s)
1.	Granite	5000-6000	2500-3300
2.	Granodiorite	4780	3100
3.	Diorite	5780	3060
4.	Gabbro	6450	3420
5.	Basalt	5400-6400	2700-3500
6.	Dunite	6800-8640	3500-4400
7.	Gneiss	3500-7500	-
8.	Marble	3700-7000	-
9.	Sandstone	1400-4300	-
10.	Limestone	5900-6100	2800-3100
11.	Anhydrite	4100	-
12.	Shale	2100-3400	-

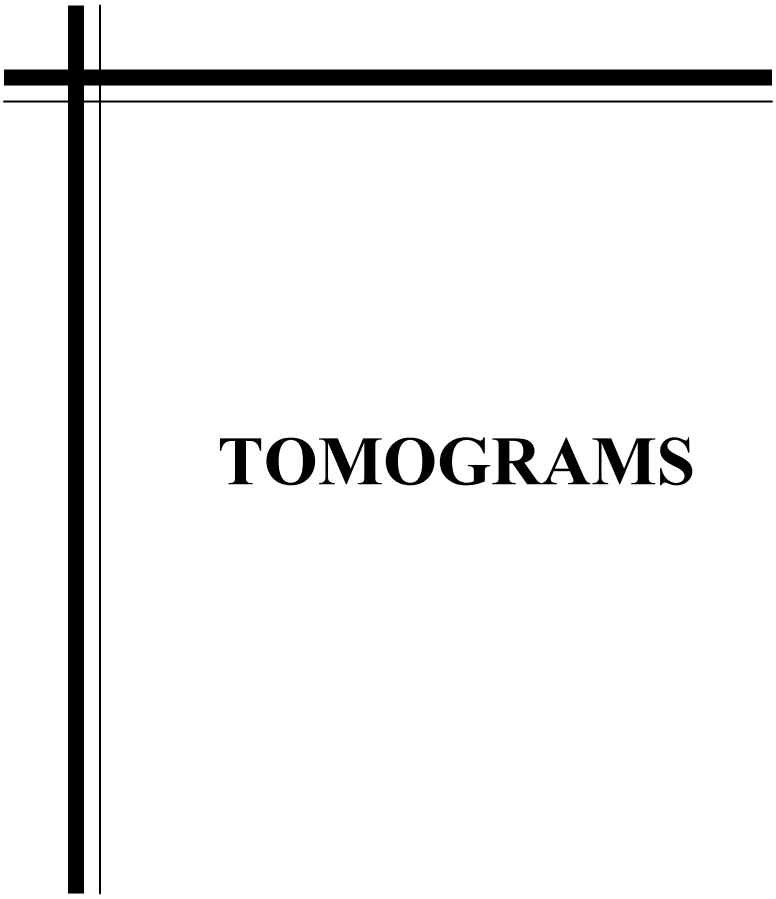
CONCLUSIONS

The Seismic Refraction Survey conducted for Satluj Jal Vidyut Nigam Limited for Power House, TRT Portal and Dam site to Wangchhu Hydro Electric Power Project (600 MW) Dam site at Silli village, Power house at Piping in Bhutan has enabled recording of the seismic P-wave velocities and depths to subsurface material along Six (06) seismic lines on the Power House, TRT Portal and Dam over the site. Three (03) layers are deciphered in all the seismic lines. It is expected that the first layer with compressional velocities in the range of 400 m/s to 1500m/sec could be related to unconsolidated overburden materials as Clay, Silt, and Sand. The second layer with recorded P-wave velocity in the range of 1500 m/sec to 3000m/sec which indicates could be the mixture of fine sand with pieces of rock fragments, weathered boulders of Quartzites and Phyllites etc., and the Third layer with recorded velocity in a range of 3000m/s to 4000m/s indicates the presence of sound bed rock, consisting of Quartzite, Phyllites with various degrees of weathering and fracturing.

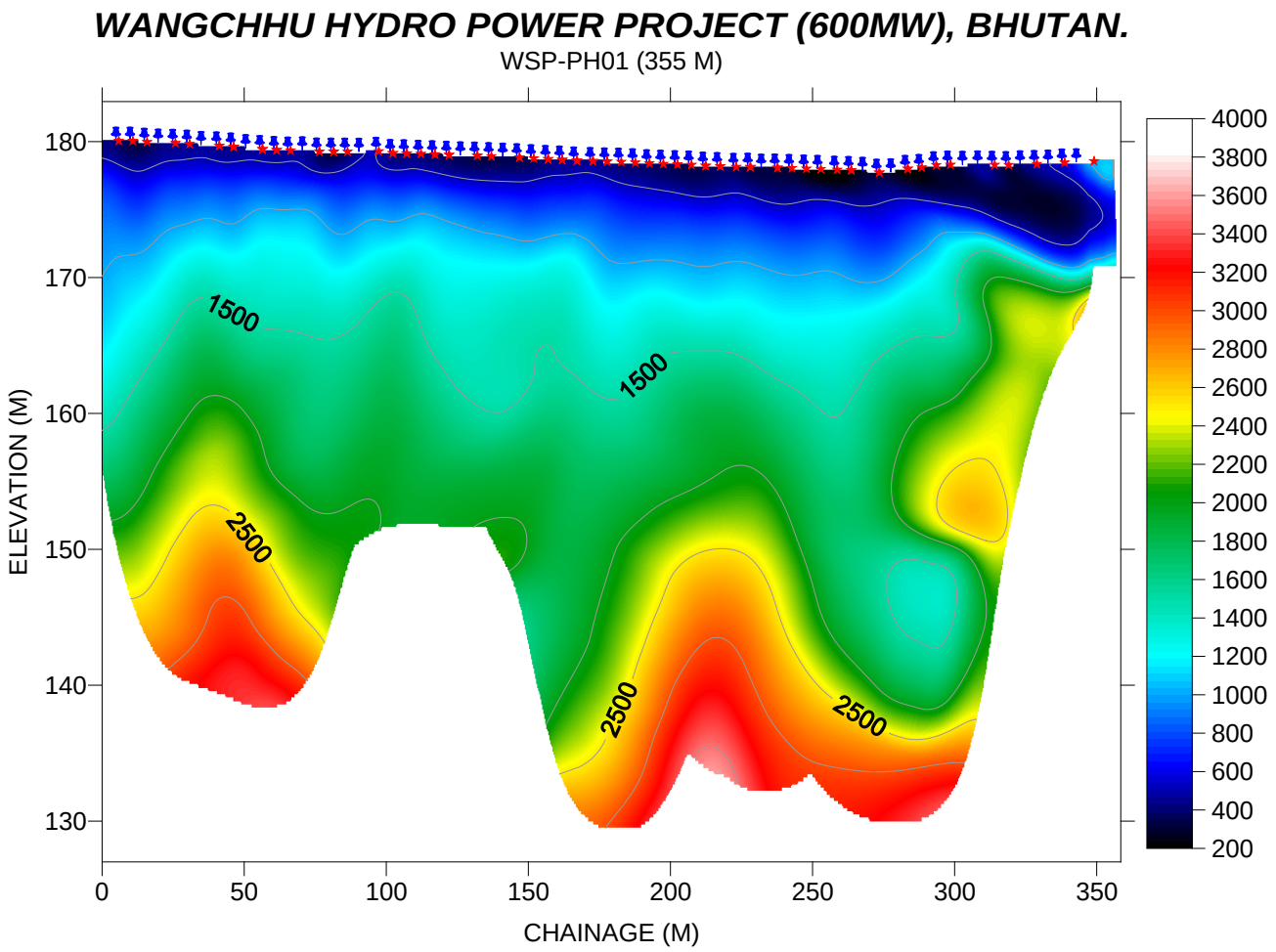
Table Showing the length of Seismic Profile and Depth of bed Rock with Interpreted Seismic Velocities at (3000m/s-4000m/s).

S.No.	Location of Seismic Profile	Length of the profile	Depth of Bed Rock as Interpreted by the seismic Velocity (3000m/s-4000m/s) Ranging from left end to right.
1.	Power House (WSP-PH01(355M))	355m	41m-52m
2.	Power House (WSP-PH02(115M))	115m	51m-55m
3.	Power House (WSP-PH03(115M))	115m	50m-54m
4.	Power House (WSP-PH04(115M))	115m	52m-54m
5.	Dam-site (WSP-DAM05(115M))	115m	51m-55m
5.	Dam-site (WSP-DAM06(115M))	72m	Bedrock not encountered due to small spread lenth.

DISCLAIMER: The results presented in this report are based on the Seismic Refraction Survey conducted by experienced personal of M/s Advanced Technology and Engineering Services according to the standards set for such survey. Interpretation given in the report are OPINIONS only based on the information collected at the time of preparing this report. However, due to inherent limitations of the technique and assumptions, there might be discrepancies and company does not own the responsibilities for any damage / loss arising out of suchdiscrepancies.



TOMOGRAMS


WANGCHHU HYDRO POWER PROJECT (600MW), BHUTAN.
WSP-PH01 (355 M)
ELEVATION (M)
CHAINAGE (M)
180
170
160
150
140
130
0
50
100
150
200
250
300
350
1500
1500
2500
2500
2500
4000
3800
3600
3400
3200
3000
2800
2600
2400
2200
2000
1800
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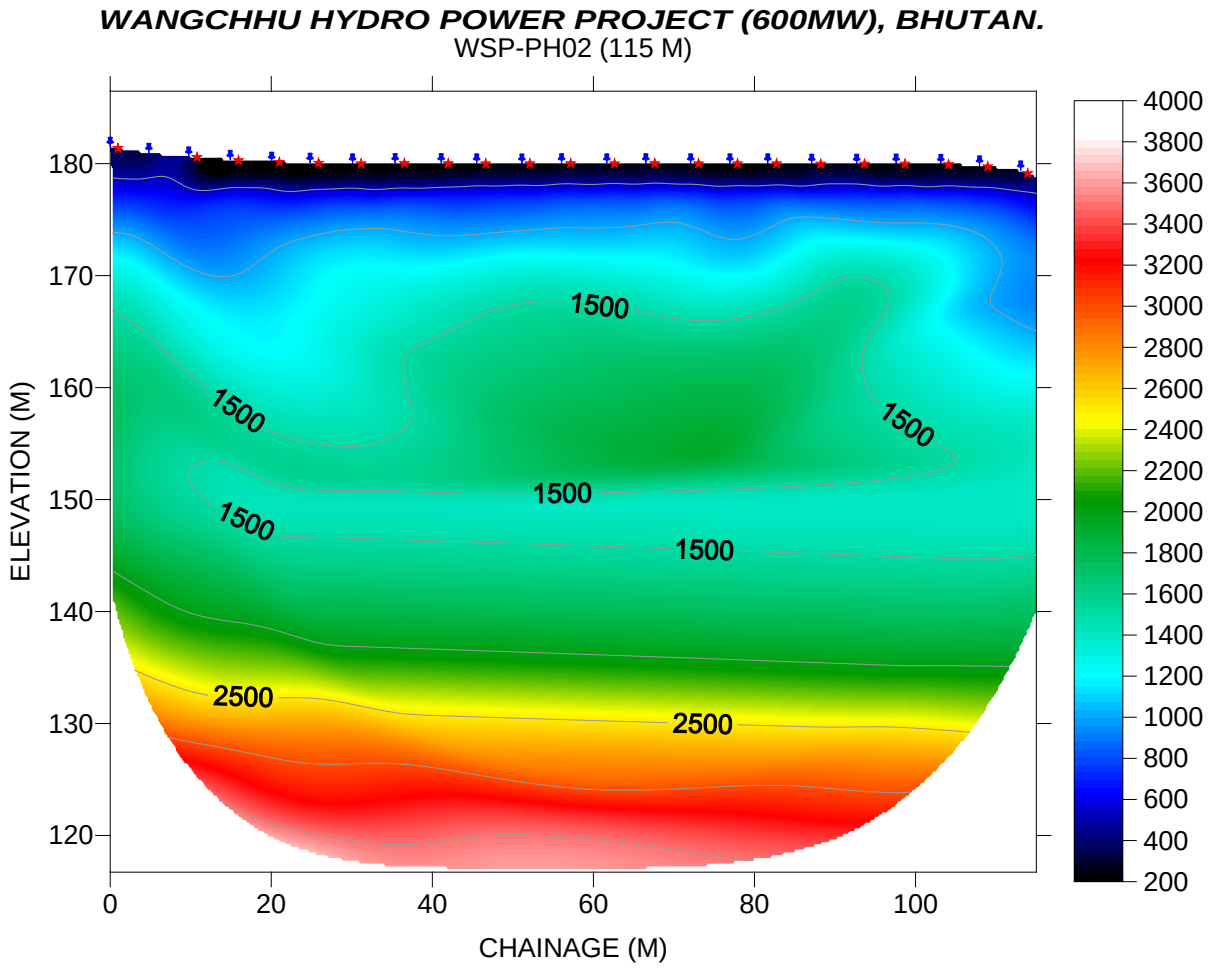
1400
1200
1000
800
600
400
200


WANGCHHU HYDRO POWER PROJECT (600MW), BHUTAN.
WSP-PH02 (115 M)
ELEVATION (M)
CHAINAGE (M)
180
170
160
150
140
130
120
0
20
40
60
80
100
1500
1500
1500
1500
1500
2500
2500
4000
3800
3600
3400
3200
3000
2800
2600
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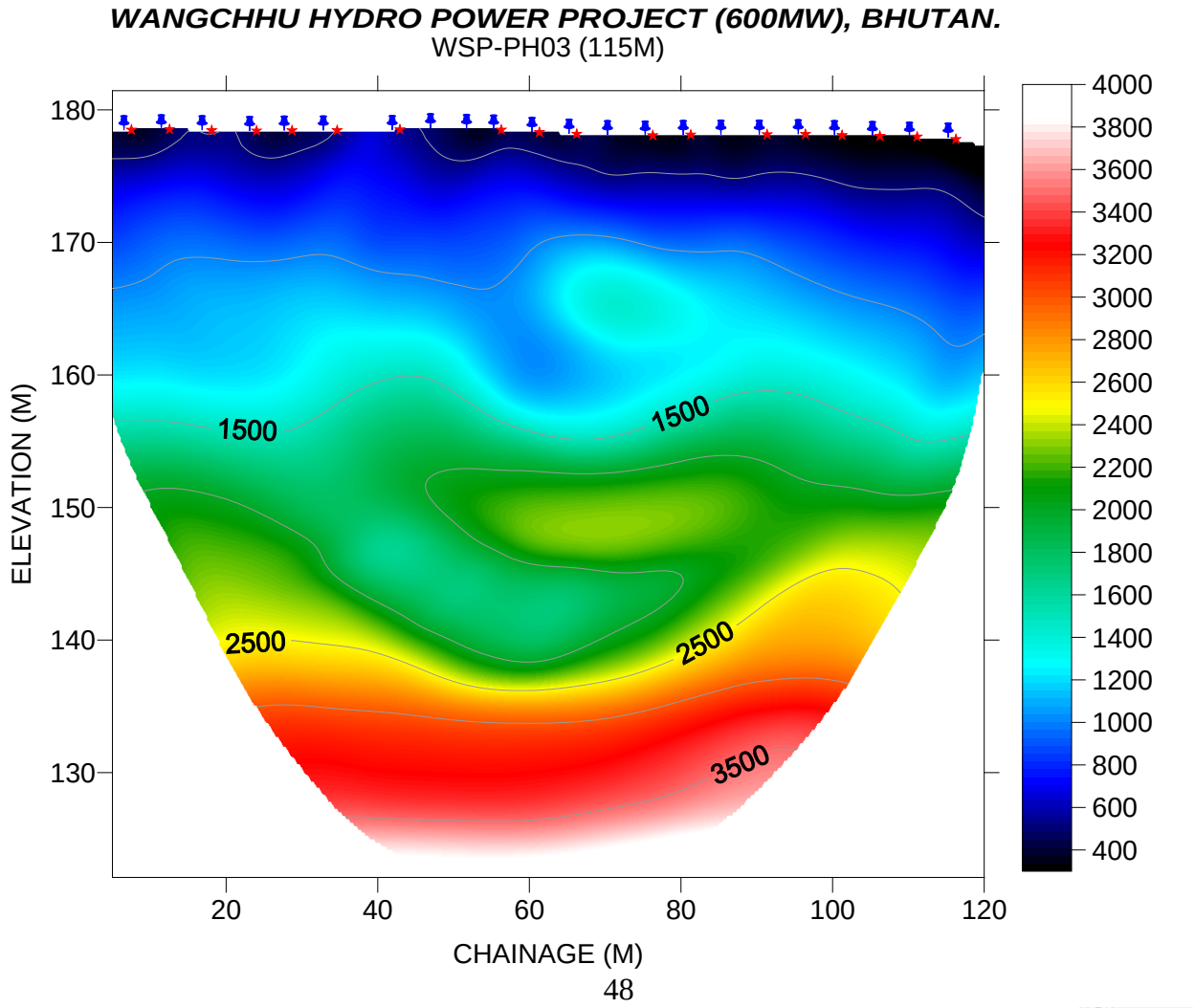
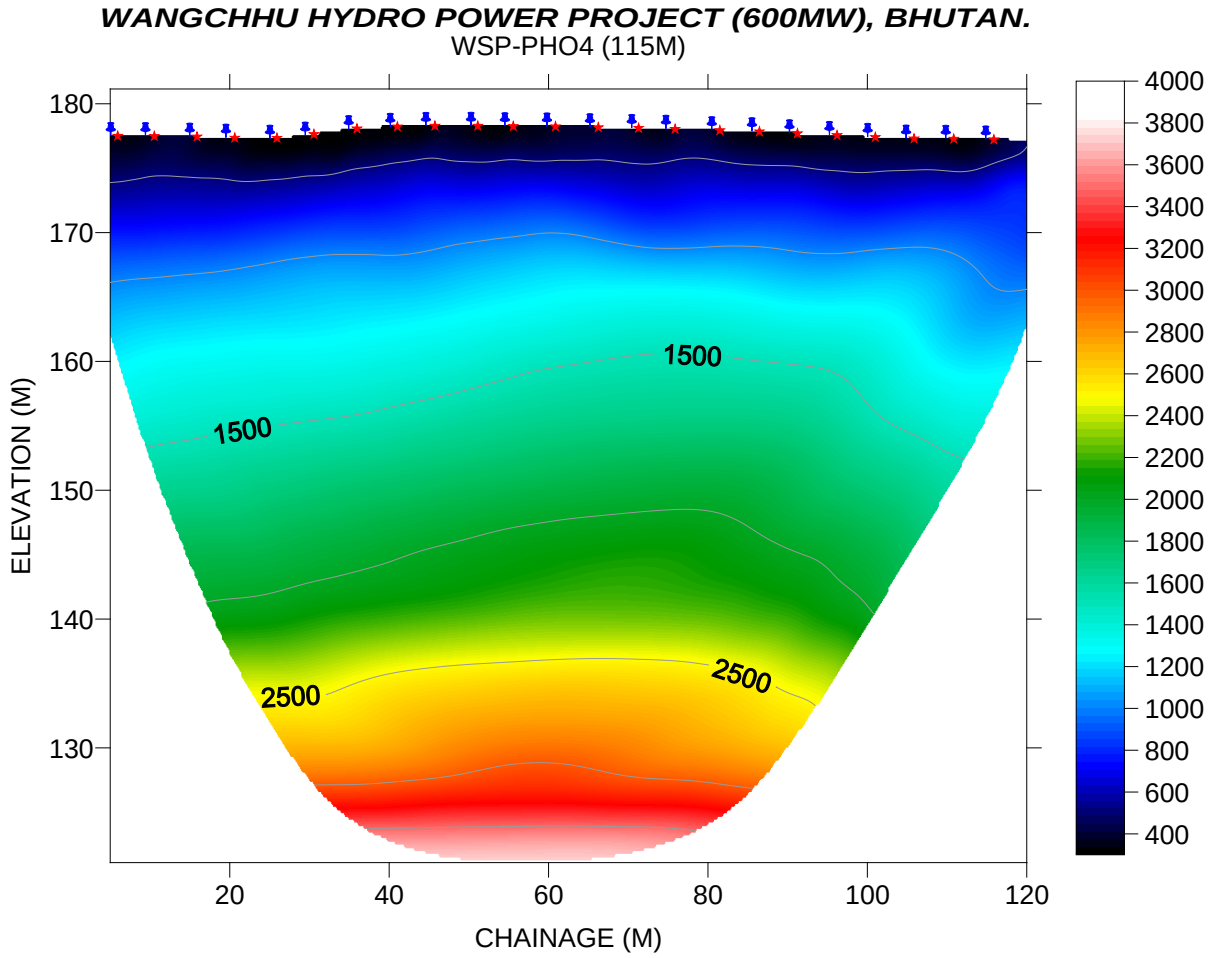
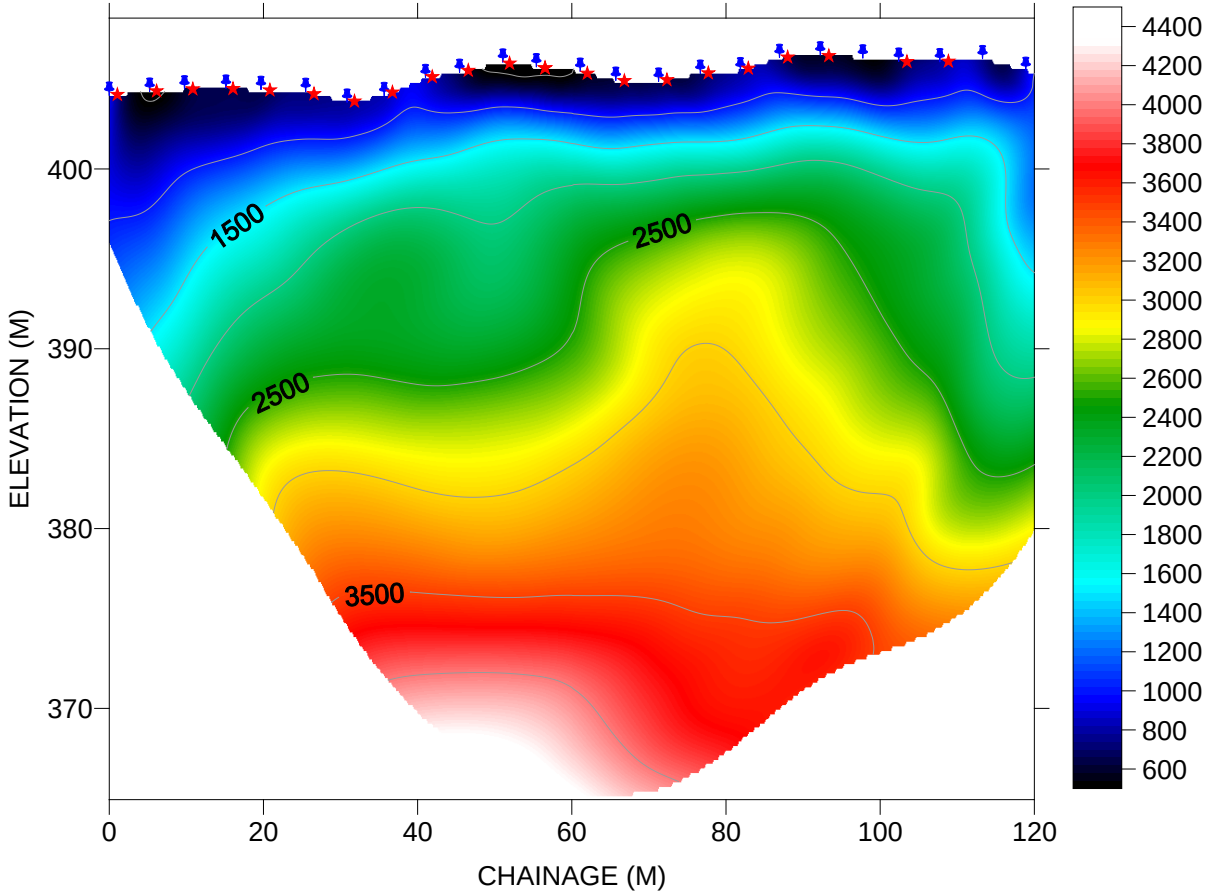
1200
1000
800
600
400
200

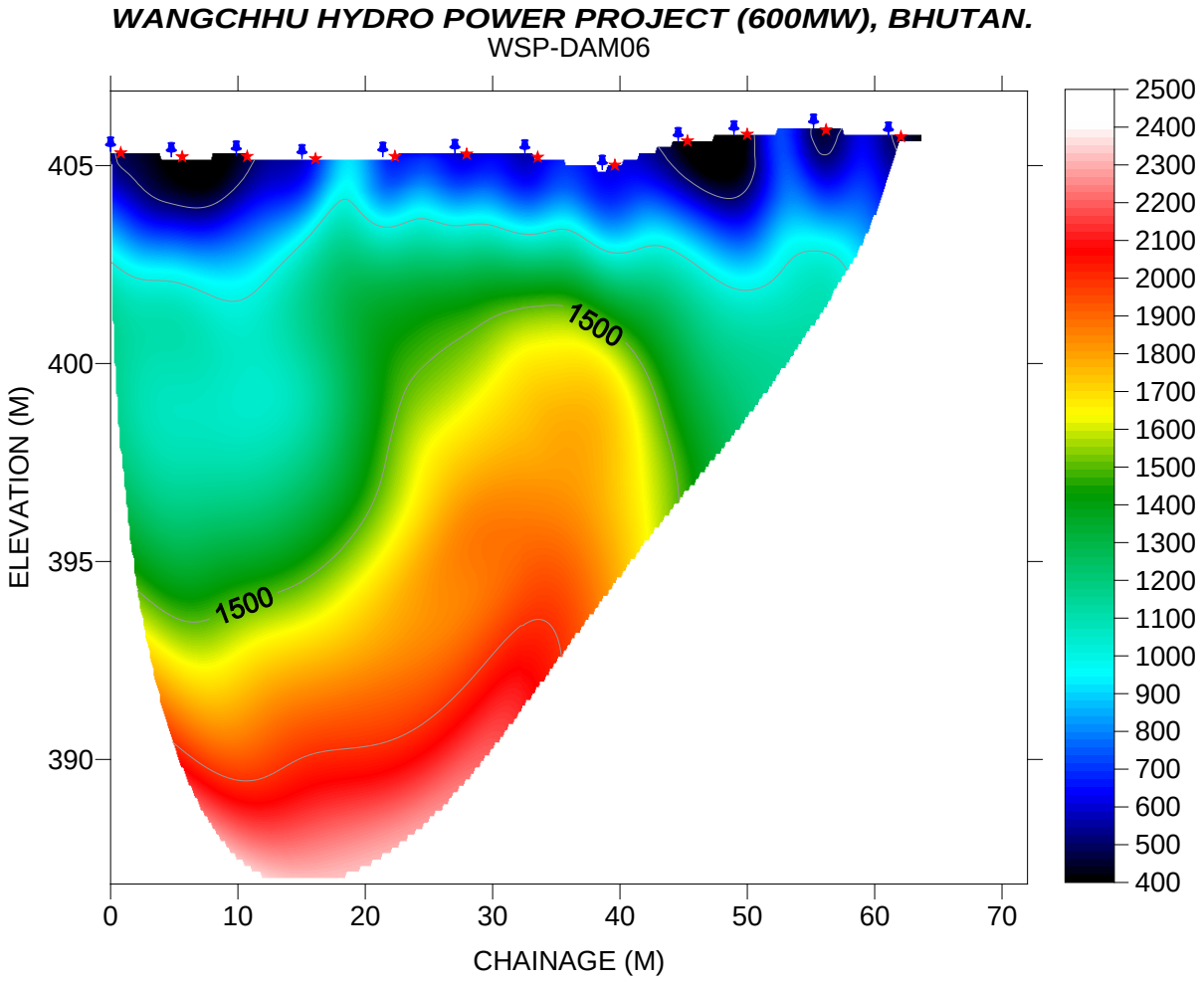

WANGCHHU HYDRO POWER PROJECT (600MW), BHUTAN.
WSP-PH03 (115M)
ELEVATION (M)
180
170
160
150
140
130
1500
1500
2500
2500
3500
20
40
60
80
100
120
CHAINAGE (M)
4000
3800
3600
3400
3200
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400


WANGCHHU HYDRO POWER PROJECT (600MW), BHUTAN.
WSP-PHO4 (115M)
ELEVATION (M)
CHAINAGE (M)
180
170
160
150
140
130
20
40
60
80
100
120
1500
1500
2500
2500
4000
3800
3600
3400
3200
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400

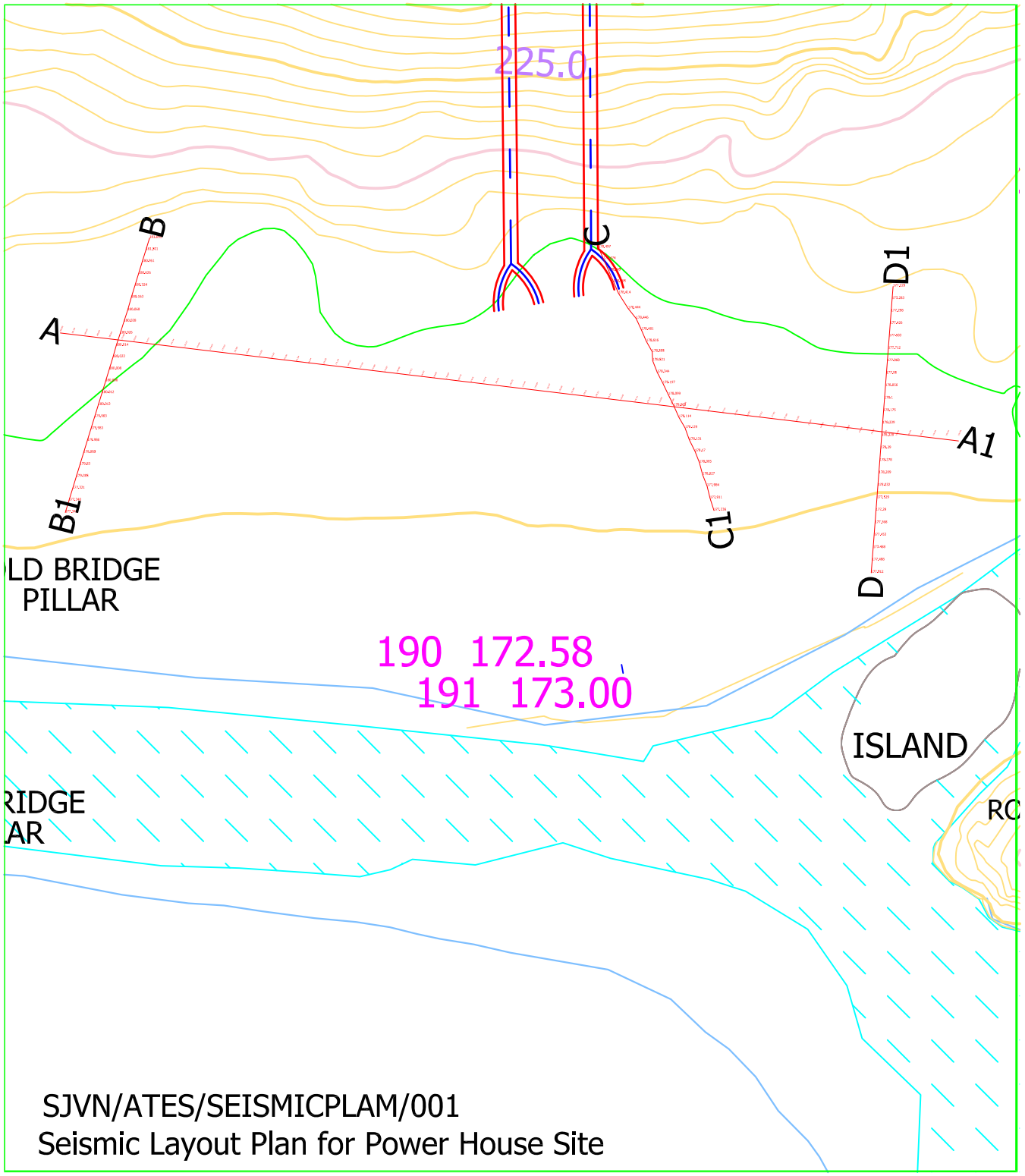
WANGCHHU HYDRO POWER PROJECT (600MW), BHUTAN.

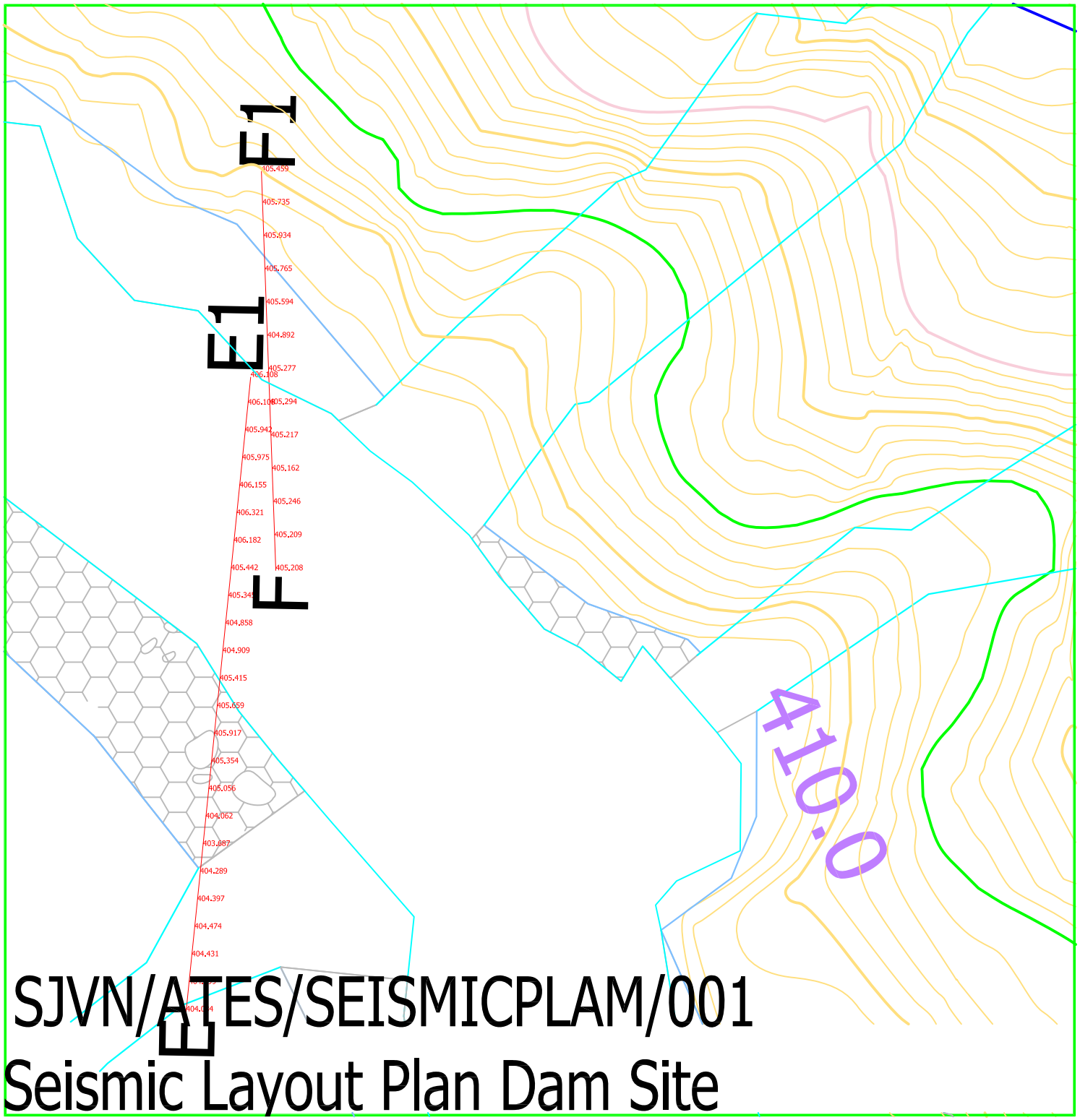
WSP-DAM05 (115M)




WANGCHHU HYDRO POWER PROJECT (600MW), BHUTAN.
WSP-DAM06
ELEVATION (M)
405
400
395
390
1500
1500
0
10
20
30
40
50
60
70
CHAINAGE (M)
2500
2400
2300
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400

DRAWINGS


225.0
A
A1
B
B1
C
C1
D
D1
LD BRIDGE
PILLAR
190 172.58
191 173.00
ISLAND
RIDGE
AR
RC
SJVN/ATES/SEISMICPLAM/001
Seismic Layout Plan for Power House Site



SJVN/ATES/SEISMICPLAM/001

Seismic Layout Plan Dam Site

SEISMIC REFRACTION SURVEY OF WANGCHHU HYDRO POWER PROJECT(600MW), BHUTAN.

WSP-PH01 (355 M)

E- 49687.634
N- 44715.954

E-50047.432
N- 44674.269

A

A1

0.0 10.0 20.0 30.0 40.0 50.0 60.0 70.0 80.0 90.0 100.0 110.0 120.0 130.0 140.0 150.0 160.0 170.0 180.0 190.0 200.0 210.0 220.0 230.0 240.0 250.0 260.0 270.0 280.0 290.0 300.0 310.0 320.0 330.0 340.0 350.0 355.0

ELEVATION (M)

Elevation (M)

190.0 180.0 170.0 160.0 150.0 140.0 130.0 120.0 110.0 100.0

NSL NSL NSL NSL NSL NSL NSL NSL

OVERBURDEN

OVERBURDEN

OVERBURDEN

WEATHERED ROCK

WEATHERED ROCK

WEATHERED ROCK

ROCK LINE

ROCK LINE

ROCK LINE

ROCK LINE

Fig : 01

LEGEND:

NSL. Natural Soil Level

ROCK LINE

Scale :

Horizontal : 1: 500

0 2.5 5 10 m

Vertical : 1: 500

0 2.5 5 10 m

CLIENT:

SATLUJ JAL VIDYUT NIGAM LIMITED.
BHUTAN

Advance Technology & Engineering Services

SEISMIC REFRACTION SURVEY OF WANGCHHU HYDRO POWER PROJECT(600MW), BHUTAN.

WSP-PH02 (115M)

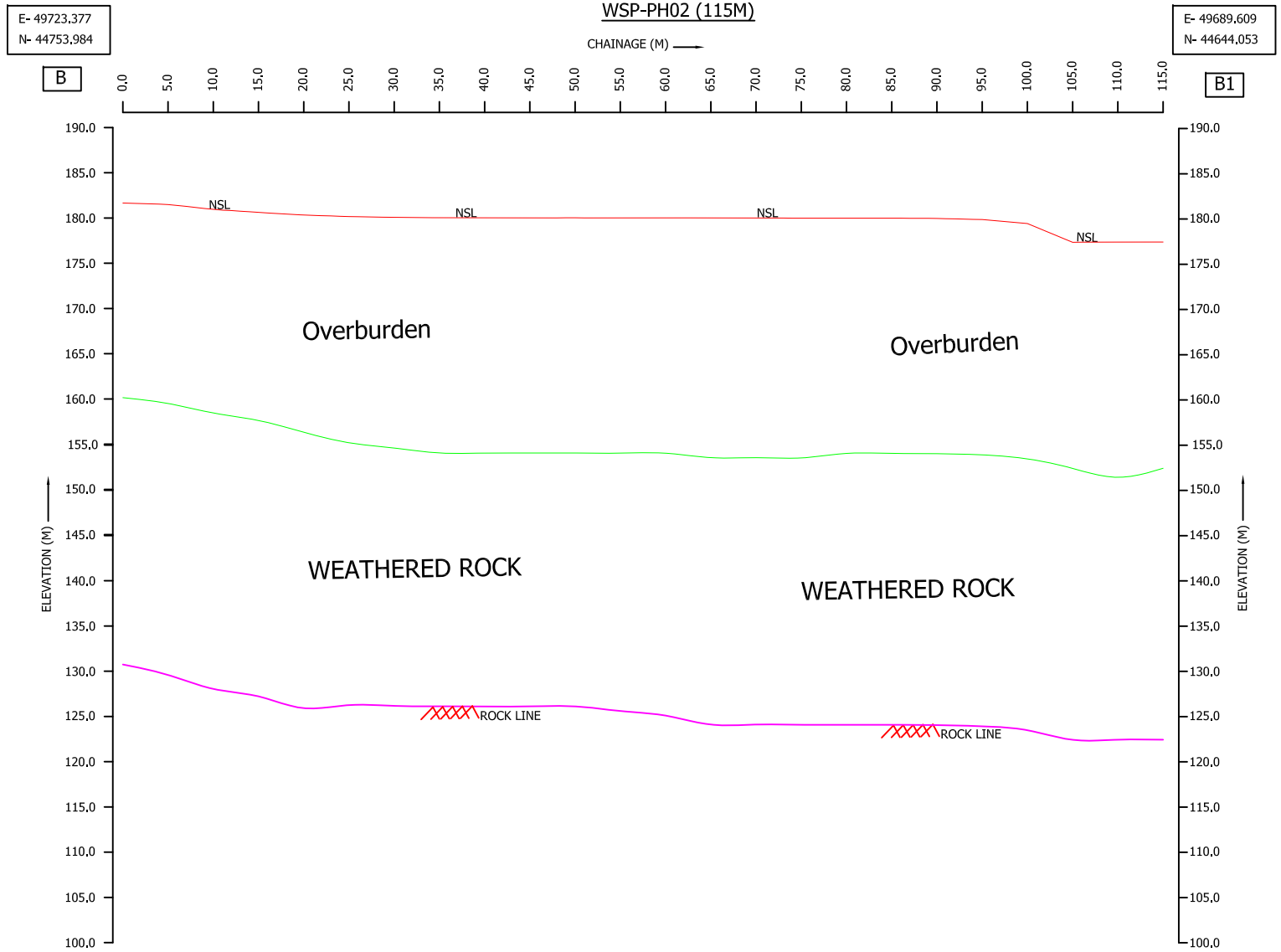


Fig : 02

LEGEND:

NSL. Natural Soil Level

ROCK LINE

Scale :

Horizontal : 1: 500

Vertical : 1: 500

CLIENT:

SATLUJ JAL VIDYUT NIGAM LIMITED.
BHUTAN

Advance Technology & Engineering Services

SEISMIC REFRACTION SURVEY OF WANGCHHU HYDRO POWER PROJECT(600MW), BHUTAN.

WSP-PH03 (115M)

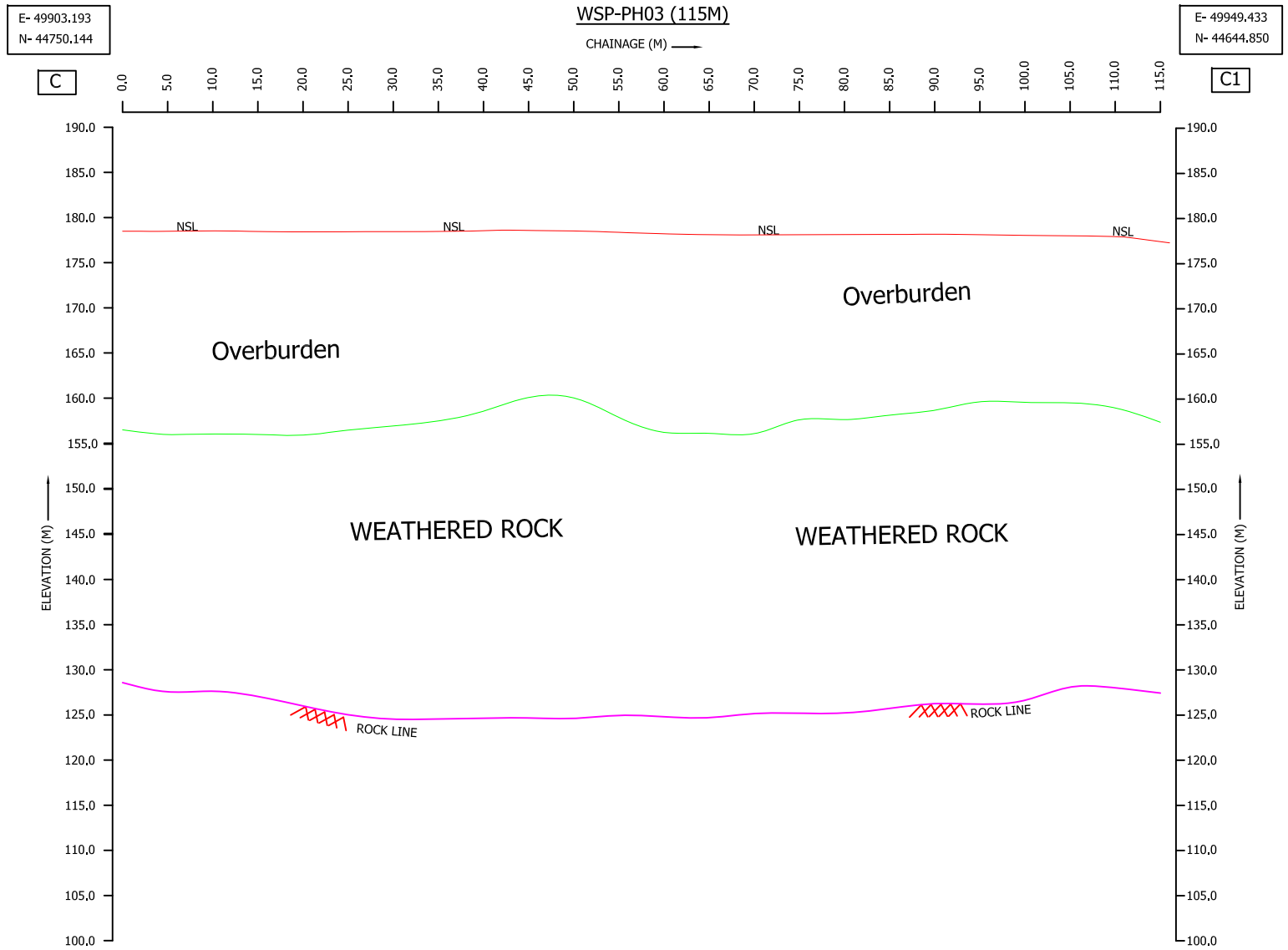


Fig : 03

LEGEND:

NSL. Natural Soil Level

ROCK LINE

Scale :

Horizontal : 1: 500

Vertical : 1: 500

CLIENT:

SATLUJ JAL VIDYUT NIGAM LIMITED.
BHUTAN

Advance Technology & Engineering Services

SEISMIC REFRACTION SURVEY OF WANGCHHU HYDRO POWER PROJECT(600MW), BHUTAN.

WSP-PH04 (115M)

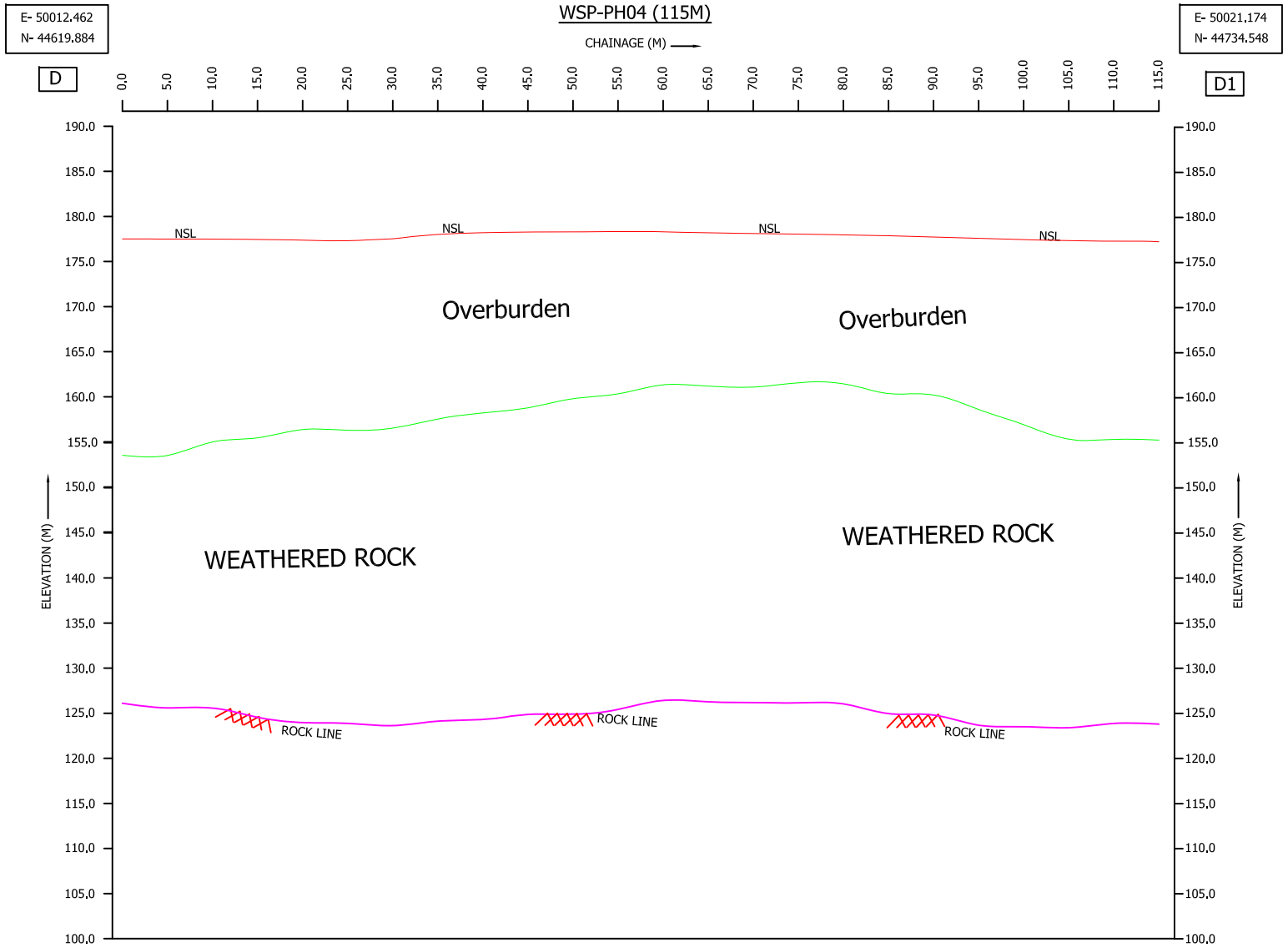


Fig : 04

LEGEND:

NSL. Natural Soil Level

ROCK LINE

Scale :

Horizontal : 1: 500

Vertical : 1: 500

CLIENT:

SATLUJ JAL VIDYUT NIGAM LIMITED.
BHUTAN

Advance Technology & Engineering Services

SEISMIC REFRACTION SURVEY OF WANGCHHU HYDRO POWER PROJECT(600MW), BHUTAN.

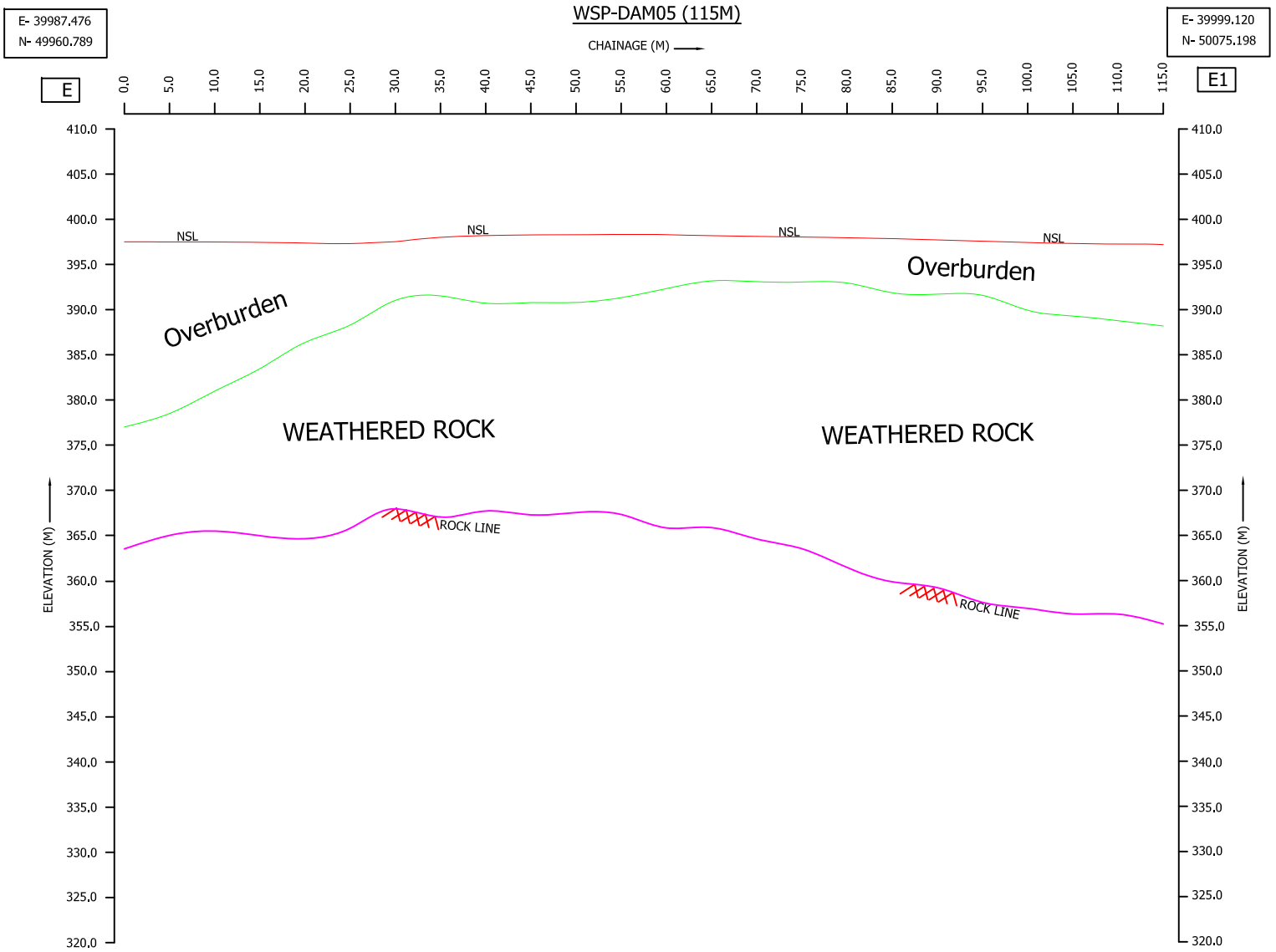


Fig : 05

LEGEND:

NSL. Natural Soil Level

ROCK LINE

Scale :

Horizontal : 1: 500

Vertical : 1: 500

CLIENT:

SATLUJ JAL VIDYUT NIGAM LIMITED.
BHUTAN

Advance Technology & Engineering Services

SEISMIC REFRACTION SURVEY OF WANGCHHU HYDRO POWER PROJECT(600MW), BHUTAN.

WSP-DAM06 (72 M)

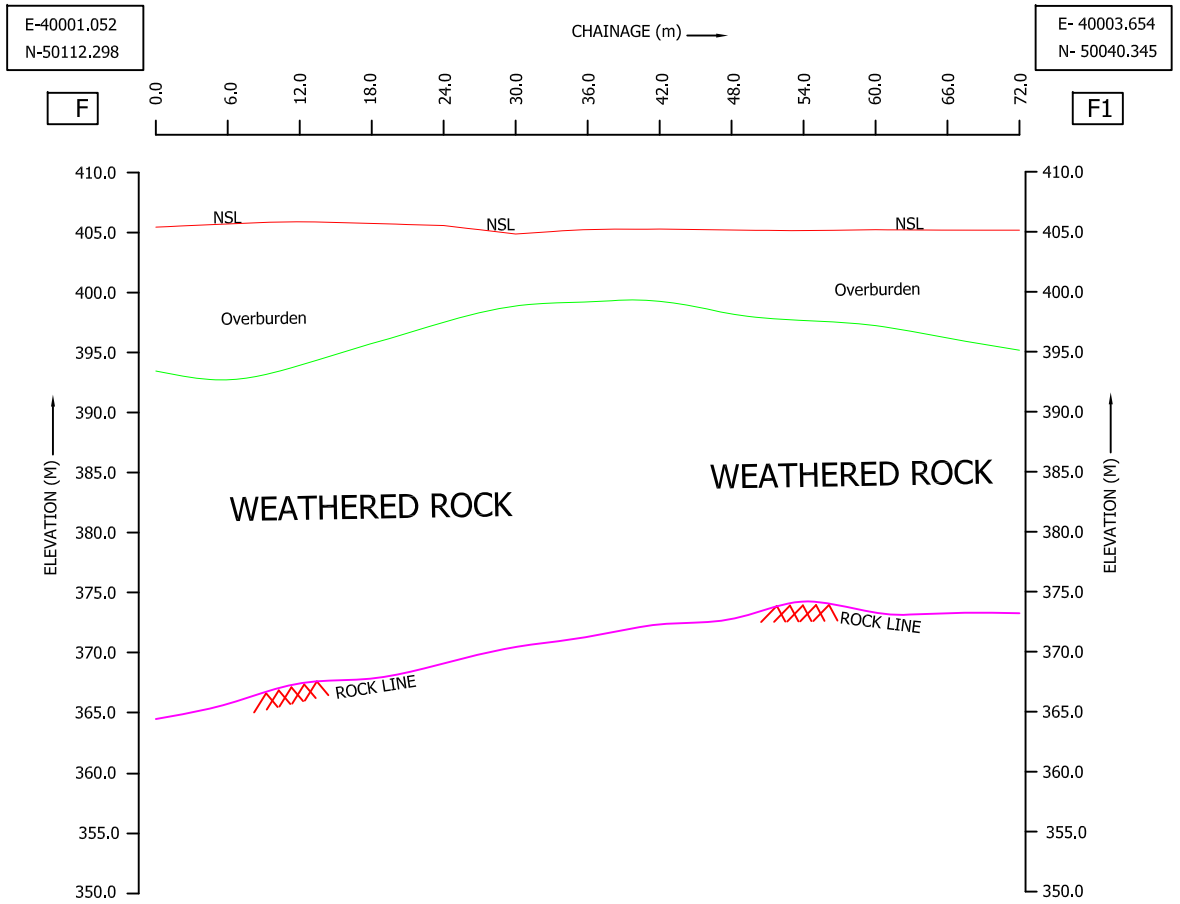


Fig : 06

LEGEND:

NSL. Natural Soil Level

ROCK LINE

Scale :

Horizontal : 1: 500

5 0 5 10 m

Vertical : 1: 500

5 0 5 10 m

CLIENT:

SATLUJ JAL VIDYUT NIGAM LIMITED.
BHUTAN

Advance Technology & Engineering Services

FIGURES

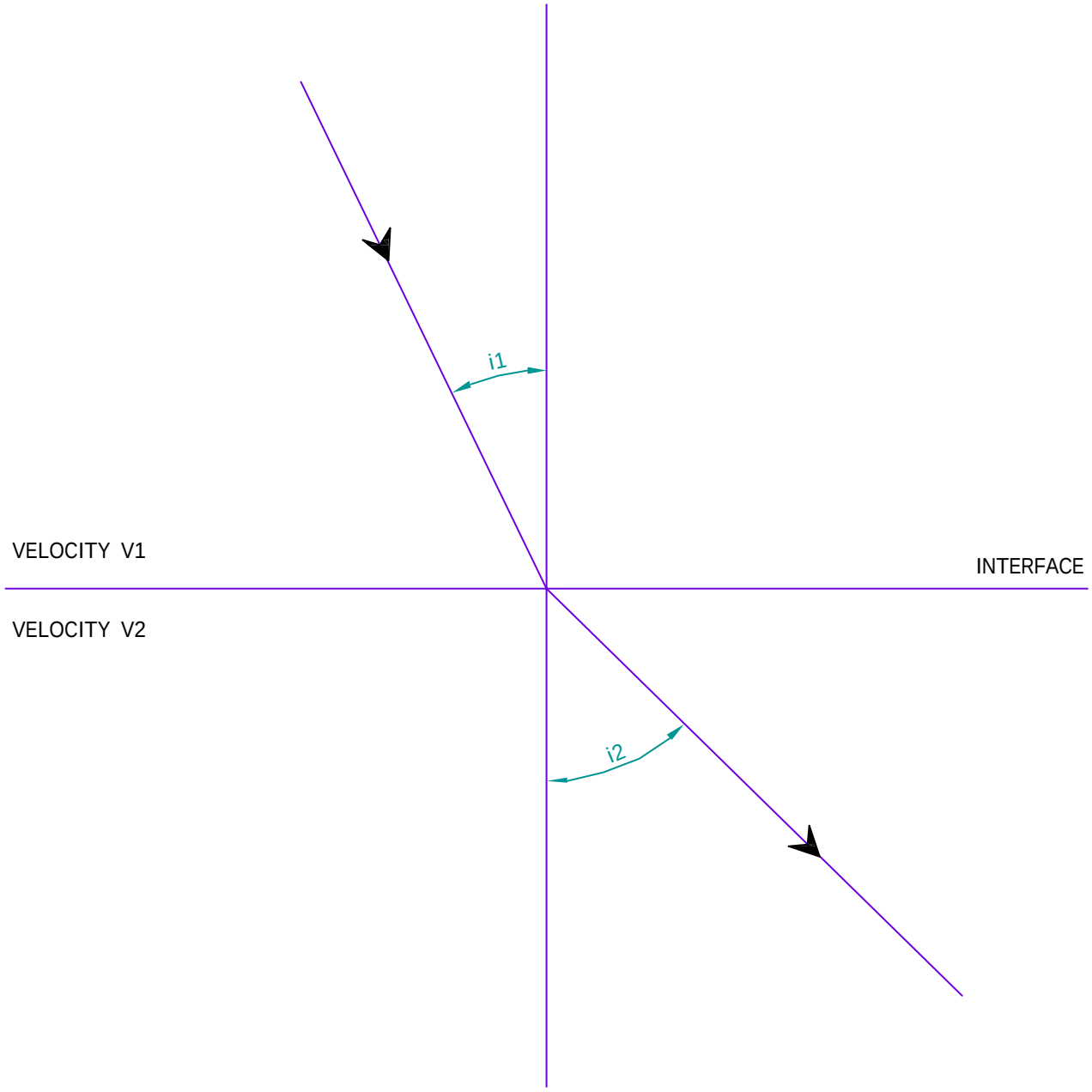
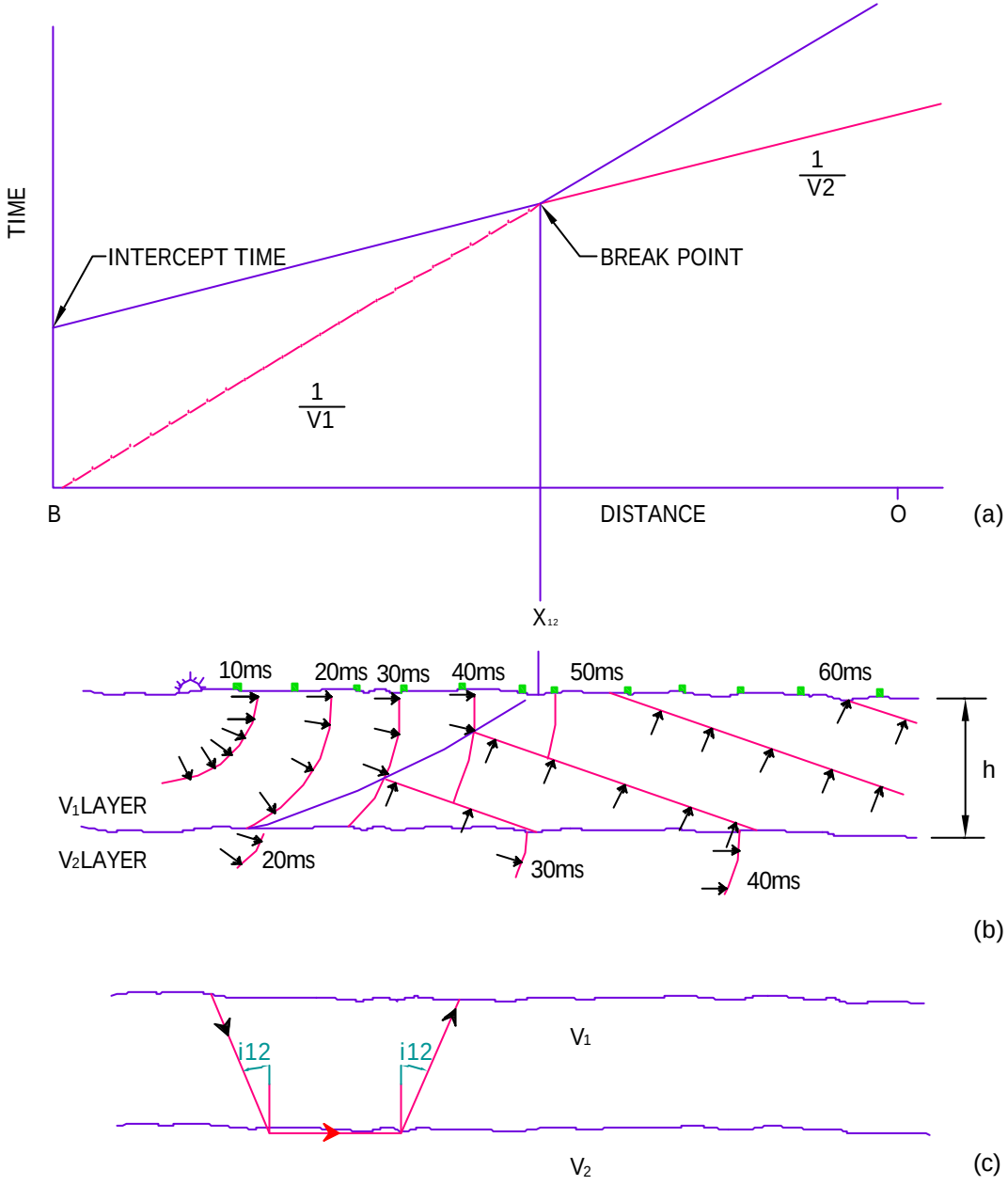


FIG A : REFRACTION OF SEISMIC WAVES



LEGEND

(a) TIME DISTANCE CURVE

(b) WAVE FRONT PROPAGATION

(c) RAY PATH (CRITICALLY REFRACTED)

FIG B: TYPICAL TWO-LAYER CASE

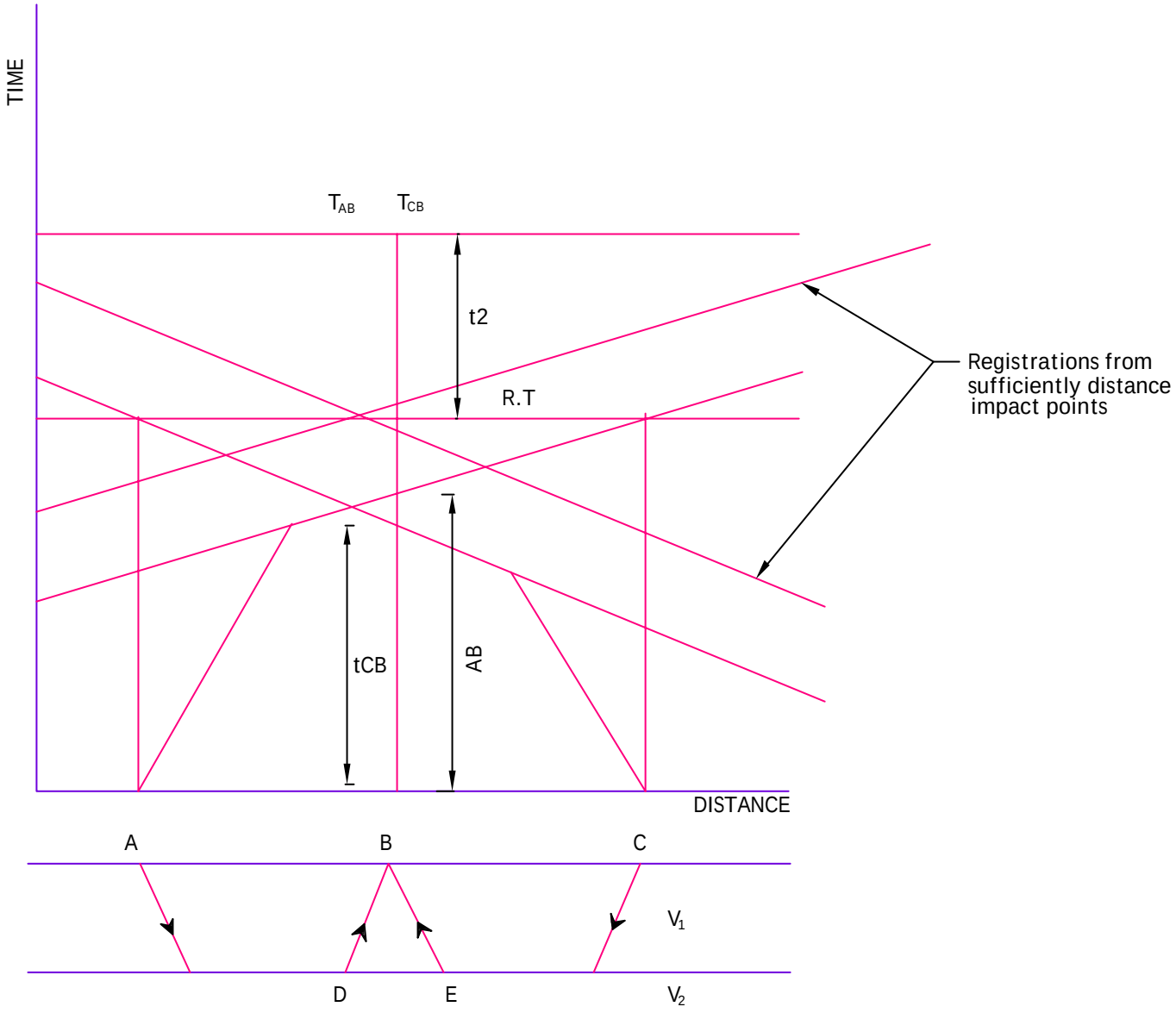
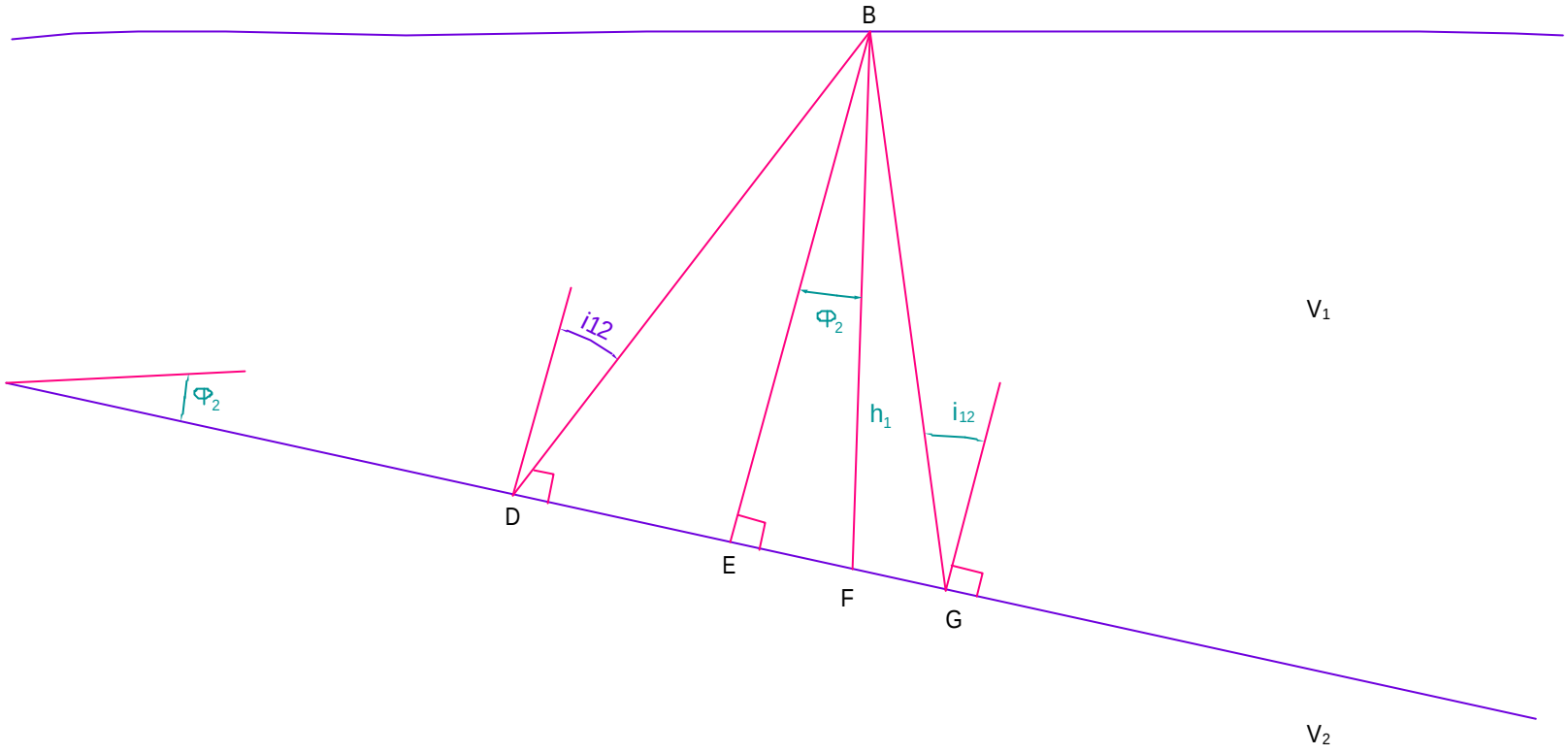


FIG C: THE ABC METHOD (HORIZONTAL REFRACTOR)


B
i12
Φ2
Φ2
h1
i12
V1
D
E
F
G
V2

ANNEXURE-V

PHOTO GEOLOGICAL STUDY

NOTE ON PHOTOGEOLOGICAL STUDY OF THE AREA AROUND TALA HYDROELECTRIC PROJECT (CHUKHA STAGE II) AND WANGCHU RESERVOIR SCHEME (CHUKHA STAGE III), BHUTAN

- S. BASU MALLICK
SR. GEOLOGIST

A NOTE ON PHOTOGEOLOGICAL STUDY OF THE AREA AROUND TALA HYDRO ELECTRIC PROJECT (CHUKHA STAGE II) AND WANGCHU RESERVOIR SCHEME (CHUKHA STAGE III), BHUTAN

BY

S. Basu Mallick
Geologist(Sr.)
Photogeology & Remote Sensing Division
Geological Survey of India
Eastern Region

Introduction

Aerial photo-interpretation of nearly 600 sq. km in Wangchu from Chukha in the north to Piping in the south along a N-S strip was taken up as per the directive of the Deputy Director General, G.S.I., Eastern Region. The study was aimed to understand the regional set up, the lineament, joint and fracture pattern and to map the broad geomorphological land forms. The objective was to help the field geologists with a map, which will, elaborate the regional geological set up and structural framework. The area covers all the proposed construction sites of both Tala Hydel Project and Wangchu Reservoir Scheme. This report is being submitted as an interim one presenting the data generated mainly from the study carried out in the laboratory with the help of aerial photographs. Later on, the author visited the field from 20.3.92 to 17.4.92 and collected a wealth of information which is being analysed and necessary modification will be incorporated in the map after another close study of the aerial photographs of the area. This study is in progress and the result will be presented in the final report.

Methodology

This area is being covered by aerial photographs available on R.F. 1:20,000 (average). Therefore, a large number of aerial photographs were studied. The geological details were studied and traced out for every stereo-pair and put together for each run. The different strips, thus interpreted and traced were assembled to produce an uncontrolled base map on R.F. 1:20,000 (average). This uncontrolled base map is reduced and the data was visually transfarred on a controlled standard base of 1:50,000; the reduction was carried out with the help of Reflecting Optical Projector.

Observations

Unit No.1

The northern part of the area, from Chukha to south of Tala, covering almost all the proposed construction sites of Chukha stage II, is covered by a homogeneous rock type which appears, to be Granite gneiss. A little variation in the rock type, is seen north of Gedu between Pade chu and Takti Chu and along a E-W tract crossing Chukha, which does not cover any of the proposed construction sites. Here, it seems, there are enclaves of rocks within the Granite gneiss which may be quartzite and calc-sillicate rock interbanded with mica schist and other schistose rocks. An open, broad synformal structure can be seen in the hills north of Pade Chu; the synform appears to be plunging southwards.

A little south of Geingo Chu's confhuence with Wang Chu or Chin Chu, the river (Wang Chu), after a long journey almost along a N-S direction, starts meandering in a southeast ward direction. This possibly is the contact of the Granite gneiss with the metasedimentaries exposed south of it. The contact between the two rocks is not well marked but it has been picked up mainly from the fracture pattern, very distinct in the northern gneissic terrain which is relatively less prominent in the south.

The significance of the structural trendlines seen north of Pade Chu or east of Wang Chu on the other side (east) of Tala can not be deciphered without a field check. North of Pade Chu a few dip facets is seen defining the open nature and the synformal fold pattern; Here the bedding appears to be parallel to the regional schistosity, whereas the significance of the trendlines east of Wang Chu may be due to compositional variation in gneiss.

Unit No. 2 & 3

The area lying along Wang Chu from the Geingo Chu confluence upto the Piping confluence appears to be more or less uniform as far as photo-character is concerned. Metasedimentary rocks are exposed all along this tract with occassional dip facets visible at few places. Before the Piping confluence, where Wang Chu has taken a northeasterly trend, there appears to be a steep scarp which may be attributed to a lithological contact between two rock types with very little compositional difference. The difference may be in the prevalence of quartzite or siliceous sediments in the unit No.2 compared to unit No.3. Presence of a fault along this NE ly trend of Wangchu can also be inferred but its continuation further Northeast

ward or southwest ward is not seen. The significance of a NE-SW structural trendline, seen nearly 2 kms upstream of the stage III dam site, may be due to compositional variation in lithology.

Lineaments and fracture pattern

A number of lineaments can be seen in the area, a few among them is (1) N80E-S80W Takti Chu lineament (2) N25W-S25W Chip jalum chu lineament (3) N35W to S 45I curvilinear lineament north of Pade Chu (4) N10E-S10W lineament east of Chalalung Chu (5) N40E-S40W lineament NW of Piping.

Among all these lineaments Takti Chu lineament is important as it cuts across the HRT alignment in stage II and the lineament no. (5) NE of Piping, which also cuts across the HRT aleginment in stage III. All the other lineaments are on the other side of Wangchu which is not of immediate concern to the engineering projects except lineament No. (3). This lineament (No.3) may be fracture cleavage developed parallel to the axial plane of the open folds seen here.

The lineament No. (5) has been explained earlier in the description of unit No. 2 and 3. The Wang Chu river at a number of places follows a straight course in N-S direction, which definitely is controlled by structures. The Granite gneiss terrain is well joined with three prominent sets (i) N 25 E-S25W (ii) N 25 W-S 25 E (iii) N 70 W-S 70 E to E-W. As mentioned earlier these are more prevalent in the gneiss than in the metasedimentary rocks.

Geomorphology

From the laboratory study of aerial photographs not many geomorphological units can be marked. In the meandering regime of Wangchu, terraces can be seen, at places paired. Three distinct levels can be identified besides the present day surface. After a visit to the area, it has been observed that an attempt can be made to map the talus scree debri slope material from aerial photographs, which may be helpful to the field geologists. This study is already in progress.

S/d

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FINAL NOTE ON PHOTOGEOLOGICAL STUDY OF THE AREA AROUND TALA HYDROELECTRIC PROJECT (CHUKHA STAGE II) AND WANGCHU RESERVOIR SCHEME (CHUKHA STAGE III), BHUTAN

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August, 1992

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INTRODUCTION

A photo-interpreted map (R.F. 1 : 50,000) of about 600 sq km in Wangchu basin from Chukha township in the north to Piping village in southeast along a North-South strip has already been presented in the interim note. This map was based entirely on the aerial photo-interpretation work carried out in laboratory without any ground truth. The Director General, Geological Survey of India deputed the author to visit the area for a period of thirty days to check the photo-interpretated map in the field and collect geological information. The author visited various sites near Tala Hydroelectric Project(THP) from 20.3.92 to 30.3.92 and Wangchu Reservior Scheme (WRS) from 31.3.92 to 1.4.92 and 6.4.92 to 15.4.92. Besides this, the author also carried out photo-interpretation work and consultation of geological maps and literature in the Geological Survey of India office at Samchi, Bhutan. The objective of the work, which has already been outlined in the earlier note, was to prepare a photogeological cum photogeomorphological map of the area, which will help the field geologists to understand the geology, structure and the fracture pattern on a regional perspective. The area, being thickly forested and sparsely populated, with very little communication links,

posed a major problem for approach to many of the important geologically interesting areas, as noted from aerial photographs. Even then, detailed geological study was carried out along the N-S corridor, the Phuntsholing-Thimpu highway from Chukha township upto Gedu and towards Tala. The Southern part of the area from south of Tala to the north of the proposed damsite location of WRS is almost unapproachable. Therefore, in this area, geological traverses are restricted along a few foot tracks and approach communication path to the proposed damsite locations of WRS. The map accompanying this note has been suitably modified in the light of the field observations and reinterpretation of aerial photographs of the area. Many field data could not be presented in the map because of scale limitation. However, with all these limitations, the author has attempted to present a simplified geological cum geomorphological cum structural map of the area, which may be useful to the field geologists. An error has subsequently been noticed in the earlier note already circulated. In the subheading 'Observations' Unit No. 1, which has been described first, will be Unit No. 3 and instead of Unit No. 2 & 3, it will be Unit No. 1 & 2. The error in regretted.

Acknowledgement

The author expresses his grateful thanks to the officers of WAPCOS and Central Water Commission at Phuntsholing and at various field sites for therir co-operation and hospitability during the course of this investigation. The author is also grateful to Sri N. Mazumder, Director, Engineering Geology Division, GSI for useful discussions on various aspects of these projects and Sri D.K. Chakrabarti, Director, Photogeology and Remote Sensing Division,

GSI for his valuable suggestions and guidance from time to time in aerial photo-interpretation work. Thanks are due to Sri B.D. Dungrakoti, Director, GSI, Bhutan Unit, Samchi for his help and co-operation in getting technical and logistic support and to Sri J. Roy Chowdhury, Geologist(Senior) for his association, at times, and valuable discussion in the field.

Methodology

This has already been described in the earlier note, therefore, it is not repeated here. During the course of this work, satellite imagery covering these project sites, has become available on R. F. 1 : 250,000. The study of this imagery (False colour composite on bands 2, 3 & 7 of Thematic Mapper data) does not reveal more geological information than the aerial photo-interpretation work, possibly because of smaller scale of satellite imagery and the masking of the geology due to thick vegetation cover.

Observations

Unit No. 3 & 3A

This unit covers all the various locations of the THP. This is a more or less homogeneous rock, with folded enclaves of quartzite, calc-sillicate rock, marble, mica-schist and basic schist (marked 3A). The rock is generally granite gneiss (known as Thimpu gneiss), which varies in composition depending on the composition of the parent rock, which has been granitised. In the northern part of the area, from Chukha township southwards, crystals of garnet in various

sizes from a m.m. to a cm. is found uniformly distributed in the granite gneiss. The enclaves of quartzite, calc-sillicate rock, amphibolite and thin bands of mica schist (3A) is seen in road section West of Chukha township. Here the rock is thinly banded and highly fractured along foliation plane, which dips moderately towards northeast. Enclaves of marble is exposed in the road section and finely folded (photo 1) NW of Honka. They are highly crystalline and their relationship is only understood from field study. Biotite is the predominant mineral which aligns to define foliation in granite gneiss. The folded enclave, north of Padechu, could not the confirmed in the field, as the hinge area could not be approached, but presence of mesoscopic folds in mica rich gneiss in seen on foliation. Isoclinal to overturned folds plunging 5° towards N 130° is exposed along road section near the U-turn north of Takti chu,. This fold is of same orientation. It has been observed in the field that wherever there are enclaves of mica schist or schist of basic composition there is a dearth of outcrops and a good development of soil in the area. Enclave of quartzite and mica schist is also seen south of Tala near surge shaft and penstock site area. The aerial extent of this enclave (unit 3A) could not be picked up from aerial photographs. The contact of granite gneiss with the underlying metasedimentaries (which should be a thrusted contact) appears to be gradational. The granite gneiss with enclaves of quartzite and mica schist appears to be slowly grading towards quartzite. In the aerial photographs the contact can only be marked from the difference in fracture pattern and the morphology of the gneissic terrain from that of the metasedimentary rocks. This contact between unit No. 3 and 2 remains the same as the prefield map submitted with the earlier note.

The granite gneiss, at places (in road section North of Gedu), appears to look like granite because of poor development of foliation planes in the rock. Presence of thin bands or lensoid bodies of pegmatite is invariably found to be present parallel to the faint foliation plane.

Unit No. 2 & 1

The contact of unit No. 2 with 1 has been slightly modified after reinterpretation of aerial photographs. The difference in photo character between these two units is very little. The density of fractures is more in unit No. 1 and the dip facets are frequently seen in unit No. 2, which possibly means that unit No. 2 has greater amount of dip than unit No. 1. The unit No. 2 could not be checked in the field because of inaccessibility of the terrain. However, it's contact with unit No. 3 was well marked by the initiation of meandering of Wangchu river.

The unit No. 1 from aerial photo appeared to be quartzite only with minor amount of interbanded phyllite. This unit covers all the project sites of WRS. Here the rocks are quartzite, phyllite, calc sillicate, dolostone and at places, marble, Metabasic, chlorite schist is also seen in the hill east of the proposed damsite West of Baikinza village. A thick conglomerate band is seen in the northern bank, east of the cliff, on way, about 2 km from Piping to the damsite. The quartzite and the phyllite is highly fractured and brittle because of intense downdip folding and development of fracture clevage in the rocks. The conglomerate outcrop, as seen in the foot track from Piping to damsite is more than 400 metres wide. It is oligomictic in composition (quartzite), well rounded, unassorted, randomly oriented and embedded in a siliceous matrix. The pebbles vary in size from 5 cm to 20 cm. The quartzite on the south bank facing the Piping camp site near the river bridge is also interbanded with a thin oligomictic conglomerate of the same composition. A notable feature of the quartzite of this area is the total absence of sedimentary structures in the rock. So the stratigraphic relationship of the the rocks cannot be deciphered. In the foot track to the damsite, outcrops of dolostone, calc sillicate rock and even carbon phyllite is seen in the road cutting. Their stratigraphic position is also uncertain because of lack of critical

evidences. The phyllite exposed in the area is often purple to purple grey in colour and occassionally they grade towards schist. Folding in the rocks is displayed in phyllite in the form of minor folds and puckers as observed in Piping river section just near its confluence with Wangchu. A calc tuffa occurence is seen in Western bank of Piping river near its conflucence.

Structure, lineaments and fracture pattern

The structure in the area can only be deciphered from field study because no definite fold pattern is seen in aerial photographs, except from the synformal hinge of a fold north of Pede chu and which is an enclave within the granite gneiss. No other fold of this dimension can be seen in this area. Study of mesoscopic and minor folds reveal that the area has undergone (F_1) folding in a E-W axis giving rise to the development of regional foliation, which is axial plane foliation with respect to F_1. The area has subsequently undergone refolding along a N-S axis giving rise to downdip puckers and fracture cleavage as seen in unit No. 1. A number of structural trend lines have been shown in the map. All these lines could not be checked in the field, mainly because of inaccessibility. The lines have not been deleted from the map as they may indicate some important feature or a clue to the field geologists.

Among the lineaments, the Takti chu lineament is important to the engineering project. The rocks on both the sides of the lineament are identical and do not show any feature of ductile shearing or faulting. It may be a tensional fracture or a major joint in granite gneiss. This do not appear to pose any major problem to the engineering project. Most of the other lineaments, as described in the earlier note, is situated on the eastern bank of Wanchu river, which is virtually inacessible. The lineament NW of Piping trending NE-SW forms a steep scarp on the quarzite. Evidences of faulting is also not seen along both the flanks of this lineament as observed along the foot track.

Geomorphology

The number of terraces as interpreted from aerial-photos remains the same after the field check. A few more terraces are recognised in the higher reaches of Wangchu and along a tributary (Gedu chu). The numbering of the terraces with T_1, as the lower most terrace after the recent flood plane, is found to be the same in the field. Only the terraces on the higher reaches of Wangchu can not be properly co-related and numbered with the terraces on the lower downstream side. An attempt has been made, as discussed in the earlier note, to map the area with moderate talus/debri material overburden. This area is overlain by a variable thickness of talus or rock scree material, which will vary from 5 metres to 15 metres. This is considerably reduced and, in most of the places, even rock outcrop is seen in the stream/river or nallah bed near its confluence with Wangchu. In rest of the areas, except in the steep escarpment (like the hills north of Takti chu) sections, thick cover of overburden exceeding fifteen metres is expected. In most of these overburdended areas, where there is a seepage and or human interference, landslides of various dimensions are noticed (photo 2)

Reference

Basu Mallick, S. 1992 : Note on photogeological study of the area around Tala Hydroelectric Project (Chukha Stage II) and Wangchu Reservoir Scheme (Chukha Stage III), Bhutan.

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ANNEXURE-VI

SEISMIC DESIGN PARAMETERS FOR WANGCHHU HYDROELECTRIC PROJECT

REPORT DOCUMENTATION SHEET

Technical Report No: 4915 **Date: January 2012**

Title : ESTIMATION OF SITE-SPECIFIC SEISMIC DESIGN PARAMETERS FOR WANGCHU HYDRO ELECTRIC PROJECT, BHUTAN

Officers Responsible for Conducting the Studies:

Dr. L.R. Pattanur, Senior Research Officer, Shri V. Rambabu, Research Officer and Smt. Namita Khandka, Assistant Research Officer under the supervision of Dr. I.D. Gupta, Director

Name and Address of Organisation Conducting the Studies:

Earth Sciences Laboratory, CWPRS, Pune

Name and Address of Authority Sponsoring the Studies:

The DGM, Design (Foreign Projects), Suraj Kunj Building, Satluj Jal Vidyut Nigam limited (SJVNL), New Shimla-171009, Himachal Pradesh.

Synopsis

Site-specific design ground motion has been estimated for earthquake resistant design of the Wangchu Hydro Electric Project, Bhutan using regional data on tectonic features, seismicity and local geotechnical characteristics in the region. Both deterministic and probabilistic approaches have been applied to arrive at the Maximum Credible Earthquake (MCE) and Design Basis Earthquake (DBE) levels of ground motion. The deterministic target spectra are governed by the MCE magnitude 8.0 on the Main Boundary Thrust at a closest distance to fault rupture plane of 29 km. The probabilistic estimate is based on the total seismicity expected to occur in various seismic source zones identified in the region. The probabilistic spectral amplitudes are higher than the deterministic spectral values in the low period range, whereas, the deterministic spectral amplitudes are higher in the higher period range for the horizontal and vertical components of ground motion. Hence the envelope of both the deterministic and probabilistic spectra have been taken to be the target response spectra for horizontal and vertical components which are used to obtain the design ground motion to ensure safety of the project. The design accelerograms of horizontal and vertical components of motion are obtained separately using the respective target spectra and suitable phase differences. The values of the peak ground acceleration for horizontal and vertical components are found to be 0.463 g and 0.273 g for MCE condition, and 0.214 g and 0.118 g for DBE condition respectively. Smoothed design response spectra are computed for damping ratios of 1 %, 3 %, 5 %, 7 %, 10 % and 15 % of critical from these design accelerograms. Recommendations are also made for site specific design seismic coefficients needed for conventional stability analysis.

Key Words: Wangchu hydro electric project, damping, design accelerograms, design basis earthquake, deterministic, geology, maximum credible earthquake, probabilistic, response spectra, rupture plane, seismicity, tectonics

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Abbreviations used

BPV	Brahmaputra Valley
DSHA	Deterministic Seismic Hazard Analysis
DSHARS	Deterministic Seismic Hazard Analysis Response Spectra
DBE	Design Basis Earthquake
Dy	Day
FEMA	Federal Emergency Management Agency
GSI	Geological Survey of India
IGP	Indo-Gangetic Plains
IS	Indian Standard
ITSZ	Indus Tsangpo Suture Zone
km	Kilometer
M	Magnitude
m	Meter
MBT	Main Boundary Thrust
MCE	Maximum Credible Earthquake
MCT	Main Central Thrust
MHT	Main Himalayan Thrust
MKF	Malda-Kishanganj Fault
Mn	Month
PGA	Peak Ground Acceleration
PSHA	Probabilistic Seismic Hazard Analysis
PSHARS	Probabilistic Seismic Hazard Analysis Response Spectra
s	Second
SHM	Shillong Massif
THH	Tethys Himalayan
THRS	Time History Response Spectra
TRH	Trans-Himalayan
TRS	Target Response Spectra
WHEP	Wangchu Hydro Electric Project
Yr	Year

ESTIMATION OF SITE-SPECIFIC SEISMIC DESIGN PARAMETERS FOR WANGCHU HYDRO ELECTRIC PROJECT, BHUTAN

Technical Report No. : 4915 **Month: January 2012**

1. INTRODUCTION

The Wangchu Hydro Electric Project (WHEP) scheme envisages the construction of a 120 m high concrete gravity dam across river Wangchu near Silli approximately 25 km upstream of its confluence with the Piping river, and a surface power house with an installed capacity of 600 (4x150) MW. The surface power house is proposed to be located near Piping village close to Wangchu – Piping river confluence. A 12.5 km long, 8.5 m diameter head race tunnel alignment has also been proposed along the left bank of Wangchu. The dam site is located at latitude 26°48' 45" N and longitude 89°38' 15" E. Fig.1 delineates the location and site plan of the project.

The Wangchu Hydro Electric Project is located in the highly seismic Himalayan tectonic province, which is having complex geological setup. In the present report, site-specific design ground motion has been estimated for WHEP site by carrying out detailed analysis of the data on seismotectonic and geological features and past seismicity in the region.

To perform detailed dynamic response analysis for earthquake resistant design of important structures like dams, the input excitation is required to be specified in the form of complete time-histories of horizontal and vertical components of ground acceleration, known as design accelerograms. In practical engineering applications, the design accelerograms are simulated to be compatible with the response spectra with damping ratio of 5%, termed as "target response spectra". The target response spectra for a project site can be estimated using several different alternatives under two basic approaches, namely "deterministic" and "probabilistic" approaches (ICOLD, 1989; US Army Corps of Engineers, 1999; Anderson and Trifunac, 1978; Gupta, 2002; FEMA, 2004). The preliminary design can, however, be based on simplified pseudo-dynamic analysis using site-specific design seismic coefficients, which can be defined from the response spectrum of the site-specific design accelerogram with a damping ratio equal to that of the dam. For this purpose, the response spectra for all the required damping ratios can be computed from the design accelerograms.

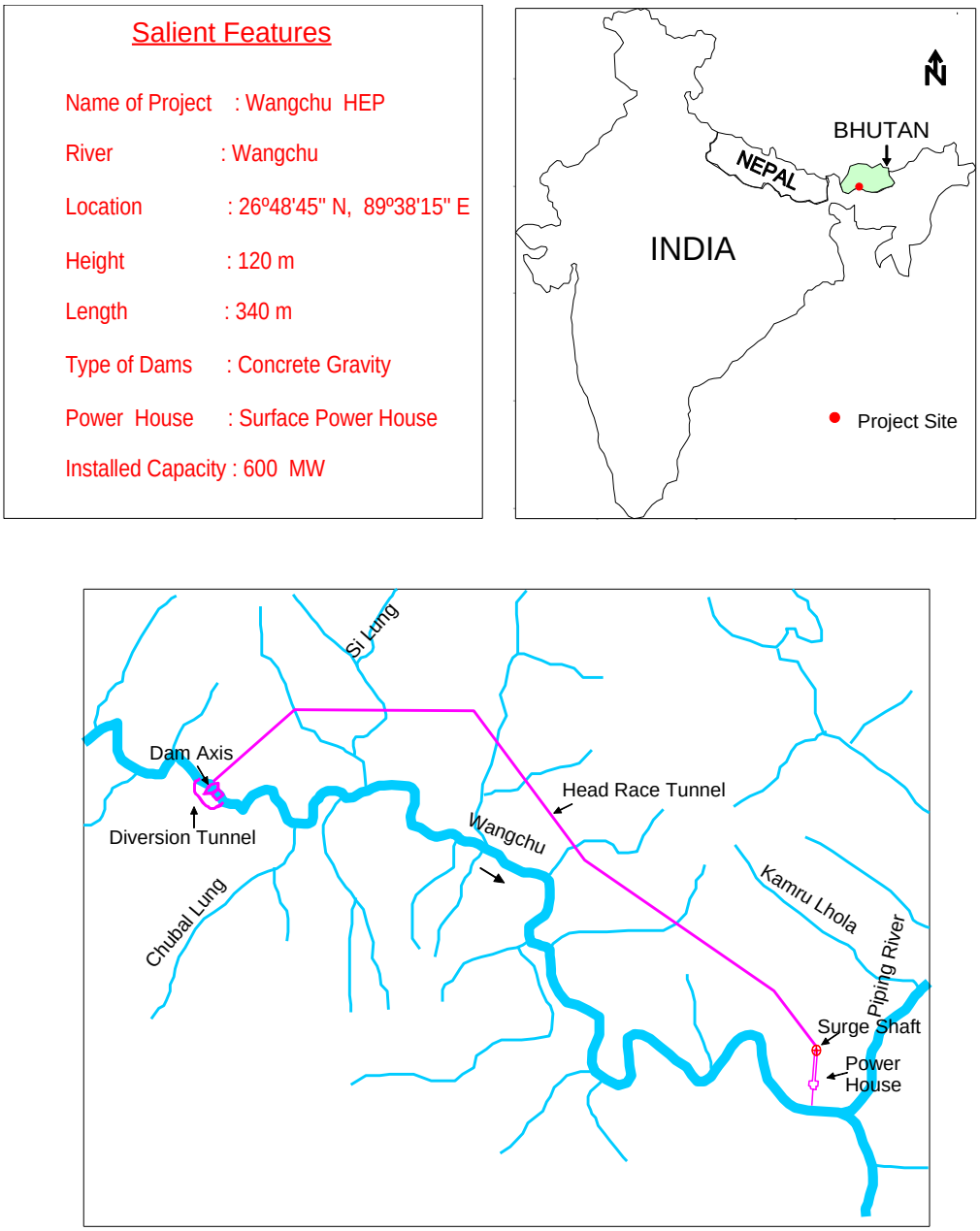

Fig. 1: *Location and site plan of the proposed Wangchu Hydro Electric Project, Bhutan*

In the deterministic approach, the mean plus one standard deviation (confidence level of 0.84) target response spectra are first obtained for various seismotectonic sources by assuming the estimated or postulated maximum credible earthquake (MCE) magnitude for each source to occur at the closest possible distance from the project site of interest. The largest, or the enveloping spectrum, is then used to obtain the MCE level of deterministic ground motion. The target response spectra in the probabilistic approach are estimated by considering the effect of

all the earthquakes with appropriate spatial distribution in the various source zones during a specified exposure period. The MCE level of probabilistic response spectra are defined with 2 % probability of exceedance during an exposure period of 50 years (FEMA, 2004). The MCE level of target spectra for WHEP site have been finally obtained from a comparison of the results from both deterministic and the probabilistic methods. The target response spectra have been used to generate compatible design accelerograms separately for horizontal and the vertical components of motion. These have been used to compute the response spectra for damping values of 1 %, 3 %, 5 %, 7 %, 10 % and 15 % of critical. Recommendation is also made for the site-specific design seismic coefficients using these response spectra.

2.0 GEOLOGY OF THE REGION

2.1 Major Geological Features

Physiographically, the Bhutan Himalaya can be divided roughly into three zones from south to north;(i) Sub-Himalaya or Foot hill zone (ii) Lesser Himalaya and (iii) Great Himalaya. The sub- Himalayan zone consists of the Siwalik sediments of Tertiary period, lying to the south of Main Boundary Fault. The lesser Himalaya starts immediately after the alluvial plains of north Bengal. This zone includes rocks of all three belts i.e. the Frontal belt, (excluding the Siwalik sediments), Central crystalline belt and the Tethyan Sedimentary belt. The great Himalayan zone in Bhutan comprises of rocks of the Central Crystalline belt, Tethyan Sedimentary belt and the younger Chomolhari granites. The main spread of the Quaternary sediments is found south of Bhutan in Indian plains. Within the Bhutan territory, the Quaternary successions are of limited extent.

Siwalik Hills are developed through out the length of the Himalaya. The Siwalik group bound by the Indian plains in south and variously by the Damuda Subgroup and Buxa group along well defined tectonic planes in north. The main rock found in this group is sandstone, siltstone, shale, clay and conglomerate.

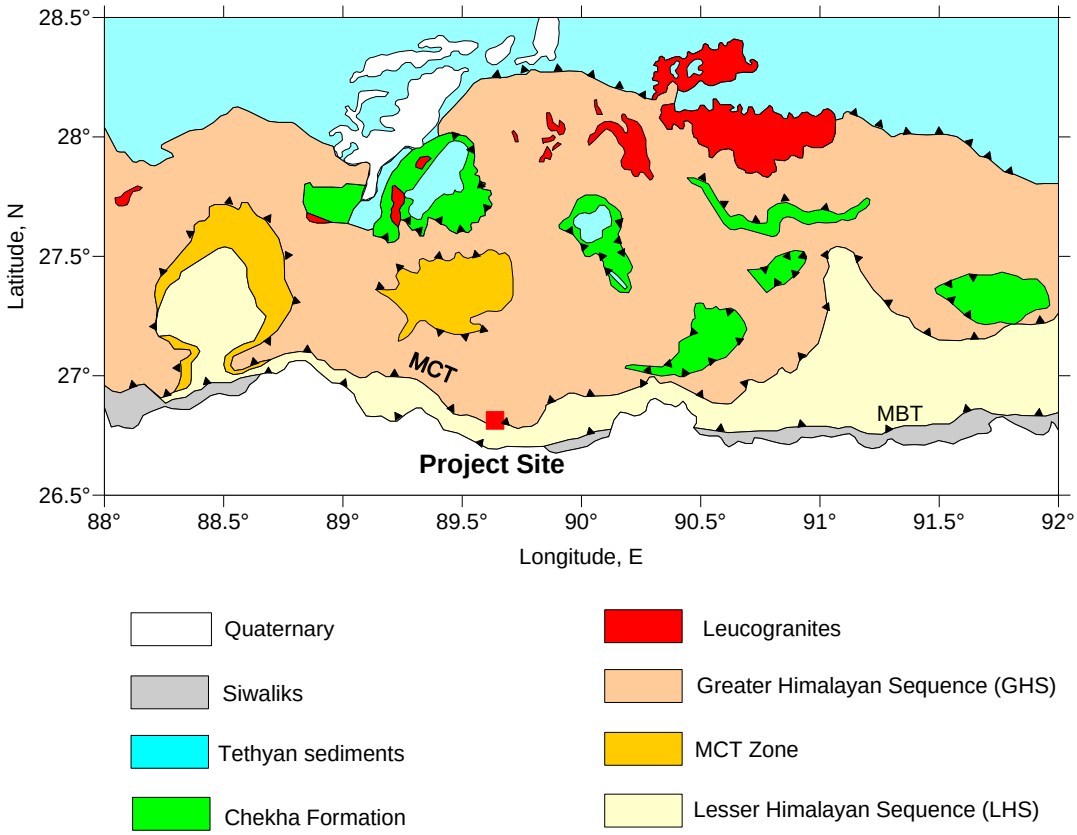

Fig. 2: *Major geological features in the region of WHEP site, Bhutan*

The Buxa Group, the main repository of dolomite and limestone in Bhutan, outcrops all along the length of the Bhutan Himalaya as a meta-sedimentary belt. It is tectonically sandwiched dominantly between the Shumar Formation in the north and the Siwalik group in the south. Broadly, the Buxa group comprises pink buff-white, gritty feldspathic quartzite, limestone, dolomite, quartzite, conglomerate, slate, quartzite, phyllite. The Buxa Group has been divided into a lower Thungsing Formation, middle Phuentsholing Formation and upper Manas Formation.

The Shumar series is a sequence of metasedimentary rocks, constituted mainly of phylite, slate, limestone and massive quartzite. The rock in the Shumar Formation is mainly quartzite, phyllite and chlorite mica schist, Barsong limestone, a few tectonic slivers of granite gneiss in lower part. Throughout the lesser Himalaya, the rocks of the Shumar Formation are overlain by the litho units belonging to the Jaishidanda Formation and in most of the sections, the Shumar Formation is underlain by the gritty, commonly feldspathic quartzite of the Buxa Group. The Jaishidanda Formation is mainly constituted of granetiferous mica schist with intercalations of micaceous quartzite.

The Central crystalline complex rocks cover an extensive E-W trending belt which occupies more than half of the area of Bhutan. These rocks overlie the meta sedimentary rocks of foothill belt and underlie the rocks belonging to the Tethyan Sedimentary belt to the north. The crystalline rocks have been generally divided into two groups (1) Gneiss dominated Thimphu Formation (2) Coarsely crystalline marbles, calcsilicate rocks interstratified with garnetiferous mica schists and quartrite referred to as the Paro `Group' of rocks. Based on the structural, lithological and metamorphic aspects, these rocks have been interpreted to be extension of the Shumar Formation below the Thimpu Thrust sheet.

The Thimphu series and generally the crystalline rocks are referred to as the Thimphu Group. The Thimphu Group has been identified as an allochthonous mass that has been thrusted over the little metamorphosed metasediments of the lesser Himalaya. The Thimpu formation includes a variety of granitoid rocks, such as migmatite, augen-gneiss, banded gneiss, granite gneiss, felspathic gneiss and schistose rocks ranging up to sillimanite grade. The Paro formation includes essentially the high grade calcareous rocks and meta-sediments such as marble-calc-silicate rock, quartz-garnet-staurolite-kyanite-sillimanite schist, graphite-schist, etc. with subordinate feldspathised schists and gneisses.

2.2 Local Geology

From the write up on geology provided by the project authorities, it is observed that the dam site area lies in the south-western region of Bhutan and falls within the rocks of Shumar Formation of the lesser Himalayan belt of Bhutan Himalayas. Broadly the Shumar Formation of rocks comprises of an alternating sequence of quartzite and phyllitic-quartzite / Mica-schist interbands. The phyllitic quartzite interbands are fine grained, commonly grey to grayish green and well foliated.

The dam site area exposes white, grey and grayish green quartzite with subordinate bands of phyllitic quartzite. An outcrop of phyllitic quartzite has been mapped as linear band along foot track on right valley slopes of Wangchu river. The dam foundation is on massive bedded, jointed quartzite below 15 m to 37 m thick riverine overburden. Fresh quartzite rocks are available for the dam foundation after stripping 2m to 3m of weathered quartzite rock in the river bed section. Both the abutments are also resting over the quartzititic rock of good quality, fairly massive and hard though jointed and sheared at places. Thus, based on the information made available by the project authorities, geology of WHEP site is taken to be rock for estimation of seismic design ground motion.

3. SEISMOTECTONIC FEATURES

The various geological formations in the WHEP area are separated from each other by E-W trending Himalayan longitudinal faults. The Main Central Thrust (MCT) separates the high grade Central Crystalline from the comparatively lower grade Lesser Himalayan rocks, which are separated from the Siwalik belt by the Main Boundary Thrust (MBT). Several subsidiary thrusts are present between MCT and MBT. Also, some NNW-SSE trending transverse faults exist in the area. The major regional tectonic features are shown in Fig. 3, which includes the Indus Tsangpo Suture Zone (ITSZ), the Tethyan Himalaya, the various Main Himalayan Thrusts, the Shillong Massif and the faults surrounding it, various faults and lineaments transverse to the Himalayas, and the subsurface faults in the Gangetic and Brahmaputra foredeeps (GSI, 2000). The project site is located between the MBT and MCT and their subsidiary thrusts in the main Himalayan thrust zone. The seismicity of the area is related to the continued movement of the Indian plate since its collision with the Eurasian plate about 40 million years to 50 million years ago. After complete subduction of the Tethys Ocean between India and Eurasia, the two continental plates collided along the ITSZ. The continued movement of the Indian plate in N-NE direction at a rate of about 5 cm per year has resulted in large scale folding, crustal shortening and vertical crustal movements forming the great Himalayas to the south of the line of suture.

The major tectonic features in the main Himalayan zone are the MCT, the MBT, and many subsidiary thrusts sympathetic to MCT and MBT. Several approximately N-S trending gravity faults are present within the Tethyan belt, but they lie at relatively longer distance from the project site. These N-S faults define some well known graben structures, viz. Pum Qu and Yadong Gulu. The Yadong Gulu graben is considered the longest one in the Tibetan Plateau, which is segmented into several smaller grabens.

According to the seismotectonic model of the Himalayas (Seeber and Armbruster, 1981), the motion of the Indian and the Eurasian plates after their collision resulted in a gently dipping detachment plane to the north of Himalayan foothills at a depth of about 20 km near MBT, and increasing to about 40 km near the suture zone. The strong earthquakes are believed to be associated with the periodical strike-slip motion along this crustal detachment plane. The MBT and MCT are steeply dipping thrust planes joining the detachment thrust plane. Thus, major earthquakes in the Himalayan block are not expected to be correlated with the thrust planes of MBT and MCT, but they mostly occur in the lithosphere below the detachment plane (Gupta, 2006).

South of the Himalayas, the Gangetic fore deep area is characterized by several subsurface faults, in addition to the other faults and lineaments. The area of Purnia Basin, west of the deep seated Malda-Kishanganj Fault (MKF), is architectured by a set of almost N-S trending faults,

resulting in the development of alternate horst and graben structures. The major faults in the area to the east of MKF are the Jangipur-Gaibandha, Tista, Katihar-Nailphamari, Garhmoyna Khandagosh, and Debagram-Bogra faults. In the eastern most part, the conspicuous tectonic discontinuity is the N-S trending Dhubri-Jamuna fault, which has a considerable down throw towards the west. This fault defines the western margin of the Shillong massif.

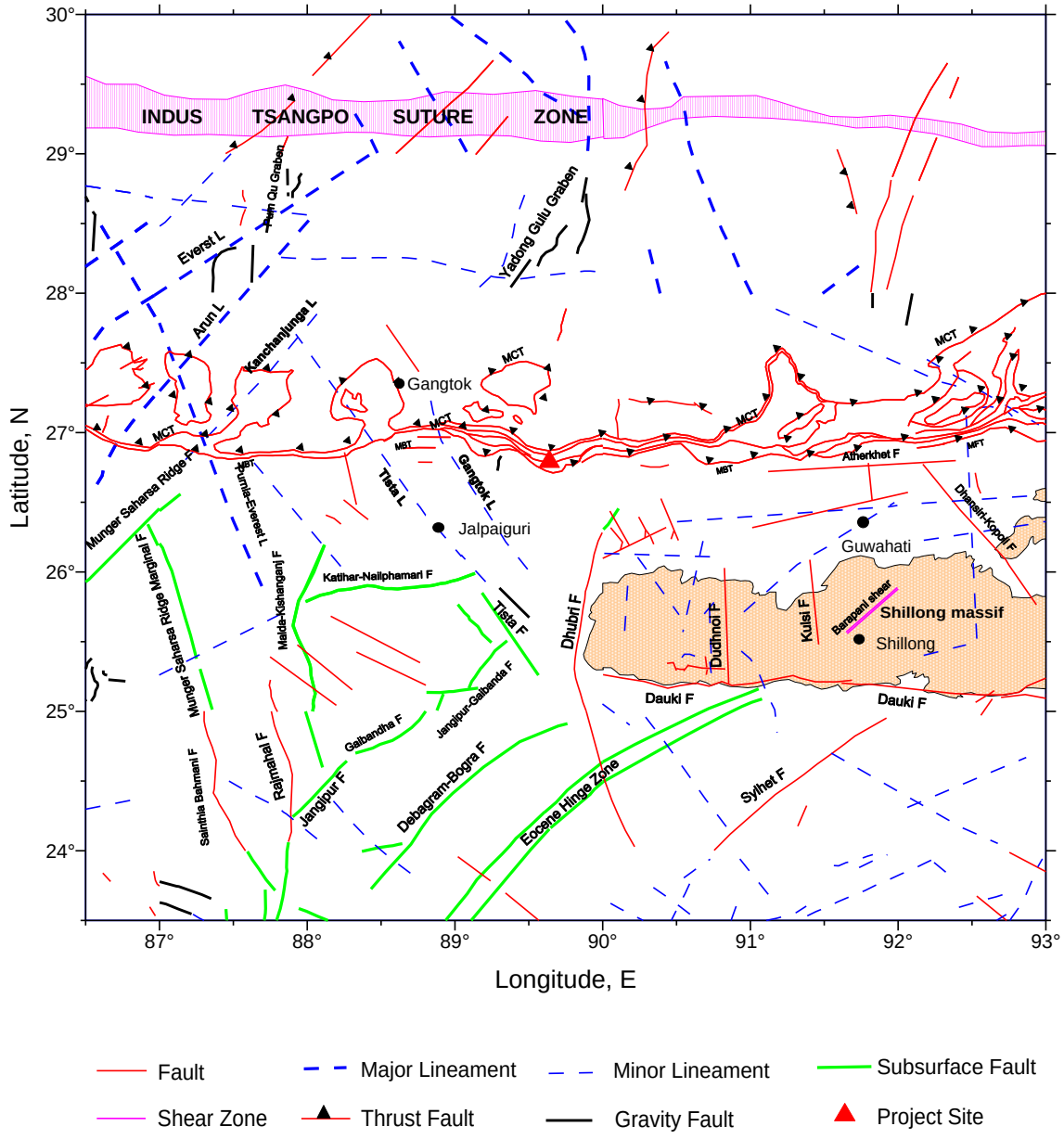

Fig. 3: *Major tectonic features in the region of WHEP site, Bhutan*

The Shillong massif consists mostly of Archaean Gneissic complex with Proterozoic intracratonic quartzite and phyllite of Shillong group, intruded by acid and basic igneous rocks. During the Jurassic-Cretaceous period, the plateau rifted along the southern margin by the E-W Dauki Fault. The Shillong Plateau is characterized by a number of faults, shears and

lineaments, which exhibit considerable seismicity. The Shillong Plateau has been the seat of the 1897 Assam earthquake of magnitude 8.0. The major faults in the Shillong Plateau are the N-S trending Dudhnoi and Kulsi faults, the NE trending Barapani and Kalyani shear zones, and several NE-SW and N-S trending lineaments. South of Dauki fault is the Sylhet trough, the Surma fold basin, the subsurface Eocene hinge zone and the Mat fault. Mikir hill is detached from Shillong plateau by the NW-SE trending Kopili-North Dhansiri fault. In the north, Shillong plateau is limited by Brahmaputra basin, which is characterized by several sets of neotectonic faults of which the NE-SW trending and the E-W trending sets are the most conspicuous. Southeast of Brahmaputra foredeep is delineated on west by the Naga thrust, and on the east by Haflong-Disang thrusts.

There are many transverse faults and lineaments cutting across the Himalayas, some of which are considered to be the continuation of the sub-surface features in the fore-deep. These transverse features exhibit north-easterly as well as north-westerly trends. The north-easterly trending Arun Lineament is considered to be the trace of the northern extension of the East Patna Fault. Parallel to this is the Kanchenjunga Lineament that extends from the fore deep to well inside the Himalayan belt. Other prominent lineaments include NW-SE trending Tista, Gangtok and Purnia-Everest lineaments. Out of several NE-SW trending lineaments, Everest lineament extends from the Indo-Gangetic plain to well within the Himalayan belt. The transverse features segregate the Himalayan longitudinal trend into several independent segments, seldom exceeding 100 km to 150 km in length. In the west the prominent faults are the Sainthia Bahmani fault, Munger Saharsa Ridge marginal fault, Munger Saharsa Ridge fault and the East Patna fault. Thus, the region depicted in Fig. 3, which includes about 350 km length of Himalayas on both sides (west and east) of the Wangchu project site, is considered to represent adequately the seismic potential of all the tectonic features of significance.

4. HISTORICAL SEISMICITY

4.1 General Description

Both the deterministic and the probabilistic approaches for evaluation of design ground motion for a project site require a comprehensive database on past earthquakes in the region of the project. A detailed analysis of the past seismicity of the region of the project is presented in this section. The data on past earthquakes around the WHEP site, as compiled from different published sources, is listed in Table-1 for magnitude 5.0 and above. For each of the earthquakes, the date of occurrence, epicentral location, focal depth, distance from the project site and magnitudes are also given. Wherever the required information is missing, the relevant space is left blank. A total of 864 earthquakes for the period from 1411 to 2010 with magnitudes greater than or equal to 4.0, are available for the region.

Fig. 4 shows the histograms for the distribution of magnitude and epicentral distances for earthquakes within 300 km of the proposed project site. The histogram for magnitude indicates that the relative number of earthquakes with magnitude above 5.6 are not represented in a consistent manner, perhaps due to limited period and area covered by the catalogue. The histogram for distance distribution also shows the significant events with magnitude greater than or equal to 6.5. Out of a total of 15 events with magnitude 6.5 and above, only one event with a magnitude of 6.5 is reported to have occurred within 100 km of the project site. This event occurred on 29 July 1960 in the Main Himalayan Thrust zone at a distance of about 66.5 km. The significant events, within 300 km of the site, having magnitude 7.0 and above are shown in table below.

Name of Place	Date	Magnitude	Distance in km
Sirajganj, Bangladesh	1787	8.3	281.3
Near Rangoli, Assam	11/06/1806	7.7	299.7
Darjeeling region	01/05/1852	7.0	134.6
Shillong plateau	12/06/1897	8.7	162.5
Srimangal Earthquake	08/07/1918	7.6	289.1
South-West Assam	09/09/1923	7.1	219.4
Dhubri, Assam	02/07/1930	7.1	149.4
Bihar Nepal border	15/01/1934	8.1	274.6

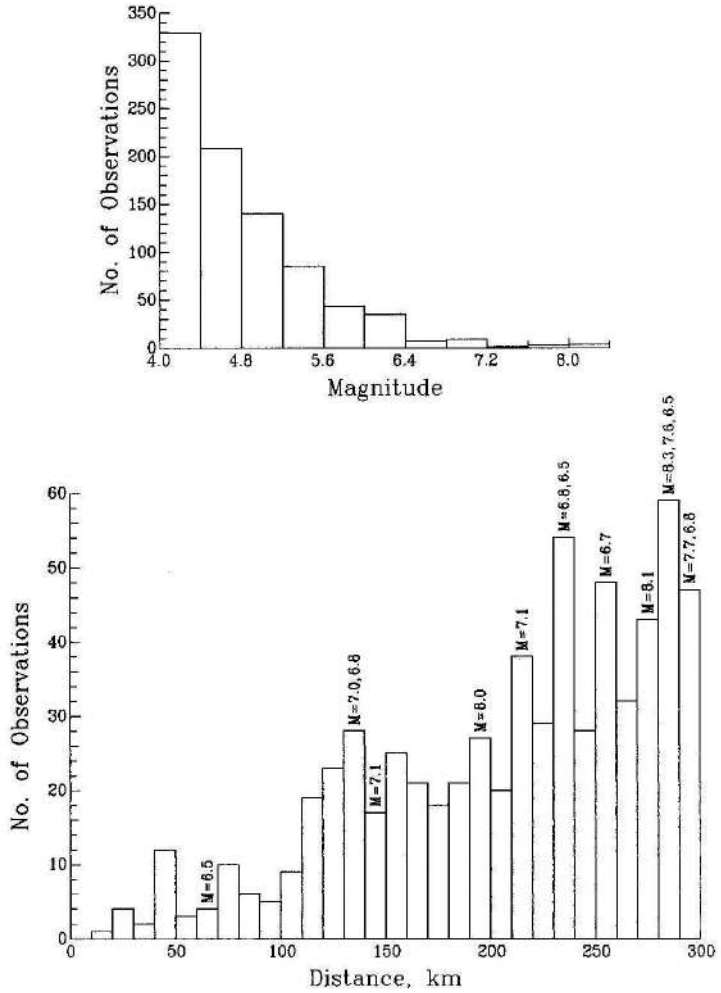

Fig. 4: *Histograms showing the distribution of magnitude and epicentral distance of the past earthquakes within 300 km of the WHEP site*

Fig. 5 shows the superposition of the epicenters of earthquakes on the tectonic features, indicating the association of the data on past earthquakes with the tectonic features in the region of WHEP. Though the epicenters are seen to follow broadly the trend of the surface traces of various tectonic features, they are scattered very widely. This may be due to inaccuracies in the epicentral location as well as the dipping nature of the tectonic features. The Himalayan thrust zone and the Shillong massif areas are characterized by the highest level of seismicity. The seismicity in the Himalayas and the area north of it is seen to be clustered at several preferred locations, mainly along the faults and lineaments transverse to the Himalayas. Similar to other parts of the Himalayas, both the detachment plane and the transverse features in the upper crust may be contributing simultaneously to the observed seismicity in the region of the project.

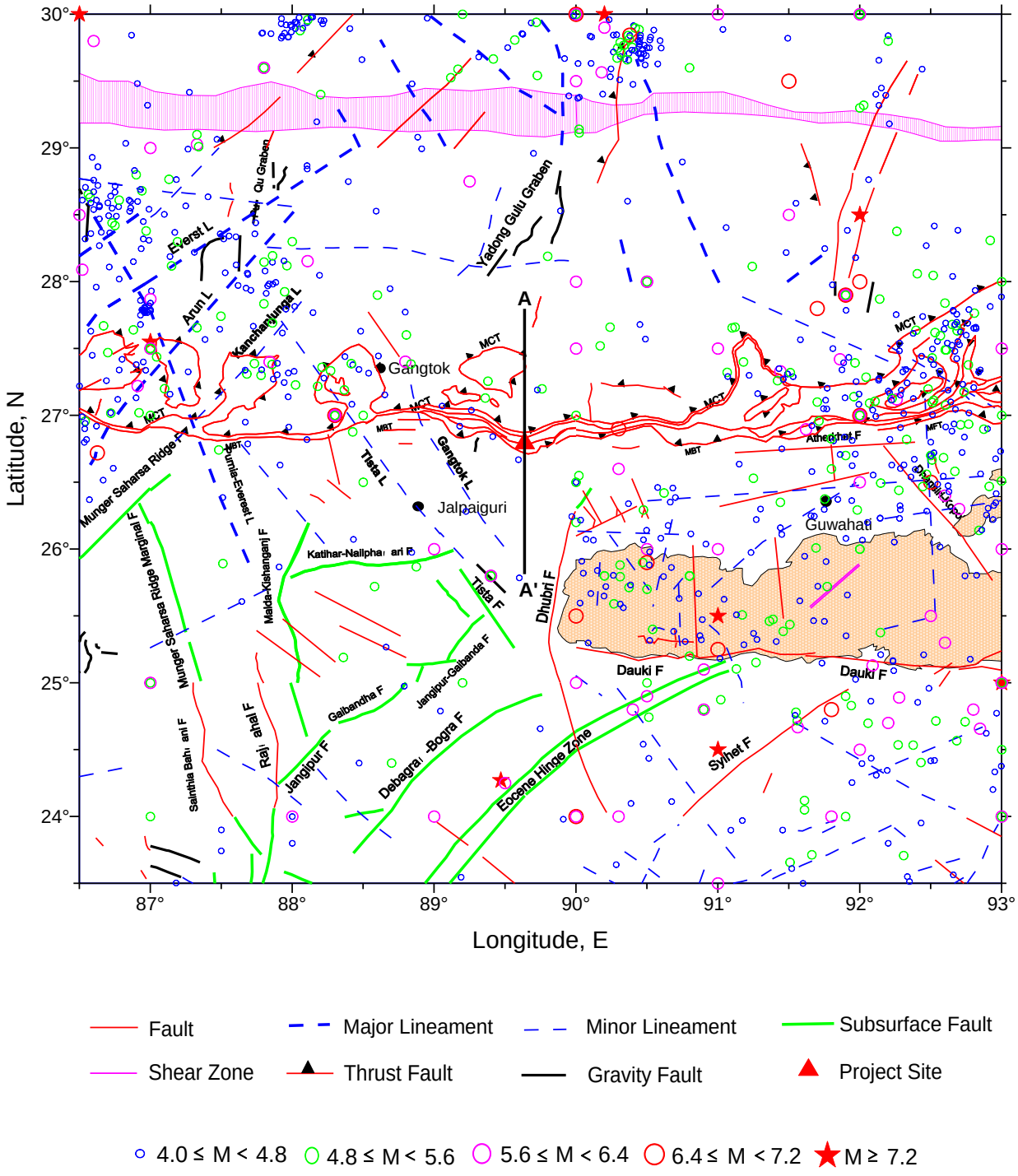

Fig. 5: *Correlation of the epicenters of past earthquakes with major tectonic features in the region of WHEP site*

4.2 Identification of Seismic Sources

A seismic source is defined as an individual fault, or an area of diffused seismicity with distinctly different seismogenic potential in terms of the maximum magnitude as well as the

occurrence rate of earthquakes in different magnitude ranges. Considering the spatial distribution and correlation of seismic activity with the tectonic features in the region of the WHEP site, six broad seismic sources have been identified as follows:

1. Trans-Himalayan (TRH) Area north of and including the Indus-Tsangpo suture
2. Tethys Himalayan (THH) Area
3. Main Himalayan Thrust (MHT) Area encompassing MCT, MBT, etc.
4. Brahmaputra Valley (BPV) Area
5. Shillong Massif (SHM) Area
6. Area of Indo-Gangetic Plains (IGP)

All these sources are shown in Fig. 6 along with the epicenters of the available data on past earthquakes.

The TRH seismic source is characterized by several isolated clusters of epicenters with varying level of activity. As this source lies far away from the project site, the effect of concentrated seismicity at certain locations is not expected to be significant at the project site. The THH source is also characterized by more concentration of activity in its western and eastern parts due to the existence of several faults and lineaments transverse to the Himalayan longitudinal trend. This source has been therefore further divided into three separate sub-sources 2A, 2B and 2C. The MHT source, in which the project site lies, is characterized by much higher level and frequency of earthquakes in its eastern and western segments. This may be attributed to both the Himalayan longitudinal thrusts and the transverse and oblique faults. The MHT source is therefore also defined by sub-zones 3A, 3B and 3C. The epicenters are seen to be spread all over the BPV source, but the activity is much lower in terms of the maximum earthquake magnitude. Further, the eastern part shows somewhat higher density of epicenters, and hence this source is defined by two sub-sources 4A and 4B. The SHM encompasses the Shillong Massif and hence has high seismicity and the highest number of large magnitude (>7.0) events.

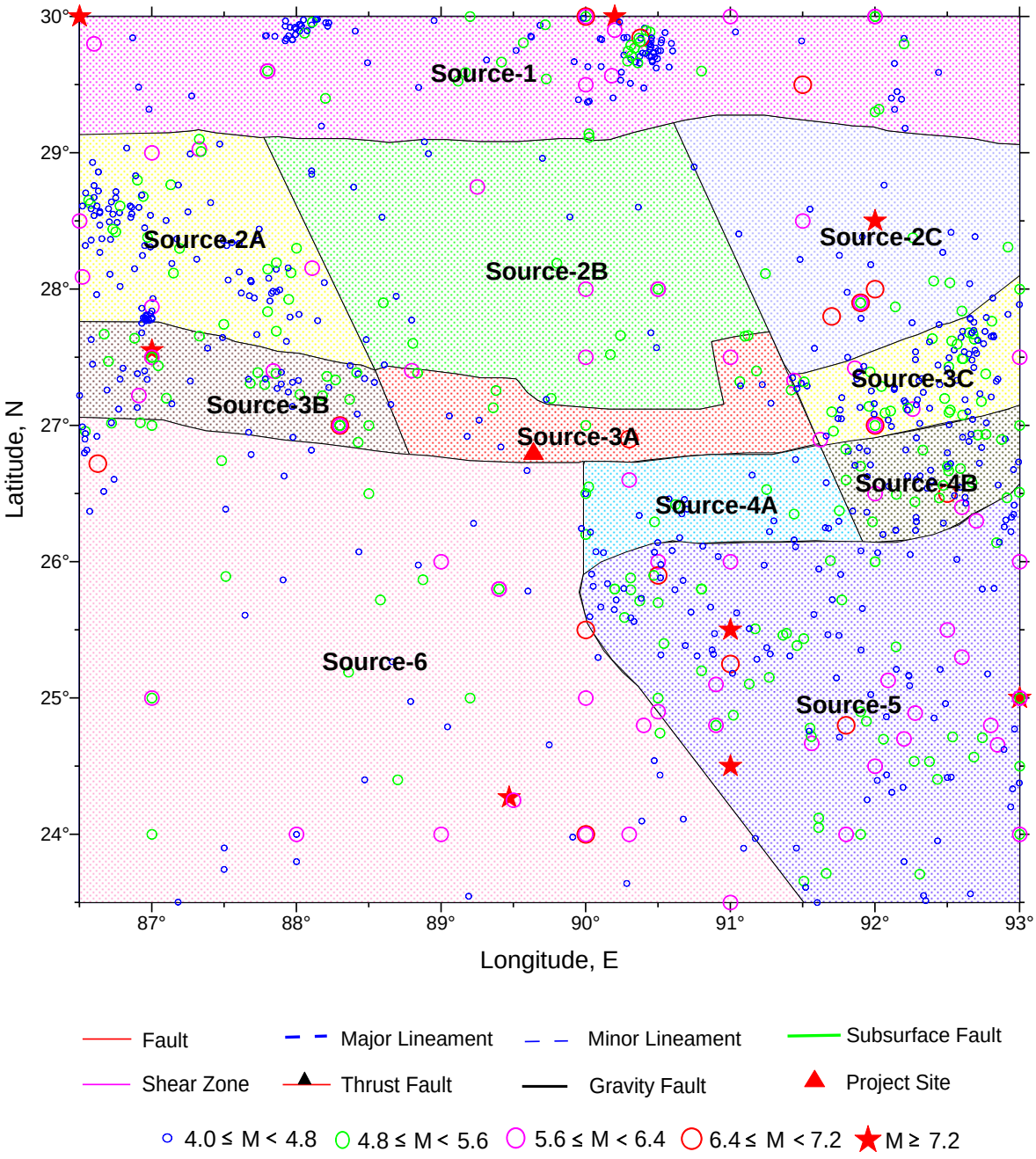

Fig. 6: *Seismic source zones in the region of WHEP site along with the epicenters of available data on past earthquakes*

5. GROUND MOTION BY DETERMINISTIC APPROACH

5.1 Basic Concepts

The design ground motion by deterministic approach is estimated for a specific earthquake magnitude occurring at a fixed distance from the project site of interest. Two different levels of earthquake are considered for this purpose, one of which represents a rare but possible event, and the other one represents a more likely event during the life of a project. These are termed as MCE and DBE, respectively. The MCE is defined as the largest possible earthquake along a

recognized fault or within a geographically defined tectonic province, under the presently known or presumed tectonic framework. Each seismic source in a project area is characterized by its own MCE magnitude, which is presumed to occur at the closest possible distance to the project site. The concept of floating earthquake is used, when no potential fault is delineated close to the project site for locating the MCE. In practical applications, largest of the ground motions due to all the magnitude and distance pairs of the MCE is used for the purpose of design. The deterministic estimate of the DBE level of motion is taken to be half the MCE level of motion. The various steps involved in the deterministic seismic hazard analysis (DSHA) approach for evaluating the 5 % damped MCE level of target response spectra are described in the following sub-sections.

5.2 Estimation of Magnitudes and Distances of MCE

Depending upon the type and quality of the available data, the magnitude of MCE for a seismic source can be estimated by several different methods. This includes the use of empirical relations in terms of the fault rupture parameters, actually recorded largest historical earthquake with or without some increment, extrapolation of magnitude recurrence relationship, and the extreme-value statistics. The fault rupture parameters needed for estimating the magnitude of MCE are the maximum rupture length or the rupture area (Wells and Coppersmith, 1994). However, the reliability of this method cannot be considered very good, because the fault rupture parameters for a future earthquake cannot be defined with confidence. Thus, the magnitude of MCE in the present study is determined from an analysis of the available data on past earthquakes only. To define the magnitude of MCE for plate boundary areas, the actually recorded largest magnitude is commonly enhanced by 0.5 units. The enhancement in the magnitude is made to account for the fact that the period of the available earthquake catalogue is not long enough to include the expected largest magnitude.

South of the MHT area lies the Gangetic and Brahmaputra alluvial plains abutting the Himalayas. This region marks a considerable physiographic elevation change, which could produce stress differentials. On this basis, the MBT is considered to be capable of sustaining high stresses and producing great earthquakes, (Khattri et al., 1984). From past seismicity, it is seen that it has indeed been the source of many earthquakes that are among the greatest ever recorded events. Also the evolutionary model of Himalaya (Le Fort, 1975) states that MBT is the younger tectonic discontinuity as compared to MCT and is more active currently. Hence, a magnitude of 8.0 has been assigned to the MBT. The tectonic zone to the north of the MBT is a region of fractured rock mass that may not be able to accumulate strain in large enough volumes to give rise to great earthquakes, although large earthquakes of magnitudes between 7.0 and 8.0 have occurred there. Also the evolutionary model of Himalaya (Le Fort, 1975)

states that MBT is the younger tectonic discontinuity as compared to MCT and is more active currently. In view of this a magnitude of 7.5 is assigned to the MCT.

The rupture that causes large magnitude earthquakes occurs at the detachment plane in the vicinity of the surface traces of the MBT and MCT, as mentioned in Section 3.0. From the distribution of past earthquakes in the region of the site, namely MHT zone (Fig.6), it is seen that the eastern and western segments of this zone are much more active compared to the area in the immediate vicinity of the site. This is perhaps due to the different tectonic environment of the central portion of this source zone from the portions to the east and west. The surface traces of the thrust faults MCT and MBT are seen to be quite undulating in the eastern and the western portions of the zone, whereas they are almost undisturbed in the central portion. The largest magnitude event reported to have occurred in the MHT zone is the 6.5 magnitude earthquake of 29 July 1960 at a distance of 66.5 km from the dam site. Thus the estimates for the MCE values for the MBT and MCT are very conservative in view of the safety of the project.

To assign the fault rupture distance R_{rup} from the site to the rupture plane of this MCE, Fig. 7 shows the N-S depth section of the available past earthquake data around the project site. It is seen that the larger magnitude earthquakes in the project area can be assumed to occur along the crustal detachment plane. The MCE can thus be assumed to occur at a closest distance from the site of the dam which is the distance to the points where steeply dipping MBT and MCT thrust planes meet the detachment surface. The fault rupture distance R_{rup} is found to be 29.0 km and 45.6 km for MBT and MCT respectively. The project site is located between the MBT and MCT and since the potential magnitude of the MBT is 8.0 as against magnitude 7.5 of the MCT, magnitude 8.0 at the closest rupture distance of 29.0 km would be the governing magnitude-distance pair for the deterministic spectra.

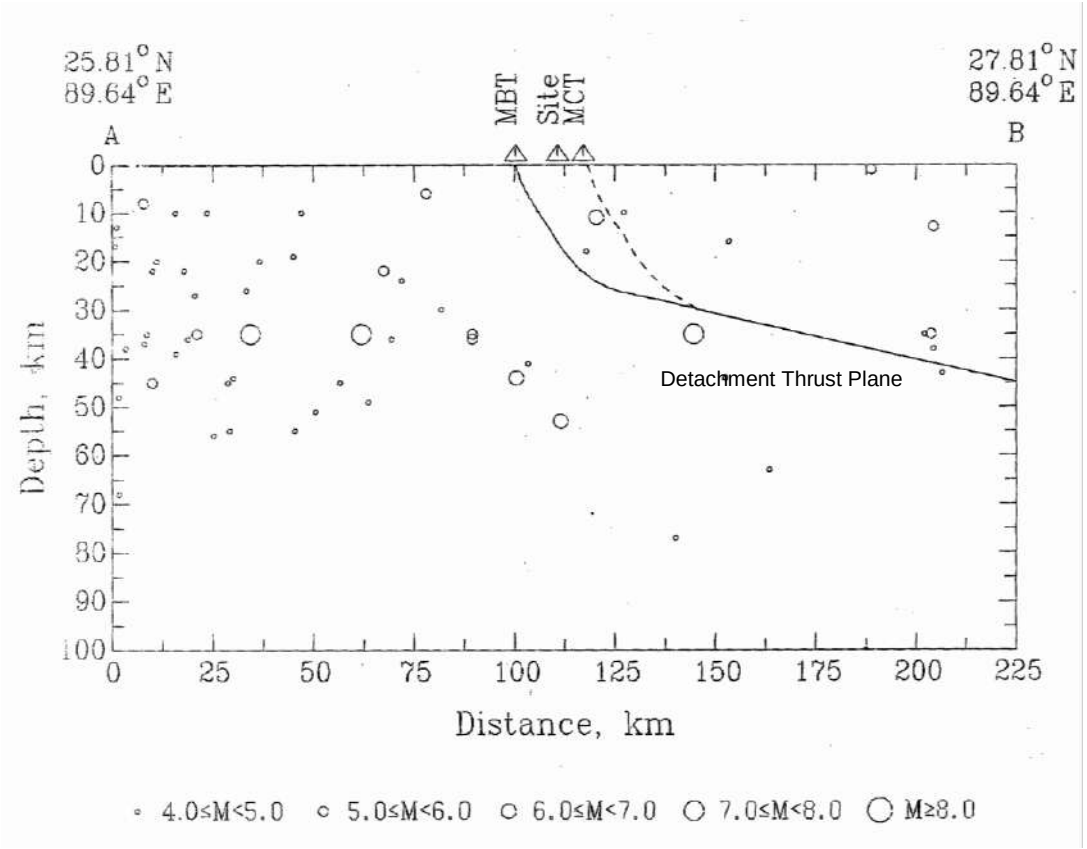

Fig. 7*: Depth section of past earthquakes and tentative locations of the MBT and detachment thrust plane in the area of WHEP site.*

5.3 Attenuation Relationship

To obtain the target response spectra of horizontal and vertical components with 5 % damping ratio for the Wangchu project site, it is necessary to have a suitable frequency-dependent attenuation relationship for the area of the project. It is generally stressed that such a relationship should ideally be based on the strong-motion data recorded in the region of a project site of interest. However, it has been now well recognized that the apparent variations in the attenuation relations may not in reality be due to regional variation, but they may be due to poorly constrained nature of the relationships (Douglas, 2007). Therefore, the use of a well constrained relationship based on a sufficiently large database, even for another region, can be considered quite suitable.

An appropriate attenuation relation has been selected from the published literature with the foregoing background. The guiding principles used for this selection are:

i) The attenuation relationship should be able to represent the magnitude and distance saturations and the variation in geometrical spreading with distance in a physically realistic way,

ii) Gives the vertical spectra independently, and

iii) For a specific application it should be possible to define all the governing parameters without much uncertainty.

From a critical review of several published attenuation relationships (Abrahamson and Silva, 1997; Campbell, 1997; Dahle et al., 1990; Lee, 1989) vis-à-vis the available information on the site geological condition and the earthquake parameters, the relationship due to Abrahamson and Silva was found quite suitable for the present application.

The frequency-dependent attenuation relation due to Abrahamson and Silva is developed using a database of 655 accelerograms from 65 shallow crustal earthquakes in tectonically active regions the world over. The attenuation relation for spectral acceleration, *SA(T)* is represented by :

$$lnSA(T) = f_1(M,R) + F \cdot f_3(M) + HW \cdot f_4(M,R) + S \cdot f_5(a_{max}) \qquad (1)$$

where *M* is the moment magnitude and *R* is the closest distance to the fault rupture plane. Parameter *F* defines the type of faulting, *HW* specifies the location of site on hanging or footwall of dipping faults, and *S* defines the site condition as:

$$F = \begin{cases} 1 & \text{for reverse fault} \\ 0.5 & \text{for reverse/oblique fault} \\ 0 & \text{for strike-slip fault} \end{cases}$$

$$HW = \begin{cases} 1 & \text{for sites over hanging wall} \\ 0 & \text{otherwise} \end{cases}$$

$$S = \begin{cases} 0 & \text{for rock or shallow soil sites} \\ 1 & \text{for deep soil sites} \end{cases}$$

Functions f_1, f_3, f_4 and f_5 in eqn. (1) are expressed in terms of 12 regression coefficients, $a_1(T)$, $a_2(T)$, ……, $a_{12}(T)$, at 28 natural periods between 0.02 sec and 5.0 sec. The expression of eqn. (1) gives the least squares median value, $\langle SA(T) \rangle$, of the spectral amplitudes.

To consider the dispersion in the observed data around the least squares estimate, Abrahamson and Silva have defined the standard deviation $\sigma(T)$ of ln *SA (T)* at each natural period. This can be used to compute the spectral amplitudes with any desired confidence level using the Gaussian distribution function as follows:

$$P[SA(T)] = \frac{1}{\sqrt{2\pi}\sigma(T)} \int_{-\infty}^{lnSA(T)} exp\left\{ -\frac{1}{2}\left(\frac{x - ln\langle SA(T) \rangle}{\sigma(T)} \right)^2 \right\} dx \qquad (2)$$

Here, $P[SA(T)]$ gives the probability of not exceeding the spectral amplitude *SA(T)* at a site due to specified values of earthquake magnitude and distance.

5.4 Deterministic Target Response Spectra

The 5 % damped response spectra of horizontal and vertical ground motion have been evaluated with a confidence level of 0.84 since the site lies in a highly seismic region. The MCE of magnitude 8.0, associated with MBT, at a closest distance of 29.0 km from the dam site gives the governing deterministic spectra. The spectra for both components are shown in Fig. 8. For DBE level of ground motion the spectra are taken to be half of those of MCE condition, the spectra for the horizontal and vertical components are shown in Fig.9.

6.0 GROUND MOTION BY PROBABILISTIC APPROACH

6.1 Probability Distribution Function

The probabilistic seismic hazard analysis (PSHA) approach is used to consider the random and uncertain nature of seismicity as well as the ground motion attenuation. This approach considers the effect of total expected seismicity with suitable spatial distribution to evaluate the 5 % damped target response spectra for a project site. The spectra obtained by PSHA approach have the property that for a specified confidence level they will not be exceeded due to any of the earthquakes expected to occur anywhere in the region during a specified exposure time. The probabilistic MCE level of ground motion is commonly specified with a confidence level of 98% during 50 years exposure time (FEMA, 2004). The PSHA approach is based on the following composite probability distribution of the spectral amplitude at a particular natural period (McGuire, 1977; Anderson and Trifunac, 1978; Gupta, 2002).

$$P[SA(T)] = exp\left\{-Y\sum_{i,j} q[SA(T)\,|\,M_j, R_i]\cdot \upsilon(M_j, R_i)\right\} \qquad (3)$$

In this expression, $\upsilon(M_j, R_i)$ is the annual occurrence rate of earthquakes within small magnitude and distance ranges $(M_j - \delta M_j, M_j + \delta M_j)$ and $(R_i - \delta R_i, R_i + \delta R_i)$, and *Y* is the exposure time considered. Quantity $q[SA(T)\,|\,M_j, R_i]$ is the probability of exceeding the spectral amplitude *SA*(*T*) due to earthquake magnitude M_j at distance R_i, which can be obtained from the probability distribution of eqn. (2). Thus, the main task to evaluate the distribution function of eqn. (3) is to estimate the occurrence rates $\upsilon(M_j, R_i)$, which is termed as the total design seismicity.

6.2 Estimation of Design Seismicity

To implement the PSHA approach for obtaining the target response spectra for the WHEP site, the following form of Gutenberg-Richter's (1944) recurrence relationship has been first defined for each of the main and sub-sources around the project site.

$$\log N(M) = a - bM \tag{4}$$

In this expression, *N(M)* is the annual number of earthquakes with magnitude M or greater and *a* and *b* are the constants specific to the seismic source of interest. These constants are evaluated using the past earthquake data in the source zone. For this purpose, the earthquake data has been converted into moment magnitude using empirical conversion relations (Chung and Bernreuter, 1981). Also, the dependent events namely aftershocks, have been removed and the completeness of data in different magnitude ranges has been accounted by the method of Stepp (1973). The maximum likelihood method of Weichert (1980) has been used to obtain the constants *a* and *b* in the present study. The parameters *a* and *b* obtained for all the sources and sub-sources are as tabulated below.

Source	Name of Source	Recurrence Parameters		
		a-value	b-value	M_{max}
1	Trans Himalayan Area	3.55	0.75	8.3
2	Tethys Himalayan Area			
	Sub-source 2A	5.21	1.14	6.7
	Sub-source 2B	1.64	0.49	6.2
	Sub-source 2C	2.54	0.64	7.8
3	Main Himalayan Thrust Area			
	Sub-source 3A	2.22	0.62	6.6
	Sub-source 3B	3.34	0.79	8.3
	Sub-source 3C	4.04	0.88	7.0
4	Brahmaputra Valley Area			
	Sub-source 4A	1.48	0.43	5.8
	Sub-source 4B	4.32	1.01	6.6
5	Shillong Massif Area	3.31	0.69	8.2
6	Indo-Gangetic Plains	3.00	0.74	8.4

From a knowledge of parameters *a* and *b* for a source or sub-source, the relationship of eqn. (4) can be used to obtain the total number $N(M_{min})$ of earthquakes above a specified threshold magnitude M_{min}, taken as 5.0 in the present study. For practical applications, it is however necessary to consider an upper bound magnitude M_{max} also. The maximum

magnitudes assigned to the various source zones are given in table above. With upper and lower bound magnitudes, the expression for *N(M)* can be written as (Cornell and Van Marcke, 1969)

$$N(M) = N(M_{min}) \frac{exp(-\beta(M - M_{min})) - exp(-\beta(M_{max} - M_{min}))}{1 - exp(-\beta(M_{max} - M_{min}))} \quad (5)$$

Parameter β in this relation is related to the *b* value as $b\ln 10$. The relationship of eqn. (5) describes an exponential decay of *N(M)* with increase in *M* up to the maximum magnitude. It may therefore not be suitable to describe the behaviour of very large magnitude earthquakes in some cases, where the largest earthquakes occur more periodically and frequently. In such cases, the characteristic earthquake model is found to describe the data better (Youngs and Coppersmith, 1985). The characteristic model is obtained by fitting the relationship of eqn. (5) to the observed data upto some much lower magnitude than M_{max}. In the range, $(M_{max} - \Delta M_c, M_{max})$ of the characteristic earthquake, a uniform occurrence rate is used with the probability density equal to that given by the distribution of eqn. (5) at a still lower magnitude, say one magnitude unit below $(M_{max} - \Delta M_c)$.

From the recurrence relationship for a source zone, the occurrence rate of earthquakes within a small magnitude range $(M_j - \delta M_j,\ M_j + \delta M_j)$ around magnitude M_j can be obtained as

$$n(M_j) = N(M_j - \delta M_j) - N(M_j + \delta M_j) \quad (6)$$

In the present study, the magnitude has been discretized into ten intervals with central magnitude M_j = 5.0, 5.4, 5.8 ….., 8.6 and $\delta M_j = 0.2$ for all the intervals. The numbers for various sources and sub-sources are distributed uniformly to get the number within a small distance range $(R_i - \delta R_i, R_i + \delta R_i)$. The total number within the *i*th distance range for all the sources and sub-sources provides the required design seismicity $\upsilon(M_j, R_i)$. By computing the probability distribution of eqn. (3) for each natural period, it is possible to estimate the spectral ordinate *SA*(*T*) with a desired confidence level at all the natural periods. The response spectrum thus obtained is known as uniform hazard response spectrum, which forms the basis of the probabilistic design ground motion.

6.3 Probabilistic Target Response Spectra

Using the total expected seismicity evaluated as above, the probability distribution function of eqn. (3) has been used to obtain the 5 % damped horizontal and vertical spectral amplitudes

at various natural periods with a confidence level of 0.98 during a life period of 50 years. These spectra are also plotted in Fig. 8 along with the MCE level of deterministic spectra evaluated in the previous section.

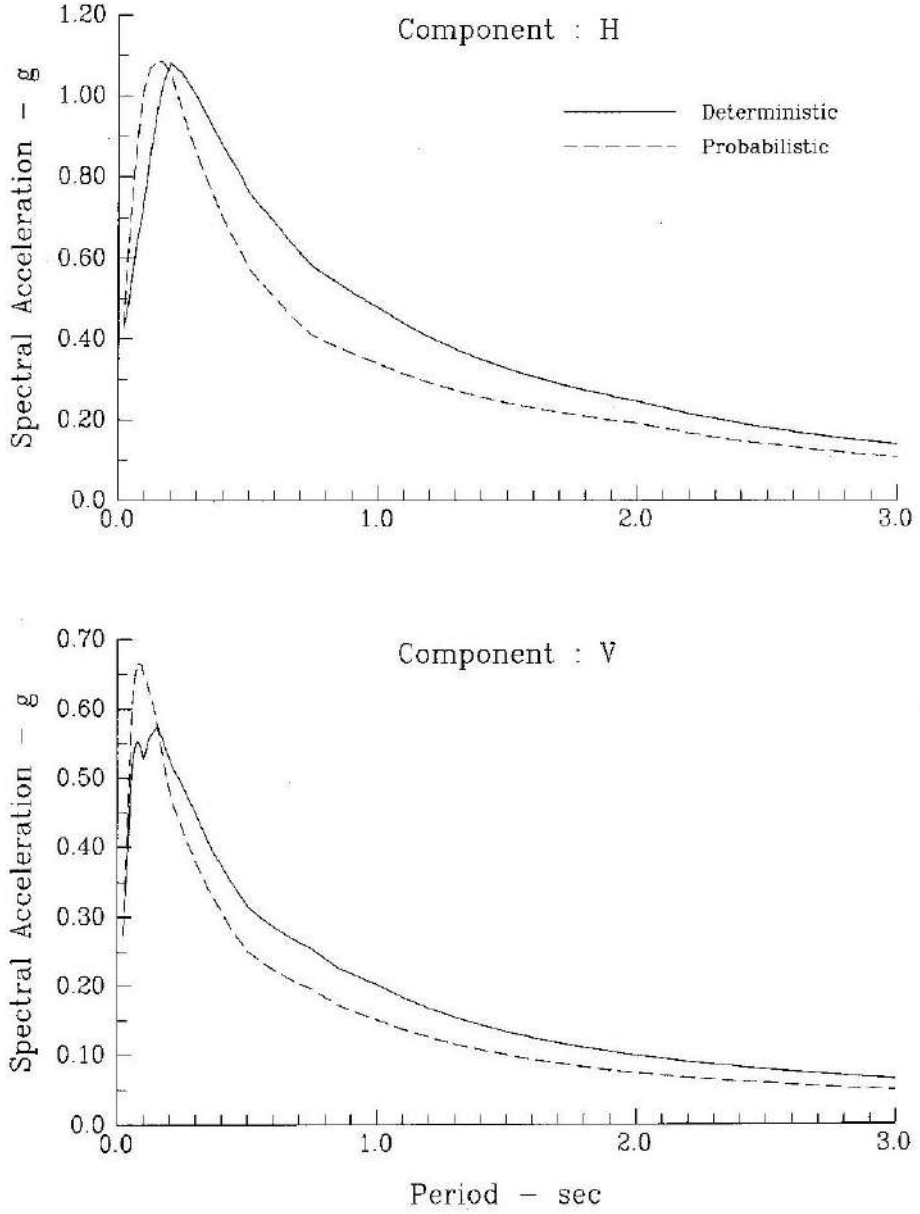

Fig. 8: *Comparison between 5 % damped MCE level of deterministic and probabilistic target response spectra of horizontal and vertical components of motion.*

The probabilistic spectral amplitudes are seen to be higher than the deterministic spectral values in the low period (high frequency) range, whereas, the deterministic spectral amplitudes are higher in the lower frequency (long period) range for the horizontal and vertical components of ground motion. Hence the envelope of both the deterministic and probabilistic spectra has been taken to be the target response spectra for horizontal and vertical components.

For the DBE level of ground motion the 5% damped probabilistic response spectra are obtained with a confidence level of 50% in 100 years by computing the probability function of eqn. (3) using the above description of seismicity for all the natural periods. The probabilistic seismic hazard analysis response spectra (PSHARS) are plotted in Fig. 9 along with the DBE level of deterministic seismic hazard analysis response spectra (DSHARS) taken to be half of those of MCE. For the horizontal and vertical components of ground motion, the deterministic spectral amplitudes are seen to be higher than the probabilistic spectral values in the entire frequency range. Hence the deterministic spectra have been taken to be the target spectra for both components.

7. DESIGN ACCELEROGRAMS AND RESPONSE SPECTRA

The 5 % damped target response spectra are used to generate the compatible design accelerograms by superposition of sinusoidal waves as follows:

$$a(t) = \sum_i C_i \cos(\omega_i t + \phi_i) \tag{7}$$

where ω_i is the angular frequency and φ_i is the corresponding phase angle. The phase angles φ_i provide the non-stationary nature to the synthesized accelerogram, and depending upon the available information these can be assigned in several different ways (Gupta and Joshi, 1993). One simple practical way is to use uniformly distributed random phases between 0 and 2π, and multiply the resulting stationary accelerogram by a deterministic envelope function to achieve the non-stationarity. The coefficients C_i at various frequencies are first estimated approximately from the target design response spectrum, and then improved iteratively to match the time-history response spectrum with the target spectrum. After the last iteration, base-line correction (Boore and Bommer, 2005) is applied to remove the long period errors in the synthesized accelerograms.

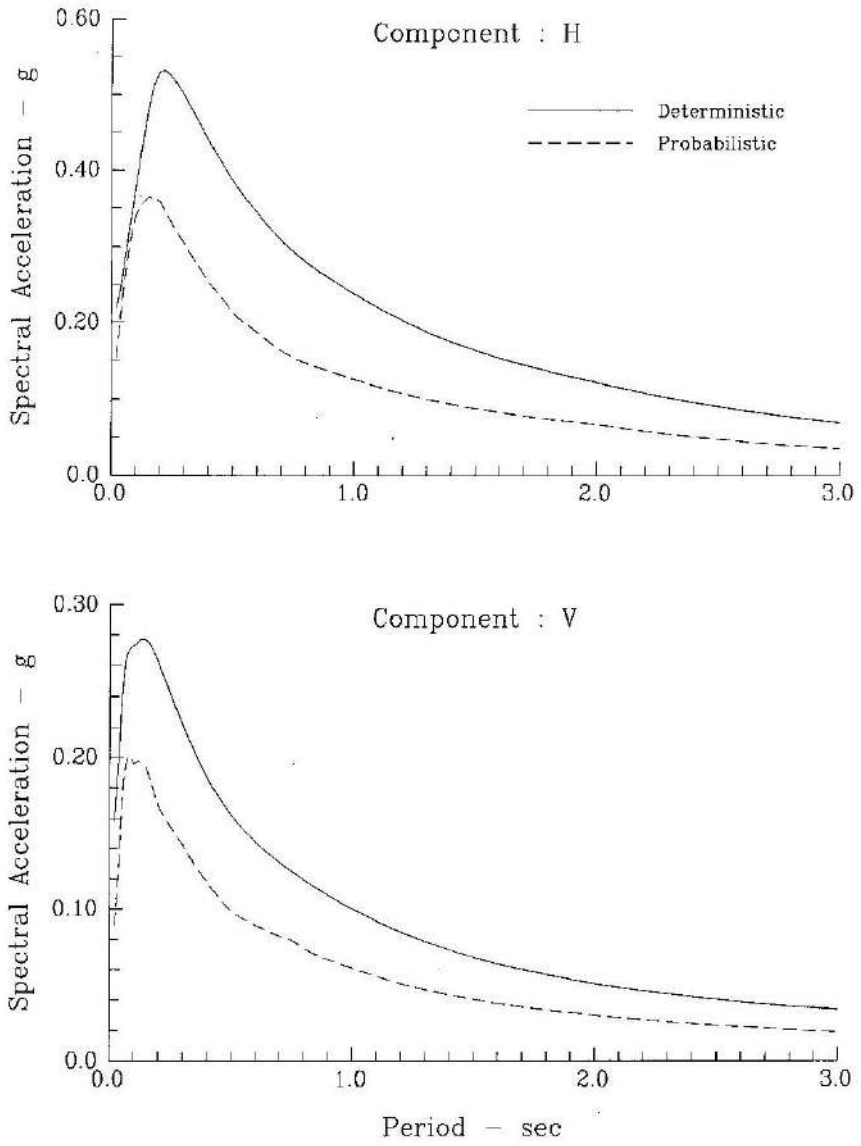

Fig. 9: *Comparison between 5 % damped DBE level of deterministic and probabilistic target response spectra of horizontal and vertical components of motion.*

Customarily, the spectrum and the corresponding accelerogram for the vertical component of ground motion are obtained by scaling down the spectrum and the accelerogram of the horizontal component by a constant factor. Thus, the time-histories of horizontal and vertical accelerations have identical phases and the frequency distribution of the energy content, which is not realistic. The phase characteristics of the accelerograms have to be such that the horizontal and vertical components have very small correlation. Also, the shapes of the response spectra of horizontal and vertical components of earthquake motion are, in general, different. Therefore, in the present study, the spectra of vertical ground motion have been computed independently and the corresponding accelerograms have been generated by introducing proper phase difference with respect to the phases of the horizontal accelerogram.

The comparison between the target response spectra (TRS) and the time history response spectra (THRS) obtained from the compatible accelerograms of both horizontal and vertical components of motion are shown in Fig. 10. The spectra from simulated accelerograms are seen to approximate the target spectra very closely, thus establishing the suitability of the method used for generation of the design accelerograms.

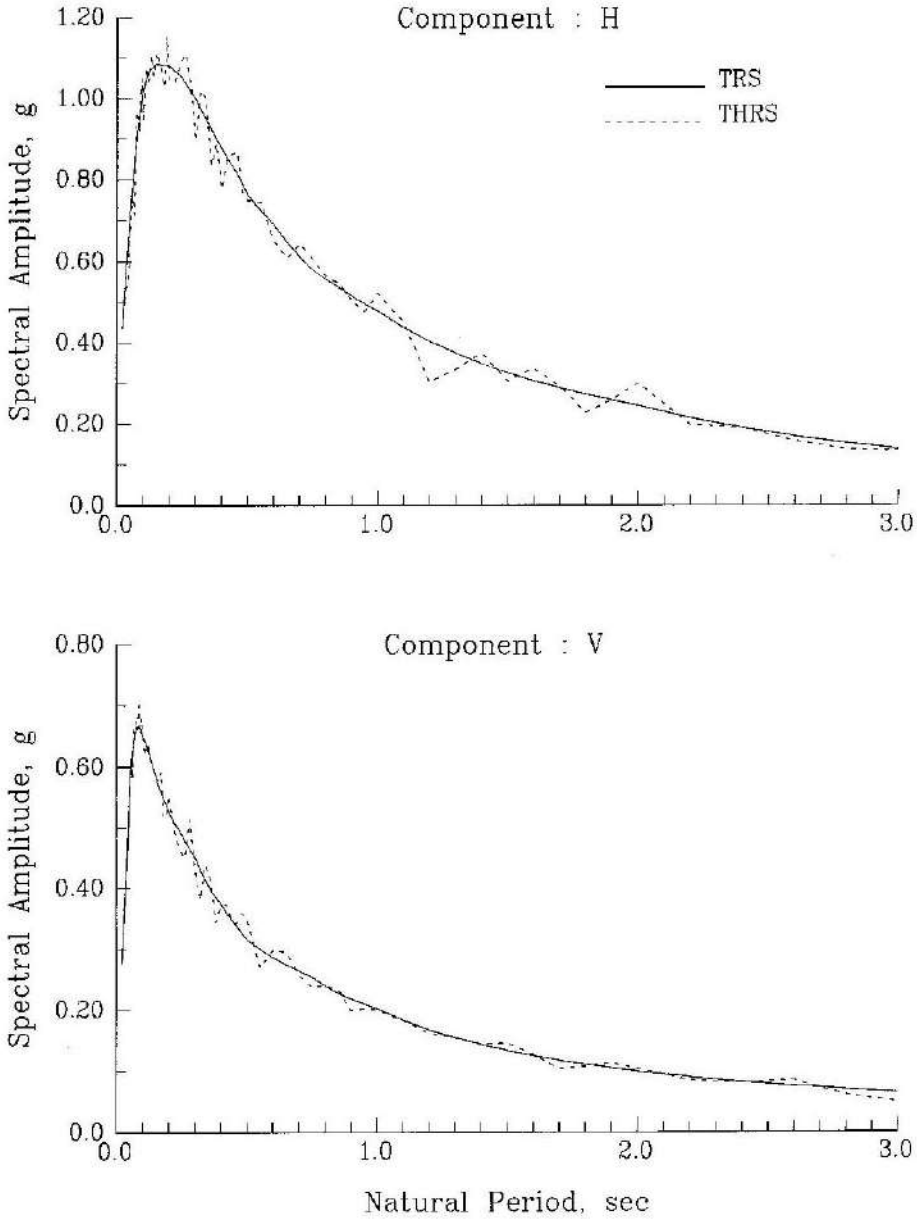

***Fig. 10**: Comparison of the time-history response spectra with the target response spectra for MCE condition*

The design accelerograms compatible with the MCE level of target response spectra of horizontal and vertical components of motion are shown in Figs. 11 and 12, respectively. These figures also show the velocity and displacement records computed from the design

accelerograms. The peak ground acceleration (PGA) values of horizontal and vertical components of motion are found to be 0.463 g and 0.273 g respectively.

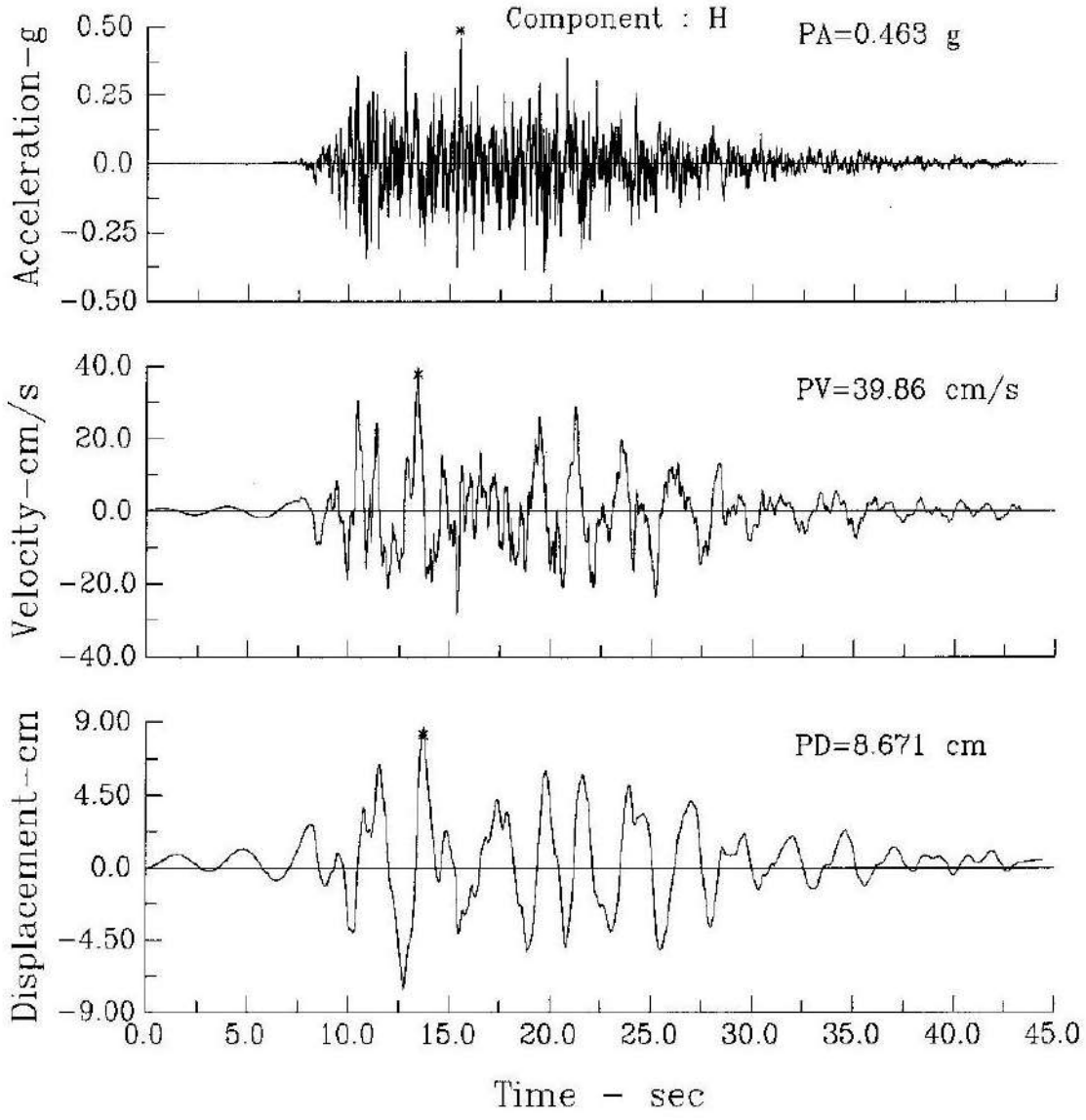

Fig. 11: *The MCE level of design accelerogram and the computed velocity and displacement records for the horizontal component of ground motion*

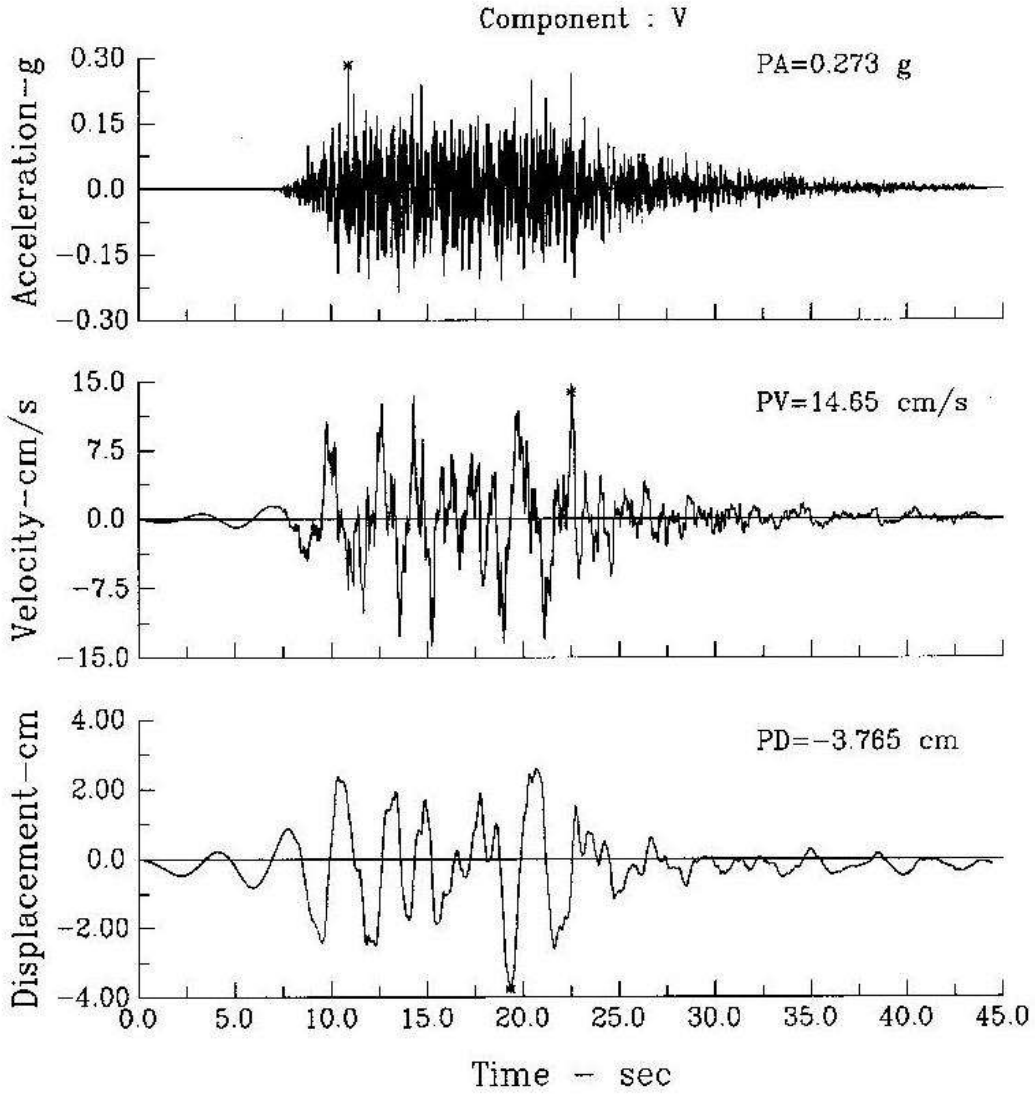

Fig. 12: *The MCE level of design accelerogram and the computed velocity and displacement records for the vertical component of ground motion*

Using the accelerograms compatible to the 5 % damped MCE level of target response spectra of horizontal and vertical components of motion for project site, acceleration response spectra are computed for damping values of 1%, 3%, 5%, 7%, 10% and 15% of critical. Fig. 13 shows the design response spectra for the horizontal and vertical components for different damping values for the maximum credible ground motion. The amplitudes of the horizontal and vertical spectra at 71 natural periods between 0.04s and 4.0 s are listed in Tables-2 and 3, respectively.

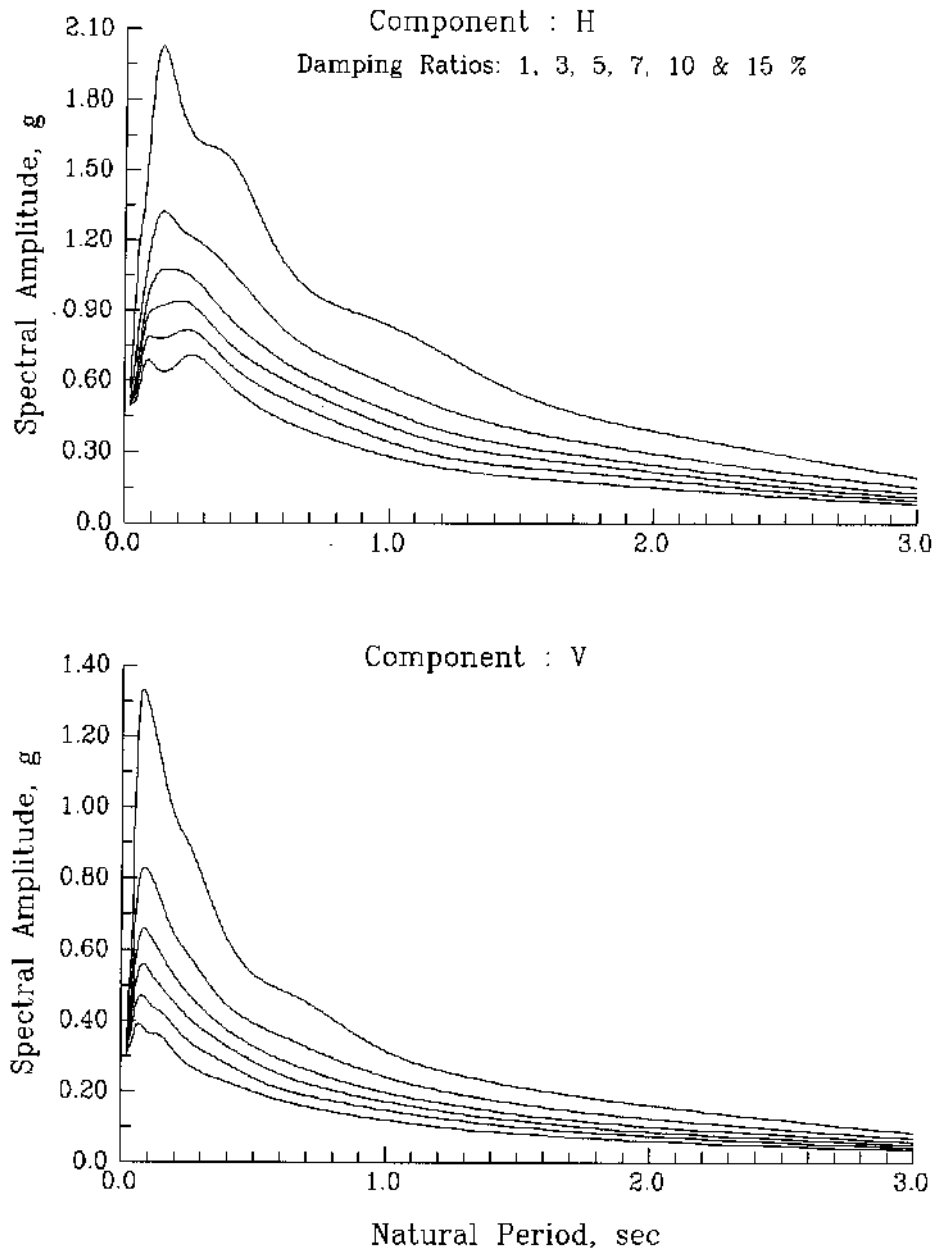

Fig. 13: *The design response spectra with damping ratios of 1%,3%,5%,7%,10% and 15% critical as computed from the MCE level of accelerograms for horizontal and vertical components of ground motion*

On similar lines the comparison between the target response spectra and the time history response spectra obtained from the design accelerogram for DBE conditions are shown in Fig. 14. It is seen that the time-history spectra are able to approximate the target spectra very well. The accelerograms compatible with the DBE level of target response spectra of horizontal and vertical component of ground motion are shown in Figs. 15 and 16 respectively. These figures also show the velocity and displacement records computed from the design accelerogram. The

peak ground acceleration values of horizontal and vertical components for DBE level of motion are found to be 0.214 g and 0.118 g respectively.

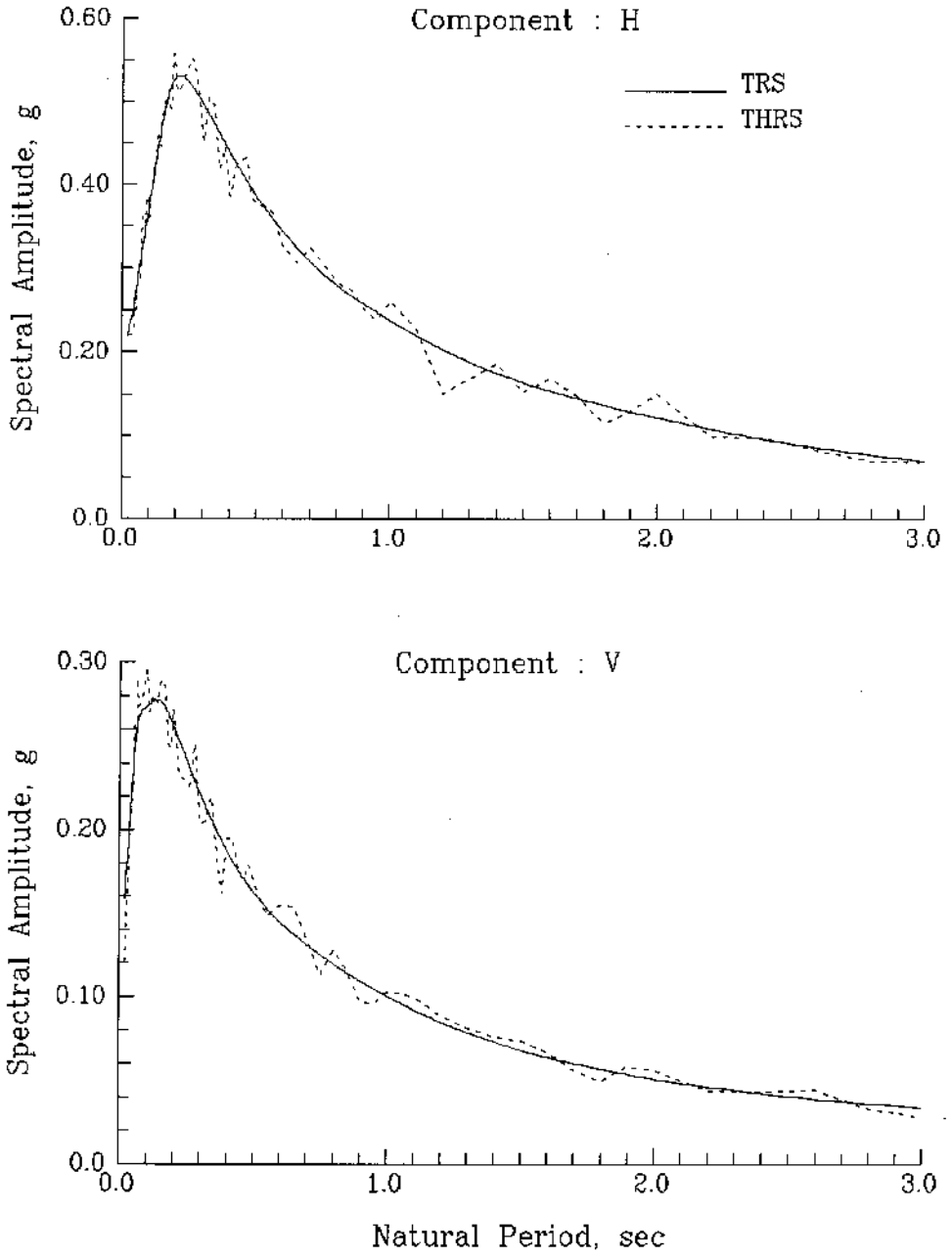

***Fig. 14**: Comparison of the time-history response spectra with the target response spectra for DBE condition*

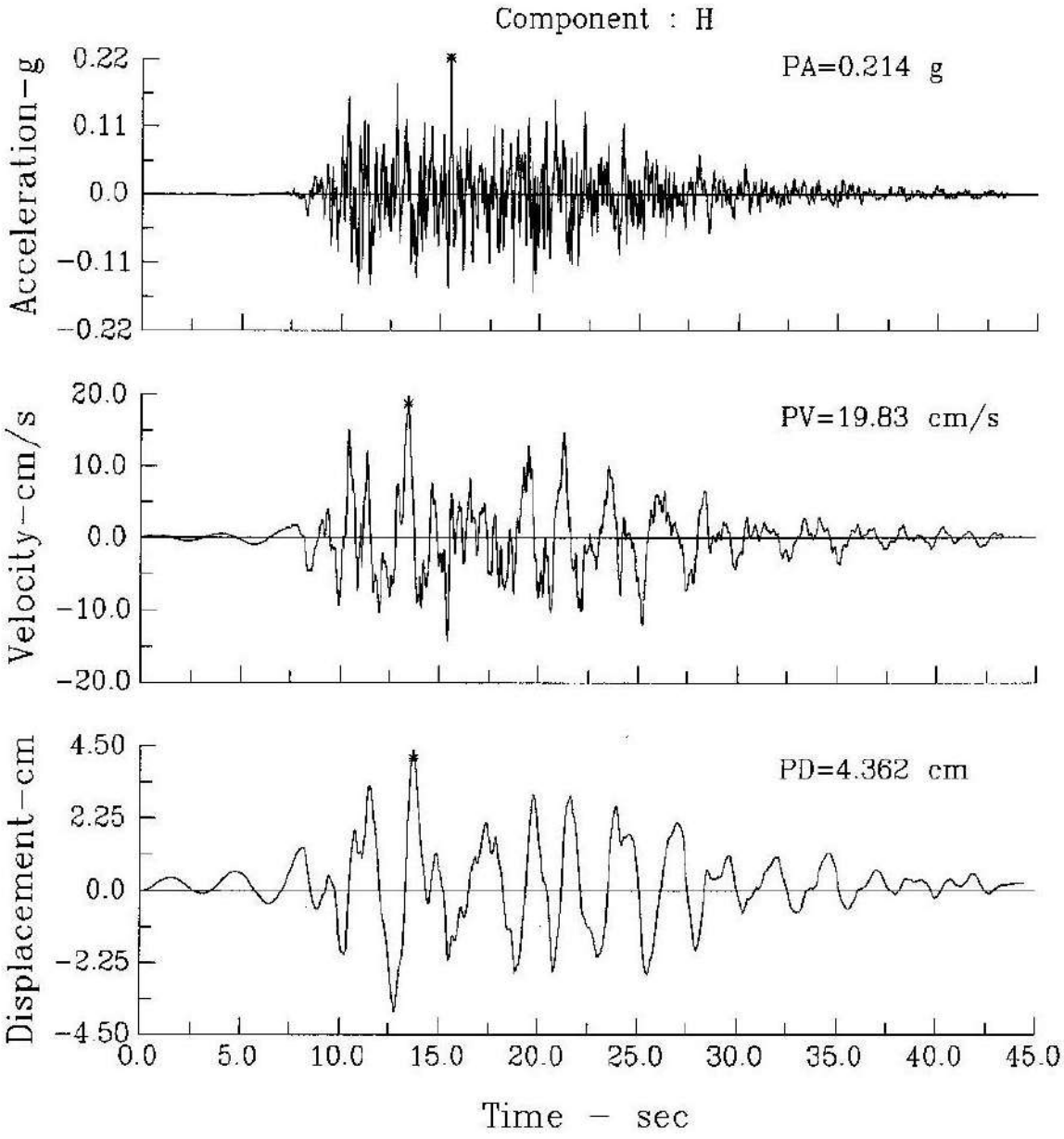

Fig. 15: *The DBE level of design accelerogram and the computed velocity and displacement records for the horizontal component of ground motion*

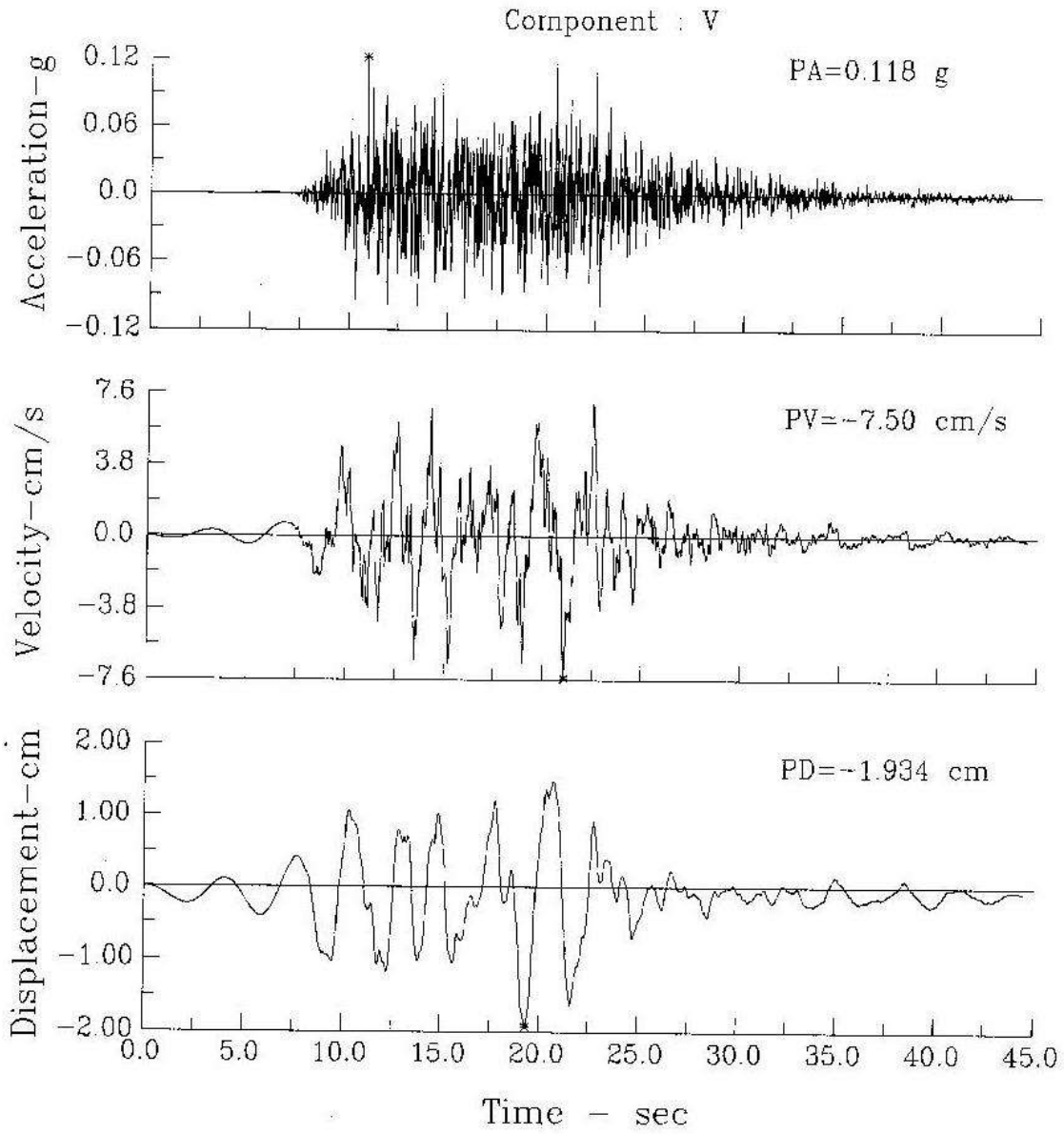

Fig. 16: *The DBE level of design accelerogram and the computed velocity and displacement records for the vertical component of ground motion*

Smoothed response spectra for damping values of 1%, 3%, 5%, 7%, 10% and 15% of critical as computed from these accelerograms are shown in Fig.17. Also, the amplitudes of the DBE level of horizontal and vertical spectra at 71 natural periods between 0.04 s and 4.0 s are listed in Tables-4 and 5, respectively.

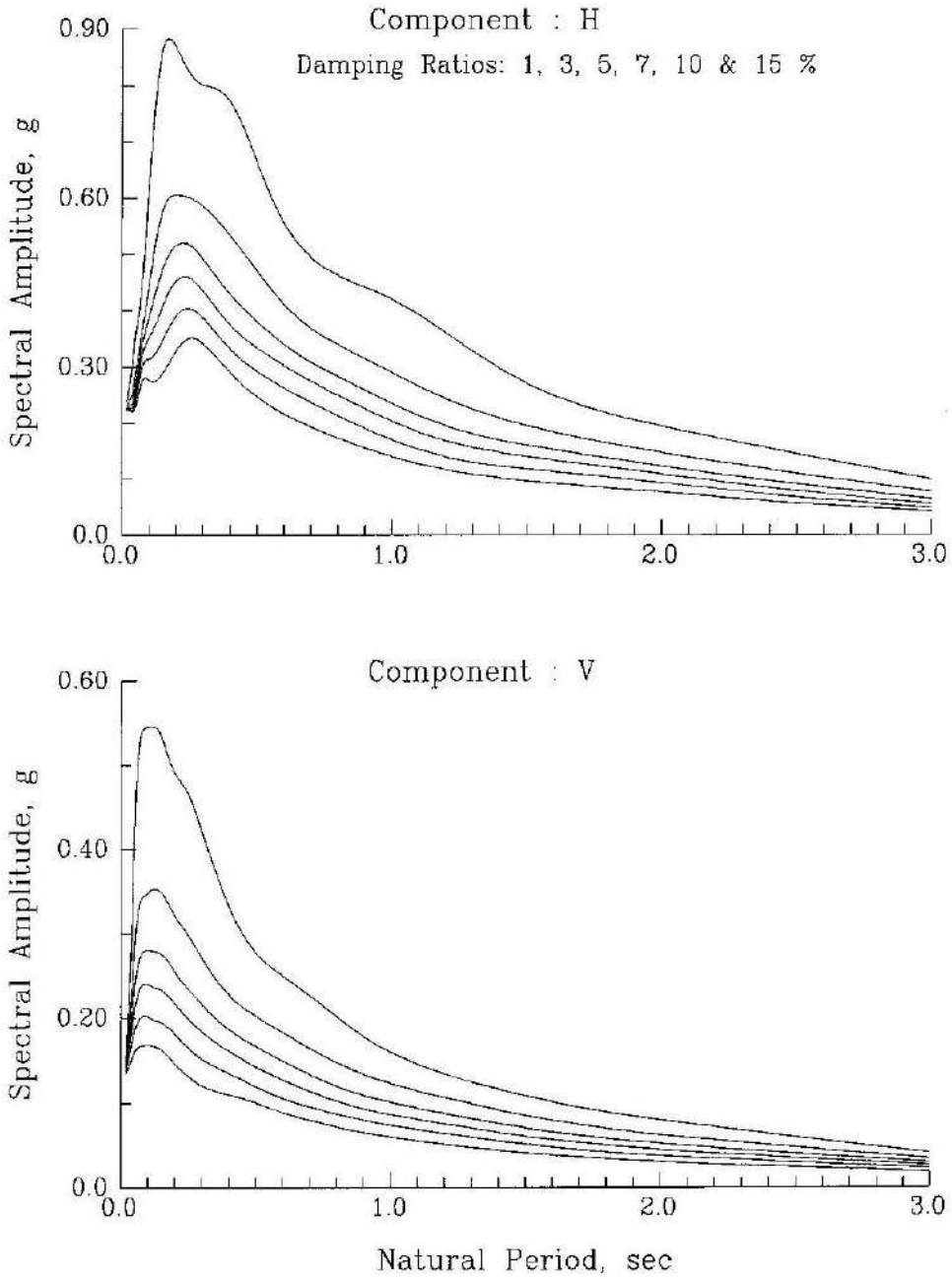

Fig. 17: *The design response spectra with damping ratios of 1%,3%,5%,7%,10% and 15% critical as computed from the DBE level of accelerograms for horizontal and vertical components of ground motion*

The MCE level of accelerograms and response spectra, as above, are recommended to be used to check the stability of a dam under extreme load conditions, so that a sudden release of water does not take place, though significant amount of damage may be permitted. This is because the chances of actual realization of MCE level of ground motion during the life of a project are, in general, extremely small. On the other hand, the dam is required to withstand

safely the loads due to DBE, though some minor and repairable damage is acceptable for this earthquake also.

The fundamental natural periods of concrete/ masonry dams can be obtained by the relationship given in Section 7.3.1.1 of the IS:1893 – 1984. The results in Table-2 can then be used to get the site-specific estimate of the horizontal design seismic coefficient, which is defined as one fourth of the spectral amplitude at the estimated natural period and damping ratio of 5 % for concrete/masonry dam. The height (H) of the concrete gravity dam is 120 m, the unit weight (w_m) for concrete of the dam is assumed to be 2400 kg/m^3 and the modulus of elasticity (E_s) as 2.0×10^9 kg/m^2. Using these values, the natural period of the dam is found to be 0.291 sec. Using the 5 % damped response spectral amplitude at this natural period from Table-2, the horizontal seismic coefficient (α_h) is found to be 0.249 g. The vertical seismic coefficient (α_v) which be taken as 2/3^{rds} of the horizontal coefficient, is found to be 0.166 g is recommended since it is higher than the α_v obtained from the vertical design spectra**.**

8. CONCLUSIONS AND RECOMMENDATIONS

i) For the deterministic estimate of the site-specific design ground motion for WHEP, the magnitude of the controlling MCE is estimated as 8.0 at a closest distance of 29.0 km from the fault rupture plane. The response spectra of horizontal and vertical components for this MCE with a confidence level of 0.84 and damping ratio of 5 % are taken as the deterministic target spectra. The DBE spectra are taken to be half of MCE spectra. The probabilistic estimate of spectra are obtained with a confidence level of 0.96 and 0.50 in 100 years for MCE and DBE conditions respectively.

ii) The MCE and DBE levels of design accelerograms for horizontal and vertical components of motion are generated to be compatible with the recommended target spectra. The design accelerograms of horizontal and vertical components of motion are obtained separately using the respective target spectra and suitable phase differences. The values of the peak ground acceleration for horizontal and vertical components are found to be 0.463 g and 0.273 g for MCE and 0.214 g and 0.118 g for DBE conditions respectively.

iii) The MCE level of accelerograms are recommended to be used for testing the safety of a dam under extreme and rare earthquake load. Some damage that does not impair the ability of the dam to hold the impounded water is permitted under this load condition. The DBE level of design accelerograms are to be used for the design.

iv) Smoothed design response spectra are computed for damping ratios of 1%, 3%, 5%, 7%, 10% and 15 % of critical from the MCE and DBE levels of design accelerograms. The site-specific horizontal and vertical design seismic coefficient for the dam are found to be 0.249 g and 0.166 g respectively.

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Table 1: Historical earthquake data in the region of Wangchu Reservoir H.E. Project for magnitude 5.0 and above

Date	Epicenter		Depth (km)	Mag.	Distance(km)
Yr Mn Dy	Lat.(N)	Long.(E)			
1411/09/29	30.000	90.200		7.7	356.3
1764/06/04	24.000	88.000		6.0	350.7
1787	24.270	89.470		8.3	281.3
1806/06/11	28.500	92.000		7.7	299.7
1816/05/26	30.000	86.500		8.0	470.3
1816/09/12	25.800	89.400		5.0	114.3
1822/04/03	23.500	91.000		6.0	390.0
1822/04/03	24.000	89.000		5.7	317.0
1833/08/26	27.700	85.700		7.6	403.6
1834/07/08	25.800	89.400		6.3	114.3
1834/07/21	25.800	89.400		6.0	114.3
1842/02/05	25.000	87.000		5.5	329.9
1842/05/21	25.000	87.000		5.7	329.9
1842/11/11	24.000	90.000		6.8	312.7
1843/08/10	27.000	88.300		5.5	134.6
1845/08/06	24.800	91.800		6.5	309.2
1846/10/18	24.800	90.400		6.0	234.8
1846/12/10	26.000	93.000		6.0	346.1
1847	26.300	92.700		6.3	309.6
1849/02/27	27.000	88.300		6.0	134.6
1849/02/28	26.500	88.500		5.0	118.3
1852/05/01	27.000	88.300		7.0	134.6
1862/06/18	27.000	88.300		5.0	134.6
1863/03/29	27.000	88.300		5.7	134.6
1863/07/08	27.000	88.300		5.0	134.6
1863/08/11	27.000	88.300		5.0	134.6
1865/12/16	27.000	88.300		5.0	134.6
1865/12/20	24.400	88.700		5.0	282.3
1866/05/23	24.000	87.000		5.5	406.5
1868/06/30	24.900	91.900		5.5	308.5
1869/01/10	25.000	93.000		7.5	389.6
1869/08/09	27.000	88.300		5.7	134.6
1885/07/14	24.000	90.000		5.7	312.7
1885/07/24	25.000	89.200		5.0	204.9
1897/06/12	25.500	91.000		8.0	198.4
1898/04/20	24.800	92.800		6.3	385.0
1899/09/25	27.000	88.300		6.0	134.6
1906/05/12	28.000	92.000		6.4	268.9
1908/04/04	25.300	92.600		5.9	338.6
1909/02/17	27.000	87.000		5.0	263.1
1910/08/13	28.000	90.000		5.6	135.9
1915/11/14	26.000	92.000		5.0	251.4
1915/12/03	29.500	91.500		6.8	349.7

Table-1 Contd...

Date	Epicenter		Depth (km)	Mag.	Distance(km)
Yr Mn Dy	Lat.(N)	Long.(E)			
1915/12/05	26.000	92.000		5.0	251.4
1918/02/04	29.600	87.800		6.0	357.9
1918/07/08	24.500	91.000	35.0	7.6	289.1
1923/04/24	29.600	87.800		5.5	357.9
1923/09/09	25.250	91.000	35.0	7.1	219.4
1924/01/30	25.000	93.000		6.0	389.6
1924/08/13	29.500	90.000	35.0	5.6	298.8
1924/10/08	30.000	90.000	35.0	6.5	353.7
1926/10/23	25.000	93.000		5.5	389.6
1926/12/04	29.600	87.800		6.0	357.9
1930/07/02	25.500	90.000	35.0	7.1	149.4
1930/07/03	25.800	90.200		5.5	125.0
1930/07/04	25.800	90.200		5.5	125.0
1930/07/04	25.800	90.800		5.5	160.8
1930/07/08	25.800	90.800		5.5	160.8
1930/07/08	25.800	90.800		5.5	160.8
1930/07/13	25.800	90.800		5.5	160.8
1932/03/06	25.500	92.500	35.0	5.6	319.3
1932/03/24	25.000	90.000	35.0	5.6	203.4
1932/03/25	30.000	89.200		5.5	354.6
1932/03/27	24.500	92.000	35.0	5.6	346.9
1932/11/09	26.500	92.000	35.0	5.6	237.4
1933/03/06	26.000	90.500	35.0	5.6	124.1
1934/01/15	27.550	87.000	35.0	8.3	274.6
1934/07/21	25.800	89.400		5.5	114.3
1935/03/21	24.250	89.500	80.0	6.2	283.3
1935/05/21	28.750	89.250	140.0	6.2	217.3
1936/02/11	27.500	87.000	50.0	5.6	273.0
1936/05/30	25.700	90.500		5.3	149.8
1936/06/09	27.500	87.000		5.5	273.0
1936/06/18	26.600	90.300		5.8	69.9
1936/09/07	27.500	87.000		5.3	273.0
1937/03/09	27.000	92.000		5.7	235.7
1937/08/15	30.000	90.000		5.8	353.7
1938/01/29	27.500	87.000	35.0	5.5	273.0
1938/02/26	28.000	90.500		5.7	156.6
1938/04/13	26.000	91.000		5.7	162.5
1939/02/13	27.000	92.000		5.7	235.7
1939/06/04	28.500	86.500		5.7	363.3
1940/02/13	27.000	92.000		5.7	235.7
1940/08/02	28.000	90.500		5.2	156.6
1940/10/04	30.000	92.000	35.0	6.0	423.0
1941/01/21	27.000	92.000	100.0	6.8	235.7
1941/01/27	26.500	92.500	180.0	6.5	286.6
1941/05/22	27.500	93.000	35.0	5.6	342.7

Table-1 Contd...

Date	Epicenter	Depth	Mag.	

Yr Mn Dy	Lat.(N)	Long.(E)	(km)		Distance(km)
1941/09/06	27.000	92.000		5.8	235.7
1942/02/21	24.000	90.300		5.9	317.5
1943/02/08	27.000	92.000		6.0	235.7
1943/10/23	26.600	94.000	35.0	7.2	434.3
1944/12/24	24.700	92.200		5.9	345.4
1945/05/19	25.100	90.900		6.1	227.0
1946/03/16	26.400	92.600		5.6	298.0
1946/07/02	30.000	92.000		5.7	423.0
1947/11/29	27.900	91.900		5.9	254.9
1948/10/07	27.900	91.900		5.5	254.9
1949/07/15	24.000	93.000		6.0	456.3
1949/12/10	26.000	89.000		6.0	109.9
1950/02/26	28.000	90.500		6.0	156.6
1950/08/15	25.000	93.000		6.0	389.6
1950/08/16	27.900	91.900		5.5	254.9
1950/08/16	27.900	91.900		6.7	254.9
1950/08/17	27.900	91.900		6.0	254.9
1950/09/05	29.300	92.000		5.5	361.3
1950/09/25	24.000	93.000		5.5	456.3
1950/12/29	24.000	91.800		6.3	377.7
1951/04/07	25.900	90.500		6.8	132.3
1951/05/28	29.000	87.000		6.0	356.5
1951/12/03	30.000	92.000		5.5	423.0
1952/03/06	29.600	90.800		5.5	328.7
1952/03/14	30.000	92.000		5.5	423.0
1952/09/15	30.000	92.000		5.5	423.0
1952/11/19	29.800	86.600		6.0	447.2
1954/02/23	27.500	91.000	33.0	5.6	155.2
1954/02/23	27.800	91.700	33.0	6.5	232.2
1955/03/27	29.900	90.200	33.0	6.3	345.4
1955/09/20	27.500	90.000		5.7	84.0
1955/11/23	26.500	90.000		5.2	49.9
1956/03/14	25.200	90.800		5.0	212.3
1956/03/23	30.000	90.000		5.0	353.7
1956/06/12	24.800	90.900		5.3	255.2
1957/12/12	24.500	93.000		5.5	420.6
1958/01/04	27.000	92.000		5.0	235.7
1958/02/09	25.000	90.500	36.0	5.2	217.7
1958/02/13	27.620	92.530		5.5	301.0
1958/11/23	28.800	86.900		5.5	349.6
1959/02/22	28.500	91.500		5.7	262.6
1959/06/10	30.000	91.000		5.7	377.0
1959/11/02	28.000	93.000		5.0	359.0
1960/05/26	27.000	93.000	33.0	5.2	334.9
1960/07/29	26.900	90.300	11.0	6.5	66.5

Table-1 Contd...

Date			Epicenter		Depth (km)	Mag.	Distance(km)
Yr	Mn	Dy	Lat.(N)	Long.(E)			

1960/08/21	27.000	88.500	29.0	5.5	115.0
1961/09/29	28.300	88.000		5.5	231.2
1961/11/06	26.700	91.900	67.0	5.0	225.2
1961/12/25	27.000	90.000		5.5	41.5
1963/02/22	27.200	87.100		5.2	255.9
1963/06/19	24.900	90.500	44.0	6.2	227.9
1963/06/21	24.800	90.900	53.0	6.2	255.2
1963/06/21	25.130	92.090	47.0	5.7	306.5
1963/09/02	26.200	90.000		5.5	76.7
1964/02/18	27.400	91.180	22.0	5.3	166.4
1964/03/27	27.130	89.360	29.0	5.0	44.6
1964/04/13	27.520	90.170	1.0	5.3	94.3
1964/08/30	27.360	88.210	21.0	5.1	154.3
1964/09/01	27.120	92.260	33.0	5.6	262.9
1965/01/12	27.400	87.840	23.0	5.9	190.1
1965/01/12	27.310	87.680	18.0	5.2	202.2
1965/04/11	26.820	92.330	70.0	5.0	267.6
1965/12/09	27.430	92.510	4.0	5.2	293.5
1965/12/09	26.700	92.500	8.0	5.3	284.8
1966/04/23	25.900	90.470	45.0	5.1	130.4
1966/06/26	26.140	92.840	74.0	5.0	326.9
1966/09/26	27.490	92.610	20.0	5.4	304.8
1967/09/06	24.000	91.900	2.0	5.0	383.5
1967/09/15	27.420	91.860	19.0	5.8	230.9
1967/11/14	24.050	91.610	24.0	5.1	362.6
1968/01/31	29.800	92.200	25.0	5.1	416.7
1968/06/12	24.830	91.940	39.0	5.3	316.7
1968/08/18	26.420	90.620	22.0	5.1	106.8
1968/12/27	24.120	91.610	27.0	5.1	356.2
1969/06/01	25.720	91.770	33.0	5.0	243.9
1969/06/30	26.930	92.710	44.0	5.0	305.7
1969/11/05	27.660	90.240	13.0	5.0	111.0
1969/11/11	26.600	91.800	33.0	5.0	216.2
1970/07/25	25.720	88.580	32.0	5.1	160.1
1971/02/02	23.714	91.662	36.5	5.4	396.9
1971/12/04	27.925	87.946	28.7	5.2	208.3
1972/08/21	27.228	88.023	33.0	5.1	167.0
1972/11/06	26.877	88.426	59.1	5.0	120.7
1973/03/22	28.118	87.149	33.0	5.0	286.3
1975/11/26	28.147	87.801	33.0	5.0	234.6
1976/09/14	29.808	89.568	75.4	5.4	330.8
1977/11/13	26.510	92.998	52.4	5.1	335.7
1977/12/23	23.708	92.309	33.0	5.1	433.6
1979/06/19	26.742	87.482	1.7	5.2	214.5
1980/11/19	27.402	88.797	1.3	6.3	105.9

Table-1 Contd...

Date			Epicenter		Depth (km)	Mag.	Distance(km)
Yr	Mn	Dy	Lat.(N)	Long.(E)			
1982/04/05			27.384	88.837	9.0	5.0	101.6

1982/07/06	25.881	90.310	8.4	5.0	122.7
1982/08/31	25.385	91.460	32.3	5.0	240.1
1983/02/02	26.897	92.874	42.0	5.2	321.9
1983/10/02	28.047	92.517	38.3	5.0	317.0
1984/05/21	23.657	91.508	12.6	5.2	394.9
1984/09/22	26.494	92.147	28.6	5.2	251.9
1984/09/30	25.436	91.507	34.1	5.0	240.1
1984/12/30	24.657	92.847	3.7	5.6	398.1
1985/01/07	27.140	91.958	12.0	5.4	233.5
1985/10/12	27.113	92.520	13.9	5.3	288.4
1986/01/10	28.653	86.563	63.4	5.5	367.1
1986/02/19	25.104	91.130	6.7	5.3	240.0
1986/09/10	25.376	92.145	47.0	5.3	295.5
1986/12/31	26.469	92.912	46.1	5.1	327.7
1987/01/24	27.633	92.686	24.4	5.0	316.3
1987/09/25	29.841	90.367	18.9	5.1	342.1
1987/10/06	29.898	90.417	10.0	5.0	349.3
1988/01/10	29.747	90.293	50.3	5.3	330.4
1988/02/06	24.668	91.562	33.0	5.8	304.4
1988/02/17	27.106	92.107	1.9	5.4	247.6
1988/04/20	27.017	86.721	55.0	5.4	290.9
1988/08/20	26.720	86.626	64.6	6.8	299.6
1988/09/27	27.191	88.367	27.5	5.0	133.1
1989/03/08	26.935	92.767	58.9	5.1	311.4
1989/04/09	29.113	90.022	10.0	5.1	256.8
1989/04/13	24.404	92.431	9.9	5.4	384.5
1989/05/22	27.381	87.858	4.5	5.0	187.7
1990/01/09	28.154	88.108	35.5	5.7	212.3
1990/09/02	26.582	92.670	57.3	5.2	302.5
1991/02/02	25.508	91.171	25.5	5.0	209.7
1992/07/30	29.566	90.180	31.4	6.1	308.7
1992/12/12	25.475	91.388	41.0	5.0	228.2
1993/03/20	29.027	87.328	12.2	6.2	335.4
1993/03/20	29.010	87.340	21.3	5.1	333.2
1993/03/31	29.100	87.328	16.2	5.0	341.3
1995/02/17	27.637	92.396	36.6	5.4	288.9
1996/04/26	27.835	87.800	24.9	5.0	214.8
1996/06/09	28.377	92.261	57.5	5.2	312.8
1996/11/19	24.567	92.683	26.5	5.4	391.3
1996/12/30	27.220	86.910	25.0	5.8	274.9
1997/04/07	27.470	86.700	33.0	5.1	301.0
1997/05/08	24.890	92.277	33.7	5.9	337.5
1997/10/30	29.542	89.727	44.7	5.1	301.4
1997/11/27	27.640	86.880	33.0	5.5	289.0

Table-1 Contd...

Date	Epicenter		Depth (km)	Mag.	Distance(km)
Yr Mn Dy	Lat.(N)	Long.(E)			
1998/03/15	28.610	86.780	55.0	5.2	346.6
1998/07/08	27.322	91.065	33.0	5.1	152.6
1998/08/18	27.655	91.100	35.2	5.0	172.5

1998/09/03	27.870	87.000	6.0	6.1	287.1
1998/09/26	27.765	92.807	4.9	5.5	332.1
1998/11/26	27.692	87.860	34.6	5.1	201.7
1999/08/01	28.090	86.520	26.0	6.0	340.5
1999/10/05	26.293	91.982	33.2	5.4	240.0
2000/01/02	27.596	92.568	5.8	5.1	303.9
2000/01/25	27.680	92.651	4.4	5.3	314.5
2000/01/25	29.940	89.720		5.0	345.3
2000/09/06	28.680	86.940	55.0	5.3	338.3
2000/09/06	28.380	86.970	39.0	5.4	316.7
2001/04/28	28.766	87.131	25.0	5.2	329.6
2001/11/06	27.393	91.966	21.4	5.1	240.1
2001/12/02	27.218	88.179	24.5	5.0	151.8
2002/05/02	27.670	86.670	35.0	5.2	309.9
2002/06/20	25.868	88.874	37.8	5.1	129.1
2002/08/31	29.878	88.055	16.0	5.0	373.2
2003/01/16	29.959	88.109	12.0	5.0	379.2
2003/03/25	27.256	89.379	50.9	5.4	55.3
2004/12/09	24.715	92.536	41.2	5.4	369.7
2005/02/15	24.534	92.376	10.7	5.5	370.7
2006/02/14	27.387	88.416	28.7	5.4	137.0
2006/02/23	26.958	91.712	14.9	5.5	206.8
2006/02/23	26.896	91.621	.6	5.6	197.4
2006/08/12	24.709	92.742	44.3	5.0	386.3
2008/10/06	29.844	90.379	6.4	6.8	342.7
2008/10/06	29.673	90.289	8.7	5.5	322.3
2008/10/06	29.815	90.375	10.0	5.0	339.5
2008/10/06	29.714	90.315	15.3	5.2	327.3
2008/10/08	29.768	90.336	2.4	5.4	333.6
2009/08/19	26.560	92.470	10.0	5.0	282.9
2009/09/21	27.330	91.440	14.0	6.1	188.0
2009/10/29	27.260	91.420	26.0	5.1	183.9
2009/12/31	27.320	91.510	10.0	5.5	194.3
2010/02/26	28.440	86.730	35.0	5.5	340.4

Table- 2: MCE level of response spectral amplitudes for horizontal component of motion

T (sec)	Spectral Amplitudes (g) for Damping Ratios (%) of					
	1.0	3.0	5.0	7.0	10.0	15.0
.040	.94146	.68284	.58680	.55707	.53638	.50947
.042	.98962	.70906	.60480	.57002	.54596	.51577
.044	1.03510	.73522	.62365	.58404	.55641	.52278

.046	1.07674	.76058	.64285	.59894	.56768	.53048
.048	1.11382	.78460	.66202	.61454	.57969	.53884
.050	1.14581	.80693	.68094	.63076	.59248	.54791
.055	1.20609	.85548	.72669	.67304	.62704	.57308
.060	1.24656	.89656	.77100	.71657	.66387	.60057
.065	1.28101	.93469	.81435	.75897	.69988	.62762
.070	1.32064	.97261	.85574	.79751	.73172	.65123
.075	1.37152	1.01102	.89339	.82995	.75691	.66916
.080	1.43476	1.04953	.92601	.85530	.77450	.68052
.085	1.50798	1.08742	.95329	.87376	.78491	.68560
.090	1.58674	1.12399	.97575	.88642	.78957	.68556
.095	1.66608	1.15858	.99433	.89480	.79033	.68198
.100	1.74182	1.19067	1.00993	.90028	.78885	.67632
.110	1.87110	1.24559	1.03459	.90650	.78379	.66295
.120	1.96164	1.28610	1.05260	.91037	.77994	.65098
.130	2.01229	1.31154	1.06497	.91389	.77847	.64235
.140	2.02753	1.32295	1.07242	.91752	.77901	.63744
.150	2.01488	1.32292	1.07597	.92132	.78110	.63627
.160	1.98320	1.31480	1.07677	.92520	.78450	.63866
.170	1.94078	1.30189	1.07587	.92908	.78904	.64424
.180	1.89406	1.28691	1.07407	.93278	.79456	.65255
.190	1.84778	1.27193	1.07184	.93605	.80062	.66262
.200	1.80436	1.25807	1.06928	.93853	.80667	.67350
.220	1.73082	1.23559	1.06245	.93931	.81613	.69367
.240	1.67683	1.21930	1.05150	.93252	.81846	.70627
.260	1.64132	1.20599	1.03489	.91772	.81170	.70812
.280	1.62031	1.19230	1.01303	.89678	.79704	.69995
.300	1.60872	1.17619	.98747	.87223	.77695	.68430
.320	1.60148	1.15720	.96026	.84632	.75404	.66418
.340	1.59422	1.13593	.93315	.82060	.73035	.64208
.360	1.58327	1.11312	.90725	.79598	.70713	.61957
.380	1.56635	1.08956	.88304	.77297	.68513	.59767
.400	1.54159	1.06546	.86054	.75176	.66467	.57680

Table-2 Contd…

T (sec)	Spectral Amplitudes (g) for Damping Ratios (%) of					
	1.0	3.0	5.0	7.0	10.0	15.0
.420	1.50858	1.04086	.83945	.73236	.64583	.55715
.440	1.46827	1.01576	.81943	.71462	.62852	.53876
.460	1.42231	.99018	.80015	.69828	.61258	.52159
.480	1.37284	.96428	.78142	.68308	.59780	.50561
.500	1.32207	.93829	.76315	.66877	.58403	.49078

.550	1.20251	.87560	.71982	.63564	.55272	.45819
.600	1.10621	.82006	.68089	.60494	.52439	.43077
.650	1.03537	.77387	.64692	.57607	.49786	.40680
.700	.98483	.73632	.61721	.54879	.47254	.38496
.750	.94836	.70509	.59040	.52284	.44817	.36452
.800	.92115	.67773	.56522	.49793	.42463	.34525
.850	.89946	.65231	.54082	.47381	.40190	.32711
.900	.88003	.62749	.51676	.45040	.38007	.31015
.950	.86016	.60270	.49303	.42781	.35934	.29437
1.000	.83802	.57785	.46988	.40626	.33994	.27976
1.100	.78389	.52918	.42688	.36754	.30619	.25416
1.200	.71961	.48496	.39057	.33613	.28002	.23338
1.300	.65367	.44744	.36177	.31209	.26086	.21700
1.400	.59319	.41651	.33920	.29386	.24686	.20412
1.500	.54156	.39061	.32073	.27926	.23591	.19362
1.600	.49904	.36807	.30448	.26645	.22626	.18450
1.700	.46422	.34767	.28924	.25420	.21684	.17605
1.800	.43531	.32867	.27439	.24183	.20705	.16781
1.900	.41028	.31070	.25973	.22919	.19680	.15959
2.000	.38763	.29353	.24526	.21631	.18616	.15136
2.200	.34555	.26098	.21715	.19055	.16449	.13509
2.400	.30499	.23045	.19088	.16629	.14384	.11978
2.600	.26576	.20181	.16688	.14460	.12535	.10596
2.800	.22864	.17505	.14512	.12562	.10927	.09371
3.000	.19411	.15014	.12533	.10896	.09532	.08285
3.200	.16240	.12715	.10728	.09415	.08306	.07310
3.400	.13375	.10625	.09092	.08084	.07212	.06426
3.600	.10861	.08777	.07636	.06897	.06237	.05625
3.800	.08710	.07182	.06366	.05847	.05367	.04901
4.000	.06957	.05863	.05297	.04946	.04607	.04256

Table- 3: MCE level of response spectral amplitudes for vertical component of motion

T (sec)	Spectral Amplitudes (g) for Damping Ratios (%) of					
	1.0	3.0	5.0	7.0	10.0	15.0
.040	.66518	.52448	.46651	.42888	.39034	.34567
.042	.72690	.55370	.48399	.44083	.39879	.35094
.044	.79068	.58333	.50130	.45264	.40726	.35636
.046	.85455	.61258	.51817	.46420	.41567	.36183
.048	.91684	.64071	.53433	.47537	.42385	.36721

.050	.97616	.66706	.54956	.48601	.43162	.37231
.055	1.10599	.72307	.58288	.50953	.44813	.38276
.060	1.20454	.76389	.60906	.52804	.45947	.38872
.065	1.27157	.79166	.62878	.54185	.46611	.39031
.070	1.31042	.80939	.64276	.55153	.46928	.38866
.075	1.32781	.81996	.65172	.55754	.47007	.38513
.080	1.33110	.82544	.65632	.56013	.46899	.38076
.085	1.32646	.82727	.65726	.55961	.46632	.37623
.090	1.31782	.82639	.65536	.55648	.46234	.37205
.095	1.30702	.82346	.65148	.55151	.45755	.36853
.100	1.29454	.81890	.64632	.54546	.45247	.36586
.110	1.26442	.80580	.63420	.53250	.44326	.36310
.120	1.22940	.78884	.62152	.52068	.43666	.36259
.130	1.19303	.76955	.60899	.51053	.43202	.36211
.140	1.15718	.74910	.59657	.50150	.42772	.35985
.150	1.12171	.72828	.58414	.49294	.42247	.35505
.160	1.08648	.70777	.57166	.48448	.41581	.34791
.170	1.05242	.68815	.55922	.47592	.40787	.33917
.180	1.02120	.66996	.54693	.46715	.39904	.32965
.190	.99416	.65357	.53501	.45823	.38984	.32008
.200	.97182	.63908	.52359	.44927	.38067	.31092
.220	.93861	.61515	.50259	.43178	.36348	.29463
.240	.91160	.59520	.48407	.41583	.34872	.28118
.260	.88179	.57591	.46738	.40185	.33653	.27019
.280	.84641	.55560	.45178	.38954	.32638	.26113
.300	.80685	.53420	.43680	.37829	.31753	.25355
.320	.76602	.51266	.42240	.36760	.30935	.24705
.340	.72646	.49212	.40870	.35723	.30138	.24125
.360	.68967	.47340	.39586	.34704	.29336	.23587
.380	.65632	.45681	.38391	.33706	.28524	.23067
.400	.62670	.44237	.37282	.32730	.27698	.22551

Table-3 Contd…

T (sec)	Spectral Amplitudes (g) for Damping Ratios (%) of					
	1.0	3.0	5.0	7.0	10.0	15.0
.420	.60076	.42981	.36245	.31776	.26865	.22028
.440	.57832	.41877	.35269	.30847	.26034	.21497
.460	.55921	.40896	.34344	.29946	.25217	.20957
.480	.54316	.40011	.33465	.29077	.24424	.20413
.500	.52991	.39201	.32629	.28245	.23669	.19871
.550	.50569	.37393	.30714	.26352	.22002	.18577
.600	.48838	.35758	.29026	.24745	.20685	.17437

.650	.47154	.34170	.27510	.23387	.19654	.16470
.700	.45181	.32573	.26116	.22215	.18801	.15643
.750	.42878	.30968	.24816	.21170	.18034	.14907
.800	.40375	.29391	.23604	.20217	.17305	.14224
.850	.37851	.27883	.22481	.19336	.16596	.13577
.900	.35457	.26478	.21447	.18515	.15909	.12962
.950	.33288	.25190	.20499	.17748	.15250	.12380
1.000	.31378	.24019	.19627	.17029	.14624	.11834
1.100	.28305	.21996	.18078	.15717	.13469	.10850
1.200	.26011	.20312	.16734	.14548	.12436	.09998
1.300	.24208	.18872	.15547	.13498	.11511	.09255
1.400	.22691	.17612	.14485	.12548	.10685	.08605
1.500	.21341	.16489	.13530	.11687	.09949	.08035
1.600	.20103	.15482	.12670	.10907	.09293	.07533
1.700	.18957	.14574	.11898	.10205	.08709	.07084
1.800	.17896	.13755	.11208	.09578	.08185	.06678
1.900	.16908	.13008	.10585	.09017	.07712	.06304
2.000	.15982	.12316	.10019	.08515	.07282	.05958
2.200	.14256	.11046	.09006	.07644	.06526	.05335
2.400	.12627	.09859	.08087	.06885	.05867	.04792
2.600	.11064	.08723	.07215	.06180	.05265	.04307
2.800	.09581	.07636	.06375	.05500	.04697	.03860
3.000	.08202	.06609	.05569	.04840	.04152	.03435
3.200	.06941	.05652	.04805	.04206	.03629	.03029
3.400	.05804	.04774	.04093	.03609	.03136	.02643
3.600	.04799	.03986	.03445	.03058	.02678	.02281
3.800	.03923	.03288	.02864	.02560	.02259	.01944
4.000	.03185	.02690	.02359	.02120	.01883	.01633

Table- 4: DBE level of response spectral amplitudes for horizontal component of motion

T (sec)	Spectral Amplitudes (g) for Damping Ratios (%) of					
	1.0	3.0	5.0	7.0	10.0	15.0
.040	.30760	.25346	.23574	.22736	.22284	.21936
.042	.31846	.25988	.24084	.23126	.22536	.22044
.044	.32896	.26656	.24647	.23577	.22844	.22199
.046	.33877	.27328	.25248	.24078	.23206	.22405
.048	.34768	.27993	.25875	.24621	.23619	.22662
.050	.35563	.28643	.26519	.25199	.24079	.22973
.055	.37228	.30207	.28147	.26733	.25370	.23922

.060	.38737	.31748	.29760	.28303	.26753	.25003
.065	.40456	.33331	.31312	.29798	.28074	.26047
.070	.42587	.34955	.32756	.31124	.29209	.26921
.075	.45153	.36580	.34051	.32228	.30086	.27550
.080	.48097	.38175	.35190	.33101	.30693	.27916
.085	.51334	.39741	.36196	.33775	.31063	.28048
.090	.54778	.41301	.37113	.34305	.31258	.28006
.095	.58338	.42878	.37989	.34753	.31356	.27862
.100	.61932	.44484	.38860	.35174	.31421	.27682
.110	.68936	.47764	.40665	.36072	.31644	.27405
.120	.75221	.50955	.42534	.37135	.32133	.27401
.130	.80354	.53797	.44361	.38341	.32887	.27687
.140	.84128	.56114	.46036	.39608	.33816	.28196
.150	.86565	.57857	.47496	.40854	.34820	.28853
.160	.87864	.59073	.48723	.42021	.35822	.29601
.170	.88290	.59860	.49728	.43072	.36774	.30404
.180	.88079	.60316	.50527	.43984	.37649	.31235
.190	.87471	.60549	.51149	.44749	.38433	.32062
.200	.86616	.60630	.51608	.45357	.39113	.32852
.220	.84617	.60532	.52066	.46060	.40089	.34181
.240	.82772	.60263	.51958	.46093	.40489	.34996
.260	.81414	.59865	.51346	.45544	.40307	.35210
.280	.80578	.59306	.50354	.44593	.39662	.34900
.300	.80125	.58561	.49121	.43415	.38711	.34205
.320	.79852	.57648	.47784	.42150	.37603	.33278
.340	.79561	.56614	.46446	.40887	.36448	.32239
.360	.79074	.55503	.45169	.39676	.35314	.31164
.380	.78277	.54359	.43979	.38547	.34240	.30104
.400	.77077	.53189	.42876	.37509	.33244	.29081

Table-4 Contd…

T (sec)	Spectral Amplitudes (g) for Damping Ratios (%) of					
	1.0	3.0	5.0	7.0	10.0	15.0
.420	.75454	.51995	.41845	.36562	.32328	.28107
.440	.73458	.50776	.40867	.35698	.31487	.27186
.460	.71173	.49530	.39926	.34904	.30711	.26320
.480	.68707	.48264	.39011	.34166	.29990	.25509
.500	.66173	.46989	.38118	.33471	.29315	.24754
.550	.60205	.43893	.35997	.31857	.27769	.23089
.600	.55410	.41129	.34091	.30352	.26357	.21693
.650	.51903	.38822	.32425	.28926	.25030	.20478
.700	.49413	.36945	.30962	.27569	.23760	.19375

.750	.47619	.35386	.29633	.26270	.22535	.18345
.800	.46272	.34024	.28375	.25017	.21349	.17373
.850	.45188	.32762	.27149	.23801	.20201	.16457
.900	.44213	.31532	.25936	.22619	.19096	.15598
.950	.43217	.30303	.24738	.21478	.18045	.14797
1.000	.42114	.29071	.23570	.20391	.17059	.14054
1.100	.39422	.26647	.21401	.18440	.15341	.12748
1.200	.36210	.24425	.19574	.16862	.14009	.11688
1.300	.32887	.22522	.18127	.15657	.13038	.10857
1.400	.29813	.20941	.16997	.14745	.12338	.10210
1.500	.27176	.19616	.16075	.14017	.11798	.09691
1.600	.25001	.18466	.15268	.13380	.11327	.09244
1.700	.23229	.17435	.14513	.12772	.10868	.08831
1.800	.21775	.16485	.13779	.12158	.10388	.08427
1.900	.20533	.15596	.13057	.11532	.09882	.08021
2.000	.19426	.14753	.12345	.10894	.09354	.07612
2.200	.17394	.13167	.10964	.09618	.08271	.06798
2.400	.15433	.11674	.09667	.08413	.07237	.06029
2.600	.13504	.10254	.08470	.07328	.06311	.05334
2.800	.11647	.08908	.07372	.06370	.05505	.04719
3.000	.09893	.07641	.06365	.05524	.04805	.04174
3.200	.08270	.06464	.05444	.04769	.04189	.03684
3.400	.06802	.05394	.04608	.04092	.03640	.03241
3.600	.05516	.04452	.03868	.03490	.03151	.02841
3.800	.04422	.03642	.03226	.02961	.02716	.02480
4.000	.03539	.02979	.02690	.02511	.02339	.02161

Table- 5: DBE level of response spectral amplitudes for vertical component of motion

T (sec)	Spectral Amplitudes (g) for Damping Ratios (%) of					
	1.0	3.0	5.0	7.0	10.0	15.0
.040	.29725	.22967	.20460	.18841	.17133	.15226
.042	.32321	.24065	.21108	.19268	.17397	.15367
.044	.34920	.25164	.21746	.19686	.17654	.15507
.046	.37437	.26242	.22372	.20098	.17907	.15650
.048	.39804	.27279	.22981	.20503	.18158	.15794
.050	.41973	.28257	.23566	.20898	.18403	.15937
.055	.46448	.30370	.24880	.21805	.18957	.16254
.060	.49629	.31941	.25922	.22542	.19384	.16471
.065	.51756	.33006	.26683	.23091	.19686	.16589

.070	.53063	.33663	.27204	.23480	.19900	.16648
.075	.53785	.34045	.27549	.23749	.20060	.16687
.080	.54141	.34272	.27774	.23926	.20178	.16724
.085	.54305	.34428	.27916	.24027	.20251	.16757
.090	.54390	.34561	.27999	.24062	.20272	.16780
.095	.54451	.34693	.28039	.24043	.20244	.16788
.100	.54504	.34824	.28048	.23985	.20178	.16779
.110	.54569	.35064	.28015	.23818	.19995	.16731
.120	.54545	.35232	.27959	.23657	.19832	.16666
.130	.54364	.35275	.27886	.23529	.19716	.16584
.140	.53947	.35148	.27762	.23404	.19615	.16460
.150	.53254	.34834	.27553	.23243	.19484	.16269
.160	.52342	.34359	.27242	.23023	.19295	.16006
.170	.51345	.33783	.26840	.22740	.19044	.15686
.180	.50402	.33170	.26374	.22403	.18743	.15329
.190	.49601	.32574	.25880	.22032	.18412	.14962
.200	.48964	.32022	.25386	.21646	.18069	.14602
.220	.47998	.31045	.24467	.20885	.17392	.13937
.240	.47002	.30132	.23669	.20186	.16766	.13359
.260	.45649	.29163	.22953	.19552	.16197	.12857
.280	.43947	.28118	.22268	.18963	.15680	.12424
.300	.42037	.27039	.21590	.18406	.15217	.12058
.320	.40069	.25988	.20924	.17881	.14806	.11758
.340	.38145	.25015	.20287	.17391	.14443	.11517
.360	.36317	.24145	.19695	.16937	.14116	.11323
.380	.34616	.23379	.19154	.16514	.13810	.11156
.400	.33062	.22708	.18661	.16115	.13510	.11000

Table-5 Contd…

T (sec)	Spectral Amplitudes (g) for Damping Ratios (%) of					
	1.0	3.0	5.0	7.0	10.0	15.0
.420	.31669	.22116	.18210	.15732	.13205	.10838
.440	.30439	.21586	.17791	.15359	.12892	.10663
.460	.29373	.21105	.17397	.14993	.12572	.10469
.480	.28457	.20661	.17020	.14634	.12251	.10259
.500	.27678	.20243	.16658	.14285	.11933	.10035
.550	.26159	.19265	.15795	.13464	.11200	.09457
.600	.24971	.18325	.14970	.12721	.10583	.08909
.650	.23844	.17390	.14170	.12040	.10063	.08421
.700	.22660	.16468	.13397	.11404	.09601	.07984
.750	.21414	.15587	.12669	.10809	.09169	.07585
.800	.20157	.14773	.12009	.10265	.08760	.07213

.850	.18952	.14043	.11428	.09781	.08376	.06868
.900	.17845	.13399	.10926	.09359	.08024	.06551
.950	.16859	.12832	.10491	.08992	.07705	.06264
1.000	.15995	.12328	.10107	.08668	.07416	.06003
1.100	.14578	.11447	.09434	.08103	.06902	.05548
1.200	.13457	.10661	.08814	.07583	.06434	.05150
1.300	.12508	.09924	.08215	.07080	.05990	.04786
1.400	.11662	.09228	.07641	.06594	.05568	.04453
1.500	.10891	.08585	.07109	.06140	.05180	.04154
1.600	.10189	.08006	.06629	.05729	.04831	.03889
1.700	.09556	.07494	.06207	.05366	.04524	.03657
1.800	.08993	.07048	.05840	.05049	.04255	.03452
1.900	.08489	.06656	.05518	.04772	.04020	.03268
2.000	.08031	.06306	.05233	.04527	.03812	.03102
2.200	.07195	.05682	.04735	.04105	.03459	.02809
2.400	.06398	.05101	.04284	.03732	.03154	.02554
2.600	.05617	.04536	.03849	.03376	.02871	.02322
2.800	.04868	.03986	.03421	.03023	.02591	.02103
3.000	.04168	.03460	.03002	.02670	.02310	.01889
3.200	.03530	.02967	.02596	.02325	.02031	.01678
3.400	.02958	.02511	.02213	.01995	.01760	.01473
3.600	.02453	.02100	.01862	.01689	.01506	.01278
3.800	.02014	.01737	.01549	.01414	.01274	.01097
4.000	.01646	.01428	.01279	.01175	.01069	.00933

ANNEXURE-VII

CONSTRUCTION MATERIAL AND GEOTECHNICAL STUDIES

CHAPTER - 8

CONSTRUCTION MATERIAL ANDGEOTECHNICAL STUDIES

8.1 QUANTITY OF CONTRUCTION MATERIALS

The quantities required for the construction of rockfill, chutespillway, intake, HRT, surgeshaft, inclined shaft, power house, tail race and appurtenant structures are as under :

i)	Fine aggregates	: 0.20 M m^3
ii)	Coarse aggregate	: 0.40 M m^3
iii)	Cement	: 0.20 Million MT
iv)	Rock fill	: 30 M m^3 (Blasted rock)
v)	Core material	: 6.7 M m^3(Impervious material)
vi)	Filter material	: 1.6 M m^3

8.2 Rock Fill Material & Aggregates

The construction materials surveys have been carried out to identify the prospective rock quarries around the project area with particular reference to rockfill material for the pervious portion of dam and aggregates and crushed sand for concrete required for chute spillway, diversion tunnel, HRT, Surgeshaft, inclined shaft, Power House and T.R.T. etc. Fig. 8.1 shows the locations of quarries. At these quarries rock samples have been collected by blasting and subjected to laboratory analysis to determine the physical and engineering properties of the rock samples.

TESTS FOR COARSE AGGREGATES :

Specific Gravity

Water Absorption

Aggregate Impact value

Aggregate crushing value

Aggregate abrasion value (Los Angeles)

Soundness

TESTS FOR ROCKFILL

Permeability

Proctor compaction

Oedo meter

Strength parameters of rockfill material

(Cohesion & Angle of Friction)

i) **Quarry No. 1**

(On Left Bank of River Wangchu, Beyond Baikinza Village)

The quarry has been identified on left bank of river Wangchu at about 2.5 Kms u/s of dam site at an altitude ranging between 300 to 900 M. The type of rock available is quartzite. The representative samples weighing about 200 Kgs have been collected from 4 locations to assess the characteristics and suitability of the rock based on the laboratory tests.

ii) **Quarry No. 2**

(On Right Bank of Wangchu river u/s of dam axis)

The quarry has been identified on right bank of Wangchu River at about 1 Km u/s of dam site at an altitude ranging between 300 to 800 M. the

type of rock available is quartzite. The quarry area is a barren land with steep slopes. The quarry is massive and can be extended further in all the directions except towards the damsite. The representative samples weighing about 200 Kgs have been collected from 4 locations to assess the characteristics and suitability of the rock based on the laboratory tests

iii) **Quarry No. 3**

(On right bank of river Wangchu, D/s of dam axis)

The quarry has been identified on right bank of river Wangchu at about 2 km d/s of dam site at an altitude ranging between 225 to 400 M. The type of rock available here is Dolomite (in 3 locations) and quartzite (in one location). The quarry area is covered with vegetation cover. Representative samples weighing about 200 Kgs have been collected from 4 locations to assess the characteristics and suitability of rock based on the laboratory tests.

iv) **Quarry No. 4**

(On left bank of Wangchu river beyond Titritar village)

The quarry has been identified on left bank of Wangchu river at about 10 Km d/s from dam site and around 2 km from Power House beyond Titritar village at an altitude ranging between 300 to 400 M. The type of rock available is quartzite. The quarry is covered with vegetation cover. Representative samples weighing about 200 Kgs have been collected from 4 locations to assess the characteristics and suitability of rock based on the laboratory tests.

The quarry has been identified on right bank of river Piping at about 10 Km d/s from dam site, 2 km from Power House at an altitude ranging between 250 to 350 M. The type of rock available is quartzite. The quarry area is a barren land with steep slopes. Representative samples weighing about 200 Kgs have been collected to assess the characteristics and suitability of rock based on the laboratory tests.

vi) **Quarry No. 6/7**

It is proposed to strip thick rockmass from the right abutment of dam site. This stripped material of dam abutment is proposed to be utilised as rockfill material. The type of rock is quartzite. The valley gorge is having steep slopes. Representative samples have been collected from Drift 1 & Drift 2 on right abutment to assess the characteristics & suitability of rock based on the laboratory tests.

vii) **Quarry No. 8/8A**

It is proposed to strip thick rockmass from the left abutment at dam site and utilise as construction material for rockfill dam. The type of rock available is quartzite. The gorge is having steep slopes. Representative samples have been collected from Drift-3 on left abutment to assess the characteristics & suitability of rock based on laboratory tests.

To assess the strength parameters of the proposed rockfill material, representative rockfill material has been collected at RL 360 M by controlled blasting for gradational analysis. From the muck, prototype particle distribution curves has been obtained and model gradation

curves derived. Based on the model gradation curves, quantities of various factions of the material has been collected and sent for laboratory analysis to assess the characteristics and strength parameters of rockfill material.

viii) River Bed Material

This area is located d/s of dam axis at an altitude of 230 M on Right Bank of Wangchu River.

From the river bed material, prototype practicle distribution curves have been obtained and model gradation curves derived. Based on the model gradation curves, quantities of various factions of the material have been collected and sent for laboratory analysis to assess the characteristics and strength parameters of rockfill material.

ix) The rock samples from these quarries have also been found suitable for rock fill material for the dam. The quantity available in these quarries is found adequate to meet the total requirement of rock fill and aggregates.

The rock from the quarries were found to be suitable for use as coarse aggregate and crushed sand in concrete for non-wearing and wearing surfaces. Petrographics tests were done on coarse aggregates & fine aggregates. The results of laboratory testing of rock samples and petrographic examination results are enclosed in Volume-VII. It is seen that suitable concrete mixes can be designed using the available aggregates. The samples were also found to be safe from view-point of alkali-silica reaction. With regard to the various underground structures, the physical properties of excavated material would need to

be tested during construction. In any case, the various quarries mentioned above are available for the purpose.

8.3 Core Materials/Filter Materials

Nine potential borrow areas have been identified at u/s and d/s of the proposed dam site and are 10 to 40 km away. The location of these borrow areas is marked in Fig. 8.2.

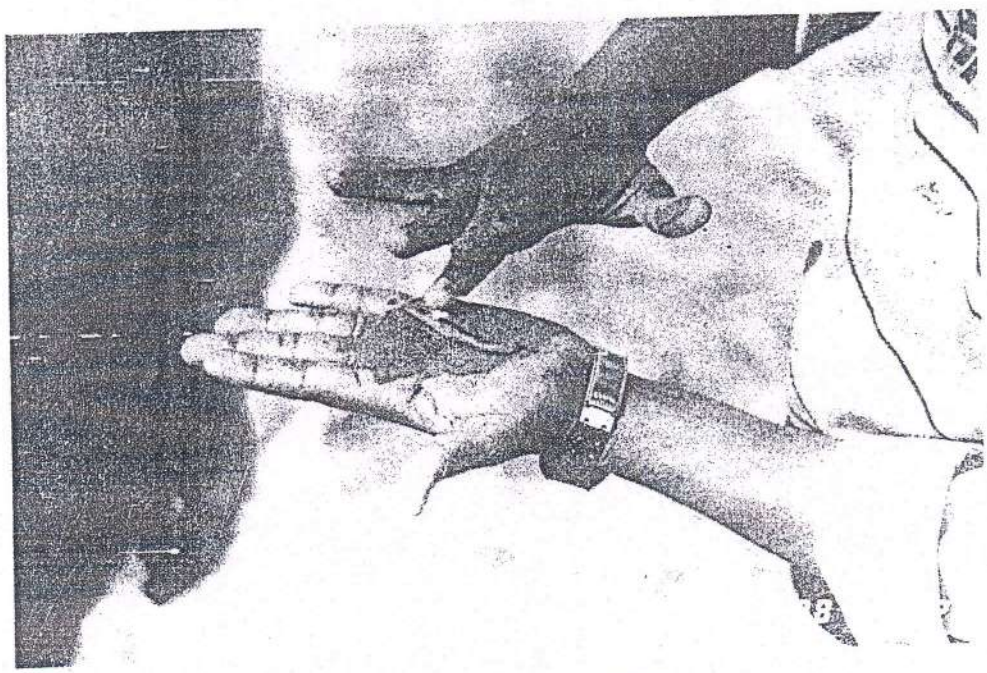
In all 265 representative soil samples were collected for core materials. For arriving at the filter criteria with the base (core) materials, a total nuber of 26 representative filter material were collected.

The under mentioned laboratory tests were carried out on core materials.

- Mechanical Analysis
- Atterberg Limits
- Standard/Modified proctor compaction
- Tri-axial shear
- Specific gravity
- One dimensional consolidation
- Permeability
- Chemical analysis

Besides this, logging of trial pits were also carried out. Suitable filter material is available at Debitar borrow area as the grainsize distribution of samples collected in this area indicate predominantly sand sizes and also non plastic characteristics. The curves of filter material have been compared with average grain size distribution curves of materials collected from borrow

COLLECTION OF SAMPLES OF FINE AGGREGATE



FIELD TEST FOR CORE MATERIAL

areas identified for core materials. The material satisfies these filter criteria viz permeability ratio, piping ratio and parallel gradation.

The field investigations conducted at the borrow areas summarised as under.

i) **Borrow area, B-1 (Village Ahale)**

The borrow are is located at about 10 Kms d/s of proposed dam site at an altitude of about 550 M on right bank of river Wangchu. The soil available in this borrow area is suitable for impervious clay core.

33 representative soil samples have been collected by excavating 28 trial pits followed by augering for laboratory tests and detailed classification. In this borrow area, it is estimated that about 0.71 Mcum of core material is available. The area is presently utilised for orange orchards.

ii) **Borrow area, B-2 (Village Piping)**

The borrow area is located at about 8 kms down stream of proposed dam site on left bank of Wangchu river at an altitude of 195 M. The area is mainly covered with bushes and a few trees.

The soil in this borrow area is suitable for impervious clay core.

Three representative soil samples have been collected by excavating trial pits for laboratory tests and detailed classification. It is estimated that about 0.1 Mcum of core material is available at this borrow area. This area has also been considered suitable for switchyard.

iii) **Borrow Area, B-3 (Village Titritar)**

The borrow area is located at about 10 kms d/s of dam site at an altitude of about 180 M on left bank of river Wangchu. The borrow area is a cultivable land. The soil in this borrow area is suitable for core. 3 representative soil samples have been collected from 3 trial pits for laboratory tests and detailed classification. It is estimated that about 0.5 M cum of core material is available at this borrow area.

iv) **Borrow Area, B-4 (Village Debitar)**

The borrow area is located at about 15 kms d/s of dam site on left bank of Wangchu river. The borrow area is a cultivable land. The field tests indicate semipervious/ gravelly type non plastic soil is available in abundance which is suitable for filter material 32 representative soil samples have been collected by excavating 29 trial pits for laboratory tests and detailed classification. It is estimated that about 2.15 M cum of filter material is available at this borrow area.

v) **Borrow Area, B-5, (Village Saku)**

The borrow area is located at about 15 kms d/s of dam site on right bank of Wangchu river. The field tests indicate that the soil is impervious and suitable for core material. This borrow area is a cultivable land. 9 representative soil samples have been collected by excavating 9 trial pits for laboratory tests and detailed classification. It is estimated that about 0.48 M cum of core material is available at this borrow area.

vi) **Borrow area, B-6 (Village Baikinza)**

The borrow area is located at about 3-4 kms on left bank of Wangchu river at an altitude ranging between 550 M to 900 M. The area is mainly

covered with orchards. The field tests indicate that the soil is highly impervious and suitable for core material. 64 representative soil samples have been collected for laboratory tests and detailed classification. it is estimated that about 1.22 M cum of core material is available at this borrow area.

vii) Borrow Area, B-7 (Village Tala)

The borrow area is located at about 40 kms u/s of dam site on right bank of river Wangchu at an altitude of 1700 M. This area is a cultivable land. The field tests indicate that the soil is suitable for core of rockfill dam.

28 soil samples have been collected from this borrow area by excavating trial pits followed by augering, for laboratory tests and detailed classification. It is estimated that about 1.78 M cum of core material is available at this borrow area.

viii) Borrow Area, B-8 (Village Geingu)

The borrow area is located at about 30 kms u/s of dam site on the right bank of river Wangchu at an altitude ranging between 850-1200 M. The field tests indicate that the soil is suitable for core material.

29 representative soil samples have been collected by excavating trial pits for laboratory tests and classification of the material. It is estimated that about 0.37 M cum of clay core material is available at this borrow area.

ix) Borrow Area, B-9 (Village Sinchula)

The borrow area is located at about 25 kms u/s of dam site on right bank of Wangchu river at an altitude ranging between 960-1650 M.

This borrow area is covered with cultivable land. The soil reaches is suitable for core material.

37 representative soil samples have been collected from 29 trial pits at this borrow area for laboratory tests and classification of material. It is estimated that about 0.47 M cum of core material is available at this borrow area.

x) Most of the borrow area materials are in general found to be suitable as core materials. However, a large quantity of materials in Baikinza borrow area are found to fall under MH group according to bureau of Indian Standard soil classification system. Eventhough this type of materials are not generally recommended for use as core materials in zoned fill dams, the same may be used with appropriate construction quality control measures and also by placing this materials as casing materials in the core section itself subject to the conditions that the materials within the core should be of GC, SC, CI and CL groups.

8.4 Geophysical Studies

The CSMRS have carried out seismic refraction studies at the alternative dam site-III. The studies were carried out for preliminary assessment of the depth of overburden and depth to bed-rock, with a view to finalise the dam axis. The relevant report is enclosed in Volume-VII.

8.5 Test on rock cores

The following tests were carried out on rock cores collected from different drill holes at dam site, along HRT alignment and at the power house location.

a) Physical properties

- Bulk density (dry)
- Bulk density (saturated)
- Specific gravity (grain density)
- Water Content at saturation (%)
- Apparent Porosity (%)

b) Engineering properties

- Ultrasonic pulse wave velocity compressive shear)
- Tensile strength
- Deformability and strength (in unioxial compression)
- Triaxial compression
- The details of the samples and results obtained after laboratory tests are tabulated as under

Table I

Physical Properties

Sl. No.	CSM Lab. No.	Location	Bulk Density (Dry)	Bulk Density (Sat)	Grain Density	Water Content at Saturation %	Porosity Apparent %
				Kg/m³			
Rock Type : Quartzite, white, fine grained							
1.	588	Dam axis at Right bank/ DS-1	2570	2580	2690	0.34	0.87
2.	589		2590	2600	2680	0.40	1.03
3.	590		2570	2580	2650	0.27	0.69
4.	591		2570	2580	2650	0.39	1.00
5.	592		2570	2580	2660	0.39	0.99
6.	593		2600	2610	2660	0.31	0.80
7.	594		2530	2540	2660	0.29	0.73
8.	595		2590	2600	2650	0.27	0.69
Rock Type : Quartzite, greyish colour, fine grained							
9.	596		2570	2580	2800	0.18	0.43
10.	597		2590	2600	2790	0.39	1.01
11.	598		2620	2630	2720	0.25	0.66
12.	599		2620	2630	2720	0.22	0.56
13.	600		2610	2620	2730	0.19	0.49
14.	601		2570	2580	2730	0.24	0.60
15.	602		2590	2600	2690	0.22	0.56
Rock Type : Quartzite, Cherty							
16.	603	250 M D/s of Dam axis on right bank, DS-3	2580	2590	2760	0.17	0.43
Rock Type : Phyllite							
17.	604		2560	2570	2730	0.24	0.60
18.	605		2670	2680	2760	0.33	0.87
Rock Type : Black Slate							
19.	606	250 M D /s of Dam axis on right bank, DS-4	2730	2750	2820	0.35	0.96

Continued... Table I

20.	607		2750	2770	2790	0.41	1.12
21.	608		2780	2790	2880	0.48	1.32
22.	609		2750	2760	2880	0.39	1.07
Rock Type : Quartzite							
23.	676	on dam axis at centre of gorge/DS-2	2600	2610	2620	0.25	0.65
24.	677		2590	2600	2620	0.34	0.89
25.	678		2590	2600	2630	0.43	1.11
Rock Type : Greenish coloured quartzite							
26.	679	At 150 m U/S of dam axis on right bank DS-5	2710	2730	2760	0.47	1.28
27.	680		2920	2930	2960	0.44	1.27
28.	681		2600	2610	2730	0.18	0.46
Rock Type : Quartzite, white to grey colour							
29.	682		2610	2620	2670	0.24	0.61
Rock Type : Quartzite white							
30.	683		2590	2600	2660	0.28	0.71
31.	684		2530	2540	2650	0.33	0.82
32.	685		2570	2580	2640	0.30	0.77
33.	686		2590	2600	2640	0.34	0.87
Rock Type : Quartzite, green colour							
34.	687		2590	2600	2670	0.28	0.71
Rock Type : White Quartzite							
35.	688		2560	2570	2690	0.36	0.92
36.	689		2610	2620	2710	0.32	0.84
Rock Type : Quartite, green colour with white band							
37.	690		2600	2610	2670	0.22	0.58

Table II

Ultra sonic Pulse Wave Velocities

Sl. No.	CSM Lab. No.	Ultra sonic Pulse Wave Velocity (Over dry), km/sec.		Rock Type
		p wave	s wave	
1.	588	3.23	2.03	Quartzite white finegrained
2.	589	2.87	1.93	
3.	590	3.49	2.43	
4.	591	3.39	2.39	
5.	592	3.38	2.29	
6.	593	3.45	2.23	
7.	594	3.25	1.96	
8.	595	3.31	2.48	
9.	596	4.11	2.61	Quartzite, greyish colored, fine grained
10.	597	3.46	2.15	
11.	598	3.27	2.36	
12.	599	3.78	2.73	
13.	600	3.32	2.05	
14.	601	3.62	2.57	
15.	602	3.45	2.48	
16.	604	3.22	1.97	Fine grained, dark grey phyllite
17.	605	4.79	2.66	
18.	606	2.79	1.88	
19.	606A	2.91	1.88	
20.	607	3.63	2.57	
21.	608	3.75	2.30	
22.	609	4.43	2.49	
23.	676	4.49	2.55	Quartzite
24.	677	4.38	2.46	
25.	678	4.36	2.56	
26.	679	3.40	2.48	Greenish colored Quartzite
27.	680	3.66	2.56	
28.	681	4.14	2.68	
29.	682	4.15	2.81	Quartzite (White to grey color)
30.	683	4.21	2.83	Quartzite white color
31.	684	3.75	2.41	
32.	685	4.07	2.71	
33.	688	3.14	1.84	White Quartzite

Table III
Tensile Strength (Brazil Test)

Sl. No.	CSM Lab. No.	Tensile Strength, MPa		Rock Type
		Oven dry	Saturated	
1.	589A		10.37	Quartzite white fine grained
2.	590		18.39	
3.	591A		17.49	
4.	592A	15.41		
5.	592B		15.08	
6.	598A		11.70	Quartzite, greyish colored, fine grained
7.	598B		14.47	
8.	598C	13.23		
9.	599A		20.40	
10.	601A	16.81		
11.	601B	15.61		
12.	601C		14.97	
13.	601D		4.81	
14.	603A	20.63		Quartzite (Cherty)
15.	603B	11.56		
16.	603C		15.70	
17.	604A		9.19	Phyllite
18.	607A		1.86	Black slate
19.	608A		2.51	
20.	677A	6.46		Quartzite
21.	683A	13.91		Quartzite (White color)
22.	683B		10.84	
23.	683C	20.33		
24.	685A		10.72	
25.	686A	11.62		
26.	686B		8.77	
27.	688A		6.91	White Quartzite
28.	689A	7.35		
29.	689B		4.78	
30.	690A	18.39		Quartzite (Green color with white band)
31.	690B		8.78	

Table IV

Uniaxial Compressive Strength

a) Oven dry specimens

Sl. No.	CSM Lab. No.	Unixal Compressive Strength, MPa	Static Elastic Parameters		Rock Type
			E, GPa	*	
1.	588	76.53	28.57	0.16	Quartzite, white fine grained
2	589	45.34	27.78	0.08	
3.	590	105.47	41.67	-	
4.	591	76.87	38.46	0.15	
5.	606a	13.95	10.53	-	Black slate (Dark grey)
6.	607	19.21	18.87	-	
7.	608	15.64	27.50	-	
8.	609	23.36	30.30	-	

b) Saturated specimens

Sl. No.	CSM Lab. No.	Unixal Compressive Strengt, MPa	Static Elastic Parameters		Rock Type
			E, GPa	*	
1.	592	105.55	47.62	0.14	Quartzite white fine grained
2.	593	51.45	34.68	0.18	
3.	594	82.32	-	-	
4.	595	101.61	45.45	0.27	
5.	679	76.07	28.57	0.23	Greenish colored Quartzite
6.	680	82.74	24.10	0.17	
7.	604	87.304	5.45	-	Fine grained, dark Grey, phyllite
8.	605	30.87	36.36	-	

* = Poissons Ratio

Table V

Triaxial Compression Test

Sl. No.	CSM Lab. No.	Lateral Pressure, MPa	Axial Stress, MPa	Shear Parameters		Rock Type
				Cohesion, c, MPa		
1.	576	1	70.21			Quartzite, greyish colored fine grained
2.	676	2	214.86@			Quartzite
3.	598	3	137.24			Quartzite, greyish colored fine grained
4.	677	3.5	160.14			Quartzite,
5.	597	4	121.66@			Quartzite, greyish colored fine grained
6.	678	4.5	311.39@			Quartzite,
7.	599	5	130.47@			Quarzite, greyish colored fine grained
8.	682	5	209.07	8.2	65°	Quartzite, white to grey color
9.	681	6	295.37@			Greenish colored to Quartzite
10.	600	6.6	139.56@			Quartzite, greyish colored fine grained
11.	601	4	320.21@			
12.	602	6.5	231.16			
13.	683	4.5	313.17@			Quartzite (white color)
14.	684	5	372.20@			
15.	685B	8	309.05@			
16.	688B	10	264.68			

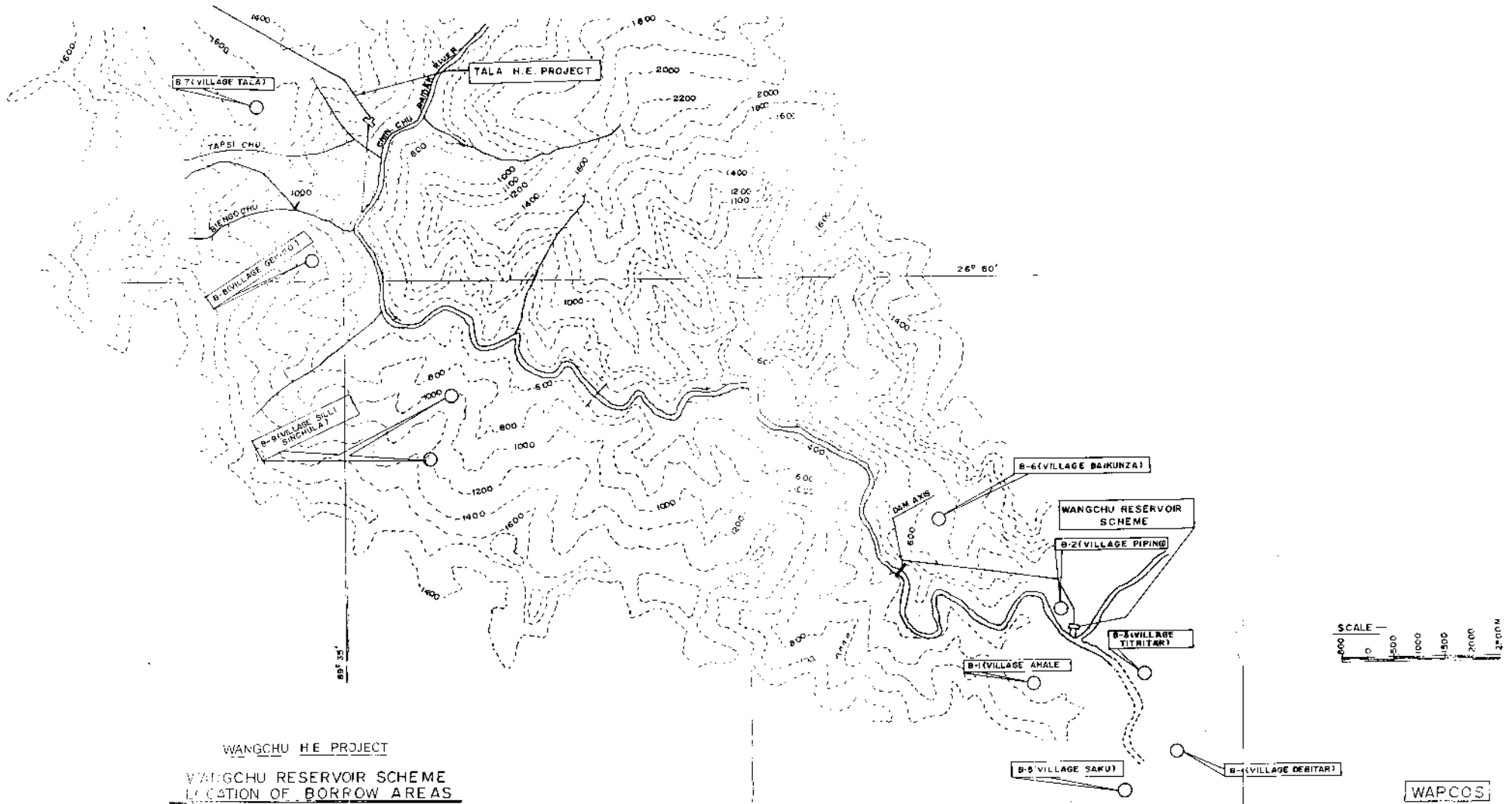
Angle of internal friction in degrees

@ - Value rejected

8.6 Petrographic analysis of suspended silt material

A total of six suspended silt samples were collected from the Piping G&D site covering fine, medium and coarse segments. The samples were

WANGCHU H. E. PROJECT

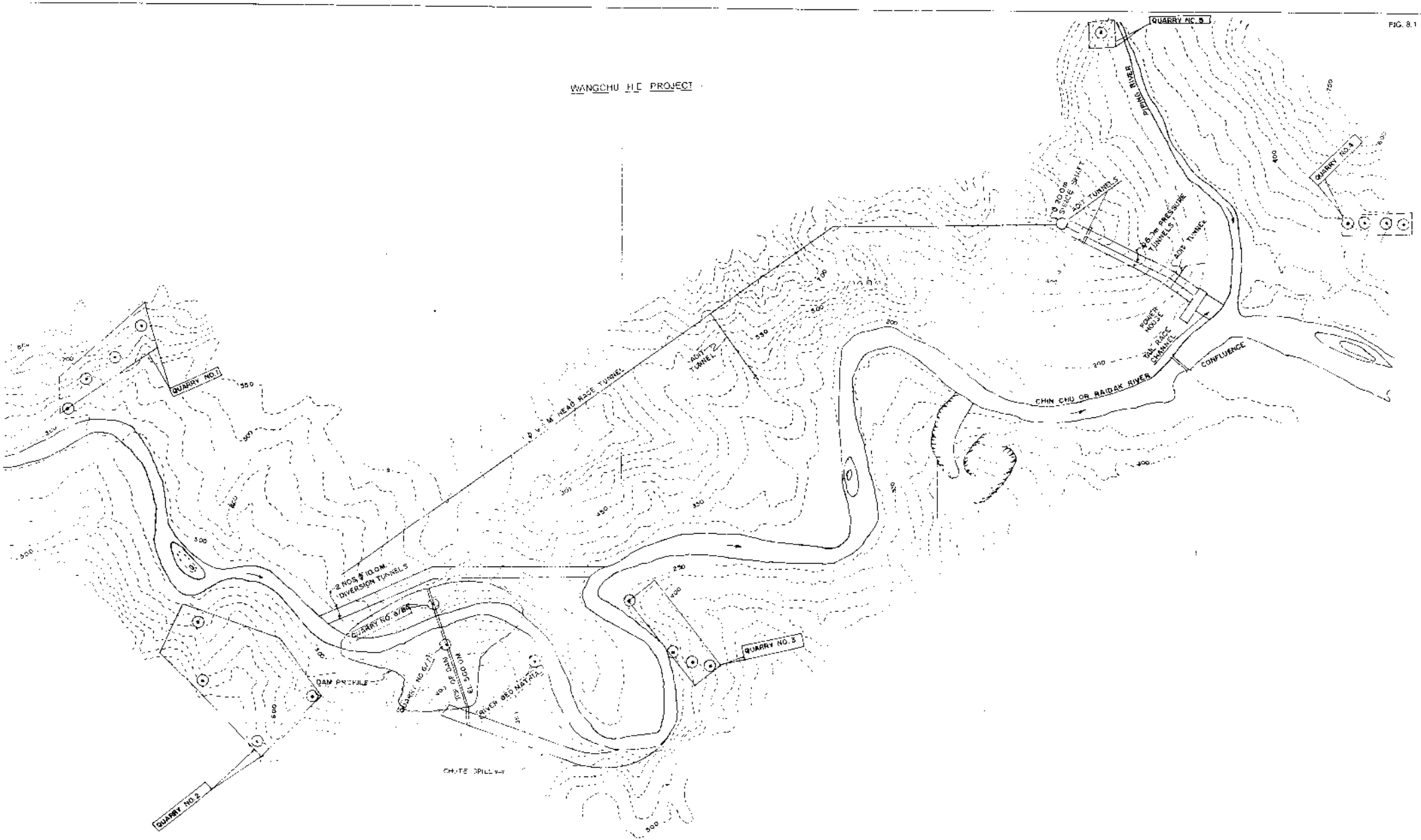


WANGCHU H.E. PROJECT

WANGCHU RESERVOIR SCHEME
LOCATION OF BORROW AREAS

FIG. 8.1

WANGCHU H.E PROJECT



WANGCHU H.E. PROJECT

WANGCHU RESERVOIR SCHEME

CONSTRUCTION MATERIALS INVESTIGATIONS LOCATION OF PROPOSED QUARRIES

SCALE- 1:10,000

WAPCOS

ANNEXURE-VIII

REPORT ON CONSTRUCTION MATERIAL SURVEY AND LABORATORY INVESTIGATION OF ROCK AND SAND SAMPLES

REPORT ON THE CONSTRUCTION MATERIALS SURVEY AND LABORATORY INVESTIGATIONS OF ROCK AND SAND SAMPLES FOR USE AS COARSE AGGREGATE AND FINE AGGREGATE IN CONCRETE FOR WANGCHU HYDRO ELECTRIC PROJECT, BHUTAN

1.0 INTRODUCTION

The Manager (Geology), Wangchu H.E. Project, Bhutan had requested CSMRS vide his letter no. Geo /SJVNL/WHEP.11-221-30 dated the 2nd May, 2011 to take up the work of Construction Materials Survey and Laboratory Investigations of Rock and Natural Riverbed materials for assessing their suitability for use as coarse aggregate and fine aggregate respectively in concrete for the proposed Wangchu H.E.Project, Bhutan.

A team of CSMRS officials had visited the project site during the period 9th to 15th August, 2011 for carrying out construction materials survey for identifying prospective quarries for rock and sand samples and collection of representative samples for laboratory assessment of their suitability for use as construction materials in concrete for the proposed Wangchu H.E.Project, Bhutan. Field investigation report of CSMRS team is attached as Appendix-I.

Based on the discussions held with the Additional General Manager and Senior Manager (Geology) of M/s SJVNL, Wangchu H.E. Project, Bhutan, it was conveyed that two potential rock quarry sites, one near the dam area and the other near power house site have already been identified by their Geologist and a request was made to CSMRS officers for inspection of the same sites. The topography sheet of the area was examined and the potential quarries were located on it.

Based on the assessment made on the type and quality of rock near the dam site by the resident geologist of M/s. SJVNL, it was conveyed that the rock type on the left bank where the HRT has been proposed, was hard quartzite. Since the excavated material could be a potential source for aggregate materials for the dam, it was decided to collect rock samples from both the drifts near the dam area where fresh rock has already been exposed after blasting. In addition to the above, an outcrop of quartzite rock has also been identified on the left bank about 700 m upstream of the dam axis. Since, this site was not accessible due to heavy discharge in the river, the project

authorities had been requested to collect the samples from this rock quarry during lean period as this could serve as an additional rock quarry for the dam.

Since the proposed length of head race tunnel is around 12.5 km, approximately 7.1 lakh m^3 of rock materials are likely to be excavated from the tunnel and 40% of the total quantity has been proposed for using as construction material in concrete after assessing their suitability. It was also suggested that river deposit from the dam area can also be considered in case of shortfall of aggregate materials for exploitation after assessing their suitability.

In the power house area near Piping village, located at about 25 km downstream of dam axis, large areas of river shoal deposits have been identified along both the banks of the river. The depth of deposits of shoal has been estimated around 15 m. Total area proposed to be exploited is of the order of around 2 lakh m^2 (2000 m long x 100 m wide) and approximate quantity available in the area is to the tune of 20 lakh m^3, if on average 2 m depth of shoal deposits are exploited every year during 5 years of the construction period.

Representative composite boulder samples from each of the three trial pits located at a spacing of around 600 m covering the entire 2 km length have been proposed for collection. Since, estimation of sand fractions in the trial pits could not be worked out due to incessant rain, the project authorities have been requested to complete this task after the monsoon period and convey the same to CSMRS for incorporation in the final report.

In the absence of natural sand quarries available within the vicinity of the dam area, suggestions were made for using crushed rock of required grading zone in place of natural sand for use as fine aggregate construction materials in concrete.
Details of aggregate rock samples collected for laboratory investigations are given as below.

Dam area

The proposed dam axis of the project is located at about 7 km downstream of power house of the existing Tala HE Project, Bhutan. The rock type on the left bank of the dam where HRT have been

proposed is predominantly quartzite. Two drifts have been made in the dam abutment. Two representative composite samples have been collected and designated as WHEP/DA/DRL and WHEP/DA/DRR.

Power house Area

Power house is located at about 25 km downstream of dam axis. Large quantities of river shoal deposits were available along the right as well as left bank of the river Wangchu. The river boulder samples were hard and predominantly quartzite with some gneiss and dolomite fragments. Since left bank was not approachable, 3 trial pits of size 3 m x 3 m x 3 m were made at an interval of around 600 m along the right bank shoal deposits. Representative boulder sample from each of the trial pits were collected and designated as WHEP/PH/RBM-1, WHEP/PH/RBM-2 and WHEP/PH/RBM-3.

The rock and sand samples that were collected from the above mentioned rock and riverbed quarries were tested at CSMRS laboratory for evaluation of their physical and chemical properties. The petrographic analysis of representative rock samples collected from various quarries was entrusted with GSI, Faridabad and as the number of thin sections to be analysed were more, a delay in submission of report by GSI was apprehended. In the mean time, results of physical and chemical tests were compiled and submitted to the project authority. However, a final report incorporating the Petrographic analysis results is being submitted on receipt of the report from the GSI.

2.0 SALIENT FEATURES OF THE PROJECT

The scheme consists of construction of a 140 m high concrete gravity dam across the river Wangchu near Silli village about 25 km upstream of Piping confluence. The length of HRT is 12.5 km and the diameter of circular shaped head race tunnel is 8.5 m. A surface powerhouse with an installed capacity of 4 x 150 MW (600 MW) is proposed near Piping village on the left bank of Wangchu river. M/s SJVNL has been entrusted with the preparation of Detailed Project Report (DPR) for this project.

3.0 FIELD INVESTIGATION

3.1 Coarse Aggregate

In all, a total number of 5 representative rock samples (3 representative samples from river bed boulders samples and 2 representative samples from rock mass) were collected from 3 prospective rock quarries. Three representative River bed materials (RBM) samples collected from river shoal deposits were located near power house site and two rock samples that were collected from right bank and left bank drifts are located near the dam site.

All the five samples were processed at site to the required grading for laboratory investigations. The project authorities were requested to transport the processed aggregate samples to CSMRS laboratory for assessing their suitability for use as coarse aggregates in concrete. The details of rock samples/RBM collected from different prospective rock quarries are furnished in Annexure-I.

3.2 Fine Aggregate

In all, a total number of 3 representative sand samples were collected from the prospective river bed quarry materials near power house from river shoal deposit. Sand deposits form an integral part of riverbed material that were located for collection of coarse aggregate materials. All the three samples were processed at site to the required grading for laboratory investigations. The project authorities were requested to transport the processed aggregate samples to CSMRS laboratory for assessing their suitability for use as fine aggregates in concrete. The details of sand samples collected from different prospective sand quarries are also furnished in Annexure-I.

4.0 LABORATORY INVESTIGATIONS

4.1 Coarse Aggregate

The following physical and chemical tests were conducted on the representative rock samples as per IS: 2386-1963 (Reaffirmed 1997) and their suitability for use as coarse aggregate in

concrete for both wearing as well as non-wearing surfaces was assessed as per IS: 383-1970 (Reaffirmed 1997).

- Specific gravity
- Water absorption
- Soundness (5 cycles with Na_2SO_4)
- Aggregate impact value
- Aggregate crushing value
- Aggregate abrasion value (Los Angeles)
- Petrographic analysis

The results of physical and chemical tests are presented in Annexure-II. The results of ASR by accelerated mortar bar test as per the modified ASTM C1260 are placed in Annexure-III.

Three representative rock samples which form a part of three identified rock quarries were sent to Geological Survey of India, Faridabad for a detailed Petrographic analysis for determination of various mineral constituents and to assess their potential in Alkali Aggregate Reaction. The report of Petrographic analysis by Geological Survey of India, Faridabad is enclosed as Appendix-II.

4.2 Fine Aggregate

The following physical and chemical tests were conducted on the representative sand samples as per IS: 2386-1963(Reaffirmed 1997) and their suitability for use as Fine aggregate in concrete was assessed as per IS: 383-1970 (Reaffirmed 1997).

- Grading and fineness modulus
- Specific gravity
- Silt and clay content
- Organic impurities
- Petrographic analysis

The results of physical tests are presented in Annexure-IV. The results of grading and fineness modulus are presented in Annexure-V. The results of ASR by accelerated mortar bar test as

per the modified ASTM C1260 are placed in Annexure-VI.

Three representatives sand samples were sent to Geological Survey of India, Faridabad for a detailed Petrographic analysis for determination of various mineral constituents and to assess their potential for susceptibility to Alkali Aggregate Reaction. The report of Petrographic examination, submitted by Geological Survey of India, Faridabad is attached as Appendix-II.

5.0 DISCUSSION OF TEST RESULTS

5.1 Coarse Aggregate

5.1.1 Dam site

Two coarse aggregate samples designated as WHEP/DA/DRR and WHEP/DA/DRL were collected from both the drifts located near the dam area where fresh rock has been exposed after blasting. The physical and chemical test results of these quarry materials are furnished in Annexure-II. Based on the test results, the rock materials from these quarries are conforming to the specification requirements as per IS:383-1970 (Reaffirmed 1997) for use as coarse aggregate for both wearing and non-wearing surfaces in concrete.

Results of ASR test placed at Annexure-III indicate that percentage expansions of mortar bar for sample no. WHEP/DA/DRR at 14 days (i.e. 16 days after casting) & 28 days are 0.163 & 0.280, respectively. Expansion between 0.10% and 0.20% at 16 days after casting are known to be innocuous and deleterious as per ASTM C-1260. Percentage expansions of mortar bar for sample no. WHEP/DA/DRL at 14 days (i.e. 16 days after casting) was found to be 0.095. Since the expansion is less than 0.10%, the rock sample is innocuous as per ASTM C-1260.

Sample designated as WHEP/DA/DRR and WHEP/DA/DRL (redesignated as lab sample no. CA-11/36 and CA-11/37 respectively) were sent to Geological Survey of India, Faridabad for carrying out a detailed Petrographic analysis. The test results revealed that the strained quartz content varied between 44.55% and 49.5%. Since the presence of strained quartz is more than 20%, these rocks are prone to AAR and results of mortar bar test too confirm their susceptibility to undergo ASR.

5.1.2 River deposit at power house site

Three coarse aggregate samples designated as WHEP/PH/RBM-1, RBM-2 and RBM-3 was collected from this quarry. The physical and chemical test results of these riverbed materials are furnished in Annexure-II. Based on the test results, the rock quarries are conforming to the specification requirements as per IS:383-1970 (Reaffirmed 1997) for use as coarse aggregate in concrete for non-wearing surfaces only.

Results of ASR test placed at Annexure-III indicate that percentage expansions of mortar bar for sample no. WHEP/PH/RBM-2 at 14 days (i.e. 16 days after casting) & 28 days are 0.141 & 0.249 respectively. Expansion between 0.10% and 0.20% at 16 days after casting indicate innocuous and deleterious behavior as per ASTM C-1260.

Sample designated as WHEP/PH/RBM-2 (redesignated as lab sample no. CA-11/40) was sent to Geological Survey of India, Faridabad for carrying out a detailed Petrographic analysis. The test results revealed that the strained quartz content varied between 49% and 59.4%. Since the presence of strained quartz is more than 20%, these rocks are prone to AAR and the results of mortar bar test too confirm their susceptibility to undergo ASR.

Strain Quartz content and its undulatory extinction angle of the rock based on petrographic analysis is tabulated below

Sample no.	Strained quartz (%)	Undulatory extinction angle (in degree)	Name of Rock type
CA- 11/36	44.55-49.5	31-35°	Sheared/ Mylonitised quartzite
CA-11/37	≈49	31-41°	Sheared/ Mylonitised quartzite
CA- 11/40	49-59.4	28° to 36°	Sheared/ Mylonitised quartzite

Details on the petrographic analysis carried out for the above samples are furnished in the Petrography Analysis report enclosed as Appendix-II.

5.2 Fine aggregate

5.2.1 River deposit at power house site

Three fine aggregate samples designated as WHEP/PH/FA-1, FA-2 and FA-3 were collected from this quarry. The physical test results of these riverbed materials are furnished in Annexure-IV.

The physical test results indicate that the sand samples separated from the composite river bed materials collected from trial pits , fall in the grading zone II and III and their silt content were found to be less than 3%. Sand samples were found to conform to the specification requirements of IS: 383-1970 for use as fine aggregate in concrete.

Results of ASR test placed at Annexure-VI indicate that percentage expansions of mortar bar at 14 days (i.e. 16 days after casting) and 28 days are 0.125% and 0.226% for sample no. WHEP/PH/FA-1 and for sample no. WHEP/PH/FA-3, the expansions at 14 days and 28 days were found to be 0.131% and 0.229% respectively. Expansion between 0.10% and 0.20% at 16 days after casting indicate innocuous and deleterious behavior as per ASTM C-1260. Percentage expansions of mortar bar for sample no. WHEP/PH/FA2 at 14 days (i.e. 16 days after casting) is 0.091 which is less than 0.10%, hence sample is innocuous as per ASTM C-1260.

Report on Petrographic Analysis of rock and fine aggregate samples of Wangchu H E Project, Bhutan is enclosed as Appendix-II.

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Coarse Aggregate

In all, a total number of five representative rock samples (three representative samples from river boulders samples and two representative samples from rock mass) were collected from three prospective rock quarries. The above samples were tested in the laboratory for evaluation of its physical properties for assessing their suitability for use as coarse aggregate in concrete. Based on the results of Physical tests conducted on the representative rock samples collected from the above-

mentioned quarries, the suitability of different rock quarries for use as coarse aggregate in concrete to be used in concrete is indicated below:

6.1.1 Suitability of coarse aggregate for use in wearing as well as non-wearing surfaces of concrete structures.

Rock samples collected from both the drifts along the dam axis have been found to confirm their suitability for use as coarse aggregates in concrete for both wearing and non-wearing surfaces. The excavated materials from left bank rock out crop for construction of intake structures, desilting chambers and Head Race Tunnel can be a potential source for use as aggregates in concrete for both wearing and non-wearing surfaces.

6.1.2 Suitability of coarse aggregate for use in non-wearing surfaces of concrete structures only

Riverbed materials collected from the power house area have been found to be suitable for use as coarse aggregates in concrete for non-wearing surfaces only. Since ample quantity of riverbed materials are getting deposited during every monsoon, this area can be considered as a potential source of RBM for exploitation every year till the completion of the project.

6.2 Fine Aggregate

Based on the results of physical and chemical tests conducted on three sand samples collected from river bed materials, the sand pockets in the riverbed materials at power house site satisfy the requirements as given in BIS: 383-1970 and can be used as fine aggregate in concrete. In few samples, presence of deleterious materials such as silt and clay fractions has been found to be in higher side and it is suggested to wash these sand with clear water to separate silt and clay fractions from sand which otherwise would aid in reducing the strength of concrete. Fineness Modulus of few sand samples has been found to be low and falls in grading zone III. Such sand needs to be blended in appropriate proportion with coarser sand. In case of shortage natural fine aggregates, crusher sand produced from the riverbed can also be considered after meeting the specification requirements.

6.3. Conclusions and recommendations in respect of Coarse Aggregate and Fine Aggregate are tabulated below:

<table>
<tr><th>Sample No.</th><th>Suitability based on Physical tests</th><th>Suitability based on ASR/Petrographic examination</th></tr>
<tr><td colspan="3">Coarse aggregates</td></tr>
<tr><td>WHEP/DA/DRR
Dam Area</td><td rowspan="2">Suitable for use in both wearing and non-wearing surfaces</td><td rowspan="4">Presence of more than 20% strained quartz in samples poses a threat to the durability of concrete from Alkali Aggregate Reaction. Accelerated mortar bar test too confirm their susceptibility for AAR. As a remedial measure to contain unwanted expansion in concrete due to Alkali Aggregate Reaction, it is suggested that Portland Pozzalona Cement with fly ash content not less than 35% or Portland Slag Cement with slag content not less than 50% can be used in making concrete. Admixtures like silica fume/ metakaolin (8-10%) can be used in concrete to improve durability performance. In case of OPC, percentage of total alkali content (as Na_2O) by weight should be less than 0.6%.</td></tr>
<tr><td>WHEP/DA/DRL
Dam Area</td></tr>
<tr><td>WHEP/PH/RBM-1
Power House Area</td><td rowspan="3">Suitable for use in non-wearing surfaces only</td></tr>
<tr><td>WHEP/PH/RBM-2
Power House Area</td></tr>
<tr><td>WHEP/PH/RBM-3
Power House Area</td></tr>
<tr><td colspan="3">Fine aggregates</td></tr>
<tr><td>WHEP/PH/FA-1
Separated from Composite RBM</td><td rowspan="3">All the samples satisfy the requirements as given in BIS: 383-1970 and can be used as fine aggregate in concrete. In few samples, presence of deleterious materials such as silt and clay fractions have been found to be in higher side. It is therefore, suggested to wash these sand with water to separate silt and clay fractions from sand which otherwise would aid in reducing the strength of concrete. Fineness of few sand samples has been found to be very high and falls in grading zone III. Such sand needs to be blended in appropriate proportion with coarser sand.</td><td rowspan="3">Results of ASR test indicates that fine aggregate are innocuous and deleterious as per ASTM C-1260.
As a remedial measure to contain unwanted expansion in concrete due to Alkali Aggregate Reaction, it is suggested that Portland Pozzalona Cement with fly ash content not less than 35% or Portland Slag Cement with slag content not less than 50% can be used in making concrete. Admixtures like silica fume/ metakaolin (8-10%) can be used in concrete to improve durability performance. In case of OPC, percentage of total alkali content (as Na_2O) by weight should be less than 0.6%.</td></tr>
<tr><td>WHEP/PH/FA-2
Separated from Composite RBM</td></tr>
<tr><td>WHEP/PH/FA-3
Separated from Composite RBM</td></tr>
</table>

Annexure-I

Details of Rock, Riverbed Materials and Natural Sand Samples collected from the site and its adjoining areas of Wangchu Hydroelectric Project, Bhutan.

Sl.No	Description of samples	Sample designation	
		Field No.	Lab. No.
Rock Quarry and Riverbed Deposits for Coarse & Fine Aggregates			
1	Right bank drift at dam site	WHEP/DA/DRR	CA-11/36
2	Left bank drift at dam site	WHEP/DA/DRL	CA-11/37
3	River deposit at PH site (CA)	WHEP/PH/RBM-1	CA-11/39
4	River deposit at PH site (CA)	WHEP/PH/RBM-2	CA-11/40
5	River deposit at PH site (CA)	WHEP/PH/RBM-3	CA-11/41
6.	Natural Sand River deposit at PH site	WHEP/PH/FA-1	FA-11/42
7.	Natural Sand River deposit at PH site	WHEP/PH/FA-2	FA-11/43
8.	Natural Sand River deposit at PH site	WHEP/PH/FA-3	FA-11/44

Annexure – II

Test Results showing Physical Properties of Rock and River bed materials collected from different quarries for use as Coarse Aggregate in Concrete

S. No	Name of Quarry	Sample Designation		Specific Gravity	Aggregate Impact Value (%)	Aggregate Abrasion Value (%)	Aggregate Crushing Value (%)	Soundness (%)	Water Absorption (%)
		Field No.	Lab. No.						
1	Right bank drift at dam site	WHEP/DA/DRR	CA-11/36	2.64	28.75	29.60	22.00	3.0	0.6
2	Left bank drift at dam site	WHEP/DA/DRL	CA-11/37	2.64	28.87	29.40	20.88	3.0	0.5
3	River deposit at power house site (CA)	WHEP/PH/RBM-1	CA-11/39	2.65	30.31	34.40	17.25	3.0	0.7
4	River deposit at power house site (CA)	WHEP/PH/RBM-2	CA-11/40	2.63	26.69	33.00	18.13	3.5	0.7
5	River deposit at power house site (CA)	WHEP/PH/RBM-3	CA-11/41	2.64	35.00	37.40	16.00	4.0	0.5

Annexure-III

Statement showing test results of Accelerated Alkali Aggregate Reactivity Test on Coarse Aggregate samples

Testing Regime — Accelerated Method in 1 N NaOH solution at 80° C temp.

Cement used — Ordinary Portland Cement

Total alkali content of cement — 1.15 % by equivalent weight of Na_2O

Age (in days)	Percentage Expansion of Coarse Samples in %	Percentage Expansion of Coarse Samples in %	Percentage Expansion of Coarse Samples in %
Sample No.	WHEP/DA/DRR (CA-11/36)	WHEP/DA/DRL (CA-11/37)	WHEP/PH/RBM-2(CA-11/40)
0	0	0	0.000
1	0.009	0.010	0.005
2	0.014	0.015	0.017
3	0.022	0.019	0.029
4	0.032	0.024	0.041
5	0.049	0.033	0.048
6	0.057	0.041	0.055
7	0.069	0.047	0.066
8	0.085	0.063	0.080
9	0.097	0.069	0.089
10	0.112	0.074	0.098
11	0.127	0.078	0.110
12	0.138	0.083	0.120
13	0.149	0.090	0.131
14	**0.163**	**0.095**	**0.141**
15	0.171		0.149
16	0.179		0.157
17	0.187		0.167
18	0.197		0.178
19	0.208		0.191
20	0.219		0.197
21	0.233		0.201
22	0.241		0.209
23	0.249		0.214
24	0.256		0.221
25	0.263		0.227
26	0.271		0.234
27	0.277		0.242
28	**0.280**		**0.249**

Expansion criteria:

Expansion of less than 0.10% at 14 days (i.e. 16 days after casting) *is indicative of innocuous behavior.*

Expansion of more than 0.20% at 14 days (i.e. 16 days after casting) *is indicative of potentially deleterious expansion.*

Expansion between 0.10% and 0.20% at 14 days (i.e. 16 days after casting) *include both aggregates that are known to be innocuous and deleterious. However, in this situation it may also useful to take comparator reading until 28 days.*

Note: Refer ASTM C 1260 for testing procedure.
Demoulding of sample after 24 hrs (1 day)
Take Zero Reading after immersion in water after 24 hrs (1day)
Take subsequent reading after immersion in 1 N NaOH soln every 24 hours for 14 days (i.e. 16 days after casting)

Annexure-IV

Test results showing Physical Properties of Natural Sand samples collected from different Quarries for use as Fine Aggregate in Concrete

Sl.No	Name of Sand Quarry	Sample Designation Field. No.	Lab.No	Specific Gravity	Fineness Modulus	Silt & Clay Content (%)	Organic Impurities
1.	River deposit (Fine aggregate-power house site)	WHEP/PH/FA-1	FA-11/42	2.75	2.60	2.0	Passes color test
2.	River deposit (Fine aggregate-power house site)	WHEP/PH/FA-2	FA-11/43	2.73	1.96	3.0	Passes color test
3.	River deposit (Fine aggregate-power house site)	WHEP/PH/FA-3	FA-11/44	2.72	2.04	3.0	Passes color test

Annexure-V

Test results showing Gradation of Natural Sand samples collected from different Quarries for use as Fine Aggregate in Concrete

IS Sieve Designation	Percentage Passing		
	Sample No. (Lab.No)		
	FA-11/42	**FA-11/43**	**FA-11/44**
10.00 mm	100	100	100
4.75 mm	100	100	100
2.36 mm	89	96.1	94
1.18 mm	66	84.0	80.4
600 Micron	50.7	70.8	70
300 Micron	24.3	37.7	37.8
150 Micron	10.0	15.3	13.6
Fineness Modulus	**2.60**	**1.96**	**2.04**
Grading Zone	**II**	**III**	**III**

Annexure-VI

Statement showing test results of Accelerated Alkali Aggregate Reactivity Test on Fine Aggregate samples

Testing Regime — Accelerated Method in 1 N NaOH solution at 80° C temp.

Cement used — Ordinary Portland Cement

Total alkali content of cement — 1.15 % by equivalent weight of Na_2O

Age (in days)	Percentage Expansion of Fine Samples in %	Percentage Expansion of Fine Samples in %	Percentage Expansion of Fine Samples in %
Sample No.	WHEP/PH/FA-1(FA-11/42)	WHEP/PH/FA-2(FA-11/43)	WHEP/PH/FA-3(FA-11/44)
0	0.000	0.000	0.000
1	0.008	0.006	0.011
2	0.016	0.013	0.022
3	0.024	0.019	0.032
4	0.032	0.027	0.044
5	0.035	0.030	0.051
6	0.039	0.034	0.055
7	0.051	0.041	0.064
8	0.065	0.049	0.076
9	0.076	0.056	0.084
10	0.087	0.064	0.095
11	0.098	0.072	0.104
12	0.107	0.079	0.111
13	0.114	0.086	0.120
14	**0.125**	**0.091**	**0.131**
15	0.131		0.138
16	0.139		0.146
17	0.146		0.154
18	0.155		0.161
19	0.163		0.173
20	0.175		0.179
21	0.181		0.185
22	0.187		0.195
23	0.193		0.202
24	0.201		0.206
25	0.208		0.210
26	0.214		0.216
27	0.221		0.225
28	**0.226**		**0.229**

Expansion criteria:

Expansion of less than 0.10% at 16 days after casting is indicative of innocuous behavior.

Expansion of more than 0.20% at 16 days after casting is indicative of potentially deleterious expansion.

Expansion between 0.10% and 0.20% at 16 days after casting include both aggregates that are known to be innocuous and deleterious. However, in this situation it may also useful to take comparator reading until 28 days.

Note: Refer ASTM C 1260 for testing procedure.
Demoulding of sample after 24 hrs (1 day)
Take Zero Reading after immersion in water after 24 hrs (1day)
Take subsequent reading after immersion in 1 N NaOH soln every 24 hours for 14 days

Appendix-I

Field Investigation report on the visit made by CSMRS team during 9th August – 16th August, 2011 for carrying out Construction Materials Survey and collection of Coarse and Fine Aggregate samples for assessing their suitability for use in Concrete for the proposed Wangchu H.E Project, Bhutan

Team Members

Sh. N Siva Kumar, Scientist-D
Sh. U S Vidyarthi, Scientist-C
Sh. Amna Kumar, Scientist-B
Sh. P Paramasivam, Lab. Assisstant

Central Soil And Materials Research Station
Olof Palme Marg, Hauz Khas, New Delhi-110016

Field Investigation report on the visit made by CSMRS team during 9th August – 16th August, 2011 for carrying out Construction Materials Survey and collection of Coarse and Fine Aggregate samples for assessing their suitability for use in Concrete for the proposed Wangchu H.E Project, Bhutan

Wangchu hydroelectric Project in Bhutan is a run of the river scheme proposed across the river Wangchu near Silli village about 25 km upstream of Piping confluence. It is proposed to construct a 140 m high concrete gravity dam. The length of 8.5 m diameter circular shaped head race tunnel is 12.5 km and a surface power house with an installed capacity of 4 x 150 MW (600 MW) is proposed near Piping village on the left bank of Wangchu river. M/s Satluj Jal Vidyut Nigam Limited has been entrusted with the preparation of detailed project report for this project.

Discussions were held with Sh. S.P.Vidyarthi, Additional General Manager who is the Head of Project and Sh. G.S.Pundir, Manager, Geology of M/s Satluj Jal Vidyut Nigam Limited, Phuentsholing, Bhutan, with regard to locations and accessibility to various potential Rock and Natural Sand Quarry sites. It was conveyed that two potential rock quarry sites, one near the dam area and the other near power house were identified by the Geologist. The topography sheet of the area was examined and the potential quarries were located on them. It was decided to collect rock samples from both the drifts near the dam area where fresh rock have been exposed after blasting. An outcrop of quartzite rock has also been identified, 700 meter upstream of the dam, on the left bank of Wangchu river. The site was not accessible due to heavy discharge in the river. However, the project authorities have been requested to collect samples from this rock quarry during lean period and send them to CSMRS for laboratory investigations. Since the proposed length of Head race tunnel is around 12.5 km, around 7.1 lakh cubic m of muck is likely to be removed from the tunnel and 40% of the same has been suggested for using in concrete after assessing their suitability. It was also suggested that river deposit from the dam area can also be considered in case of shortfall of aggregate materials for exploitation after assessing the physical properties of material.

In the Piping power house area, located at about 25 km downstream of dam axis, large areas of river shoal deposits have been identified along both the banks of the river. The depth of deposits of shoal has been estimated around 15 m. Total area proposed to be exploited is of the order of around 2 lakh sq. m (2000 m long x 100 m wide) and approximate quantity available in the area is to the tune of 20 lakh cu. m, if 2 m depth of shoal deposit is excavated every year for 5 years, i.e. the construction period of the project. Representative composite boulder samples from three trial pits at a spacing of around 600 m covering the entire 2 km have been proposed. Since, estimation of sand fractions in the trial pits could not be taken up due to incessant rain, the project authorities have been requested to segregate the sand fraction from the boulder in the pit for determining the ratio of coarse aggregate to sand fraction. In the absence of natural sand quarries within the vicinity of the dam area, suggestions were made for using crushed rock of required grading zone in place of natural sand for concrete. Details of aggregate rock samples collected for laboratory investigations are given as below.

Dam Area:

A visit was undertaken to the dam area quarry site located near Silli village. The rock type on the left bank of the dam where HRT have been proposed is predominantly quartzite. Two drifts have been made in the dam abutment. Two representative composite samples have been collected and designated as WHEP/DA/DRL and WHEP/DA/DRR for laboratory investigations at CSMRS. Both the samples were processed to the required grading at site itself.

Power house Area:

Power house is located at about 25 km downstream of dam axis. As the approach to the site along the river was not possible, the site was reached through Bhutan Ghat which was around 100 km from Phuentsholing. Large quantities of river shoal deposits were available along the right as well as left bank of the Wangchu river. The river bed boulder samples were predominantly quartzite with some gneiss and dolomite fragments. Since left bank was not approachable, 3 trial pits of size 3 m x 3 m x 3 m were made at an interval of around 600 m on the right bank shoal deposit. Representative boulder samples from each of the trial pits were collected and designated as WHEP/PH/RBM1, WHEP/PH/RBM2 and WHEP/PH/RBM3. All the three samples were processed at site to the required grading for laboratory investigations.

The project authorities have been requested to transport the processed aggregate samples to CSMRS laboratory for assessing their suitability for use as coarse and fine aggregates in concrete.

On behalf of CSMRS, we take this opportunity to thank Sh. S.P.Vidyarthi, Additional General Manager, Sh. G.S.Pundir, Manager, Geology and his team of Engineers for extending their cooperation to our field team throughout the investigation work without which the work could not have been completed in a short period.

(N.Sivakumar) (U.S.Vidyarthi)

Scientist-D Scientist-C

Appendix-II

REPORT ON PETROGRAPHIC ANALYSIS OF ROCK AND FINE AGGREGATE SAMPLES OF WANGHCHU H.E. PROJECT, BHUTAN

PETROLOGY DIVISION
GEOLOGICAL SURVEY OF INDIA
OP: P.H. & H.P.
FARIDABAD

JULY 2012

REPORT ON PETROGRAPHIC ANALYSIS OF ROCK AND FINE AGGREGATE SAMPLES OF WANGHCHU H.E. PROJECT, BHUTAN

PETROLOGY DIVISION
GEOLOGICAL SURVEY OF INDIA
OP: P.H. & H.P.
FARIDABAD

INTRODUCTION:

This report describes the petrographic study of three coarse and three fine aggregate samples of Wangchu H.E.P., Bhutan. The samples were received from CSMRS vide letter No. 29/49/ CSMRS/2012-C-II/176 dated 22.02.2012.

The petrographic observations given hereunder solely pertain to the sample supplied by the sender and veracity of the sample and its extent of generalization to the field area may be ascertained by the collector of the sample alone.

The entire work was carried out at Petrology Laboratory, GSI, Faridabad on payment basis for a total charge of Rs. 17879/- (Rupees Seventeen Thousand Eight Hundred Seventy Nine only) including service tax.

1. SAMPLE NO. CA- 11/36

PETROGRAPHIC STUDIES

MEGASCOPIC STUDY:

The sample is milky white coloured rock. It is very hard and compact rock with small brown coloured specs on the surface of the sample. The specific gravity of the sample is medium. The only mineral identified in the hand specimen is quartz.

MICROSCOPIC STUDY:

It is a medium grained, compact rock. It consists of quartz (~99%) and muscovite around 1%. The strained quartz content is around 45-50% and the undulose extinction angle ranges between 31-35°. Crude planar fabric (schistosity) is defined in the rock by the elongate, highly strained quartz grains which may have been originally more or less equant grains left behind by after development of peripheral sub grains at preferred sites around the clasts. Strains lamellae

are very well seen in the strained quartz grains in the rock thin section. The subgrains, at places, are also elongate, subparallel to the schistosity/ foliation. Grain size reduction and formation of new grains are also observed at some places.

Rock type: Sheared/ Mylonitised quartzite

2. SAMPLE NO. CA-11/37

Megascopic study:

The sample is a milky white medium grained massive, hard and compact rock. It has medium specific gravity. The mineral identified in the hand specimen is quartz with very small amount of mica.

Microscopic study:

It is a fine grained, compact rock. The mineralogical content of the rock is quartz (~98%) and muscovite (~2%). The content of strained quartz in the sample is around 50% with the undulose extinction of the strained quartz varying between 31° to 41°. The mica flakes are swerve around the bigger grains of quartz. Most of the bigger quartz grains show strain effect which is shown by development of strain lamellae and undulose extinction. The bigger quartz grains seem to float in the finer quartz grain matrix. The bigger quartz grains have sutured grain boundaries with the subgrains. At places the quartz grain boundaries are diffused. Grain size reduction and grain growth are also observed in the quartz grains at some places.

Rock type: Sheared/ Mylonitised quartzite

3. SAMPLE NO. CA- 11/40

MEGASCOPIC STUDY:

This sample is similar to the sample no. CA- 11/37. It is hard, compact and massive in character. It is medium grained rock with medium specific gravity. A 6cm brown coloured banding is present in one end of the sample. Minerals which could be identified in the hand specimen is quartz.

MICROSCOPIC STUDY:

It is a fine grained, compact rock. It mainly consists of quartz which constitute around 98-99% and the rest is muscovite which varies from 1-2%. The percentage of strained quartz is about 50-60% and the undulose extinction angle of the strained quartz varies between 28° to 36°. Planar fabric (foliation/schistosity) is developed in the rock along which the bigger stretched/

elongated quartz grains and very thin muscovite flakes are oriented. The finer quartz grains are also showing preferred orientation and are parallel/ sub parallel to the foliation/schistosity. Sutured grain boundaries are present between the quartz grains. At places the quartz grain boundaries are diffused and at other places curvilinear quartz grain boundaries are observed. Grain size reduction and grain growth are observed in the quartz grains at some places. Some quartz grains have very well developed strain lamellae which reflect that the rock has undergone deformation and these grains also show undulose extinction.

Rock type: Sheared / Mylonitised quartzite

4. SAMPLE NO. FA- 42

MEGASCOPIC STUDY:

The sample is light grey coloured sandy sediment with lots of pebble to gravel sized fragments which are angular to sub angular in shape. The sand is coarse to fine grained. The pebbles/gravels include the rock fragments of phyllite, sandstone, quartzite and vein quartz. In the sand sized fraction, quartz muscovite and biotite are identified. This is a poorly sorted sample.

MICROSCOPIC STUDY:

The sample contains quartz (~ 88%), feldspar (~5%), mica (~4%, both biotite and muscovite) and lithic fragments (~3%). The microscopic examination of the sediment sample has shown that the sample consists of angular to sub angular quartz grains which are the dominant mineral phase. Polycrystalline quartz grains are present in the fine aggregate sample. The feldspar grains occur as both twinned and un twinned grains. In the feldspar grains lamellar twinning is observed. The biotite flakes are pleochroic in brown. The muscovite flakes show high second order interference colour. Some quartz grains show undulatory extinction. Rock fragments of schist and quartzite are also present in the sample. Preferred orientation is observed in the schist fragments.

Rock type: Loose sandy sediment

5. SAMPLE NO. FA- 43

MEGASCOPIC STUDY:

It is a sample of light grey coloured sandy sediment with lots of granule/pebbles of various rock fragments which are angular in shape. The pebbles in the sample include quartzite, schists and vein quartz. The sand is coarse to fine grained. In the sand sized fraction,

quartz feldspar and lots of muscovite is identified. It is a ill sorted sample.

MICROSCOPIC STUDY:

This sample consists of quartz (~ 82%), feldspar (~6%), muscovite and biotite (~5%) and lithic fragments (~7%). The grains are mostly angular with a few sub rounded grains. The quartz grains are generally angular with some grains having very sharp edges. Polycrystalline quartz grains are also present. Some quartz grains show undulose extinction. The muscovite and biotite occur as flakes in the sample. Muscovite occurs as more stubby flakes with little or no pleochroism and higher interference colour. The feldspar grains show lamellar twinning and they also occur as untwinned grains. Lithic fragments of quartzite or schist are partially weathered.

Rock type: Loose sandy sediment

6. SAMPLE NO. FA- 44

MEGASCOPIC STUDY:

This sample is light grey coloured sand sample with granules/pebbles of rock fragments which are angular to sub rounded. The sand is medium to fine grained. The granules/ pebbles consist of fragments of phyllite, quartzite, schists and vein quartz. In the sand sized fraction, quartz and mica is identified. This is a moderately sorted sand sample.

MICROSCOPIC STUDY:

The mineralogical content of the fine aggregate sample is quartz (~83 %), biotite and muscovite (~ 5 %), feldspar (~ 4 %) and lithic fragments (~ 8 %). The grains are angular to sub angular in shape. The quartz grains are mostly angular with a few sub rounded grains. Some bigger quartz grains are broken which has led to development of very sharp edged longer grains. Some grains also exhibit undulose extinction which could not be measured due to the unnatural orientation of these grains. Polycrystalline quartz is present. The feldspar grains are mostly angular and some show very well developed lamellar / cross hatched twinning. Quartz rich lithic fragments are present which may be of metamorphic origin. Mica occurs as thin and small flakes and both biotite and muscovite are present. A few hornblende grains which are pleochroic in light green to dark green are also present in the sample.

Rock type: Loose sandy sediment

PHOTOMICROGRAPHS

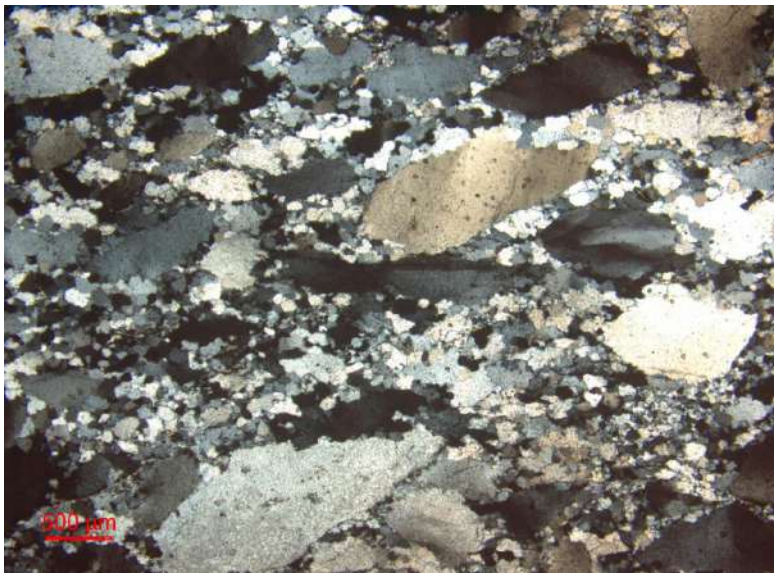


Photo 1. Crude foliation/ schistosity in the rock shown by stretched quartz grains. Some of the grains also showing marked undulose extinction.
Sample No. CA-11/36 XPL

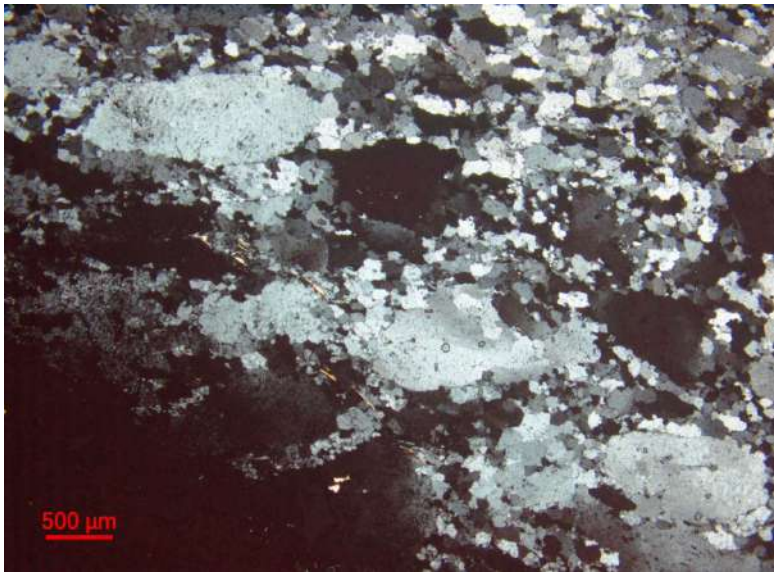


Photo 2. Stretched quartz clasts in finer grained quartz grain matrix in the sample.
Sample No. CA-11/36 XPL

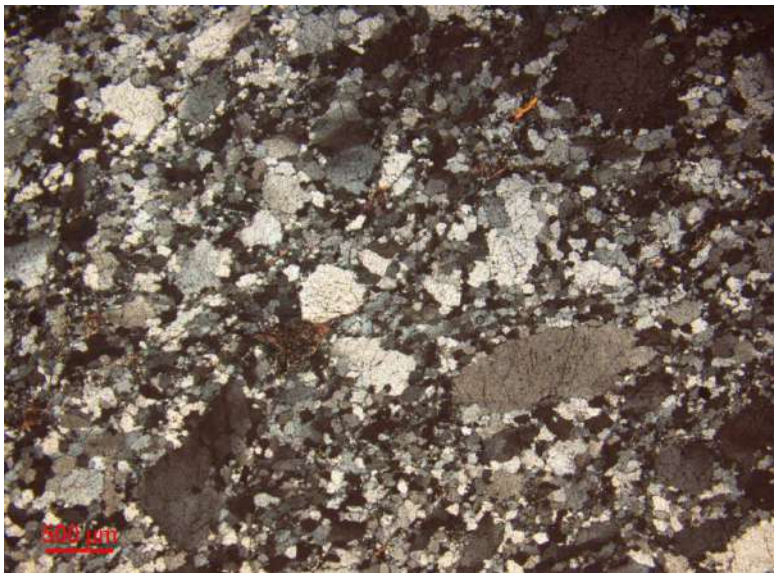


Photo 3. Quartz clasts appear to float in the matrix of quartz sub grains.

Sample No. CA-11/37 XPL

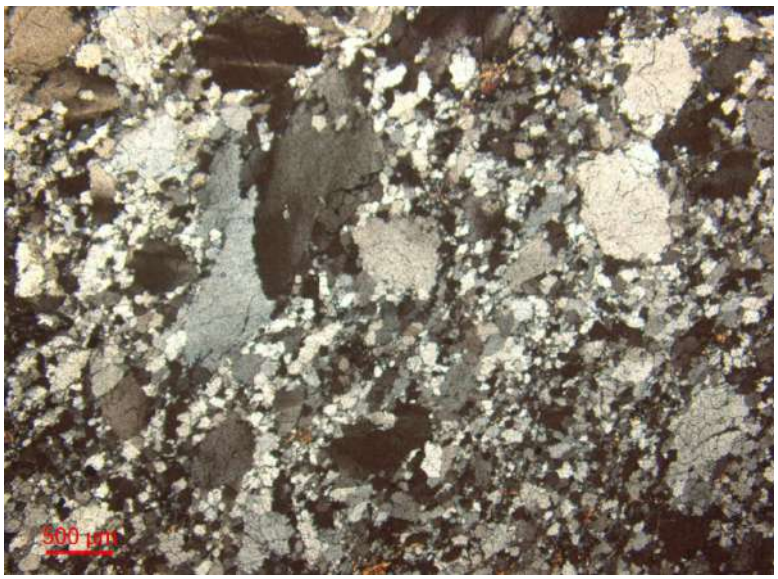


Photo 4. Elongated strained quartz grains defining foliation showing undulose extinction.

Sample No. CA-11/37 XPL

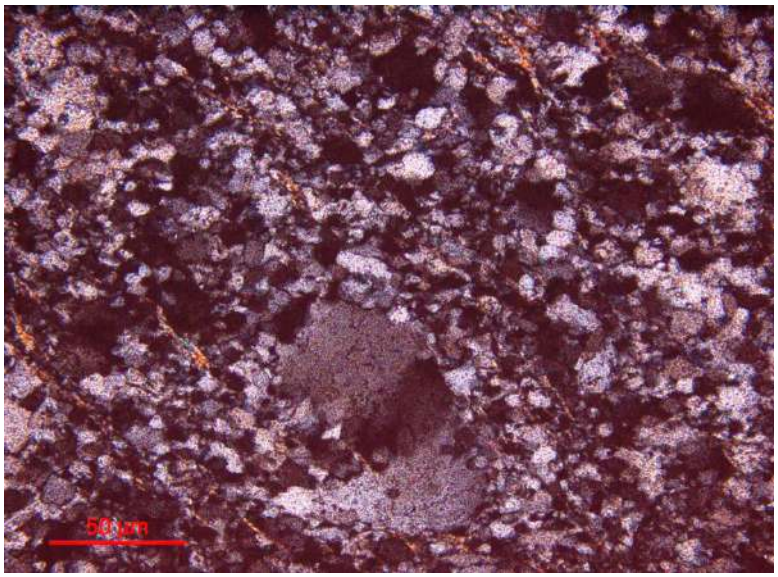


Photo 5. A big clast of quartz in fine grained quartz matrix. Crude foliation is defined by the mica flakes in the rock.
Sample No. CA-11/40 XPL

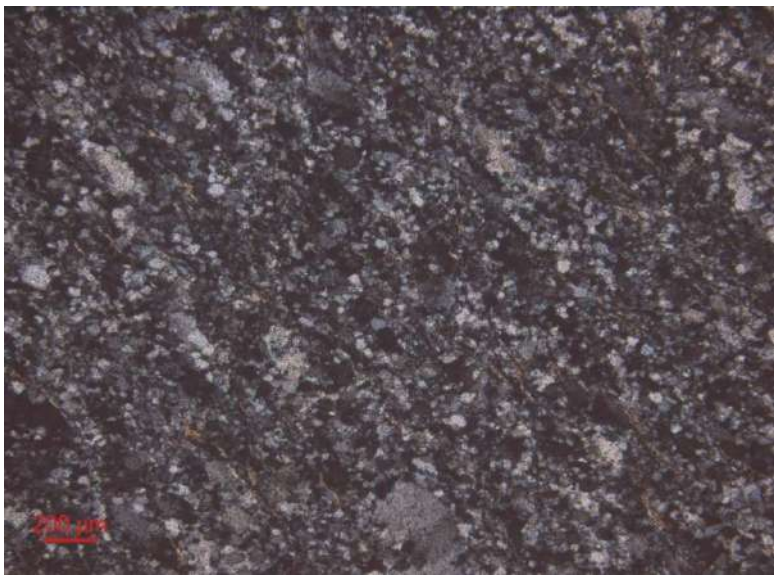


Photo 6. Foliation in the rock is defined by elongated quartz grains and mica flakes.
Sample No. CA-11/40 XPL

Photo 7. The angular quartz grain and a feldspar grain showing lamellar twinning. Also note the lithic fragment in the left side of the photograph.
Sample No. FA-42 XPL

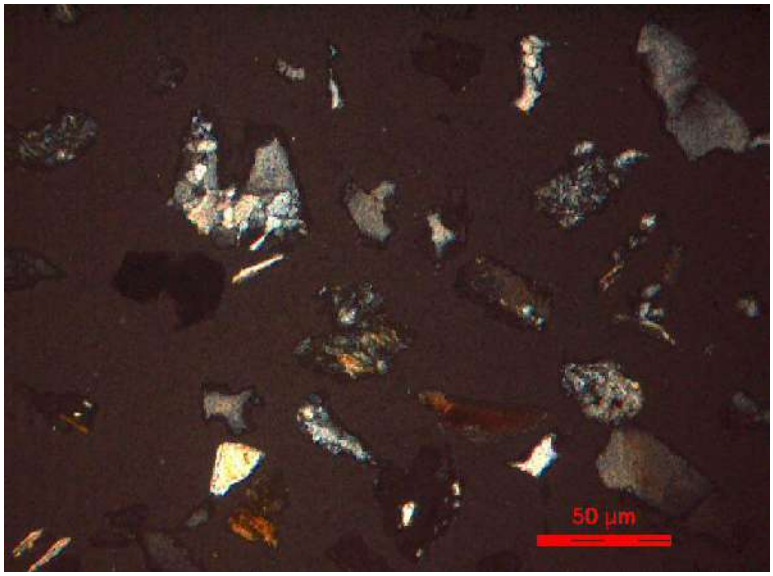


Photo 8. Various lithic fragments in the sample
Sample No. FA-42 XPL

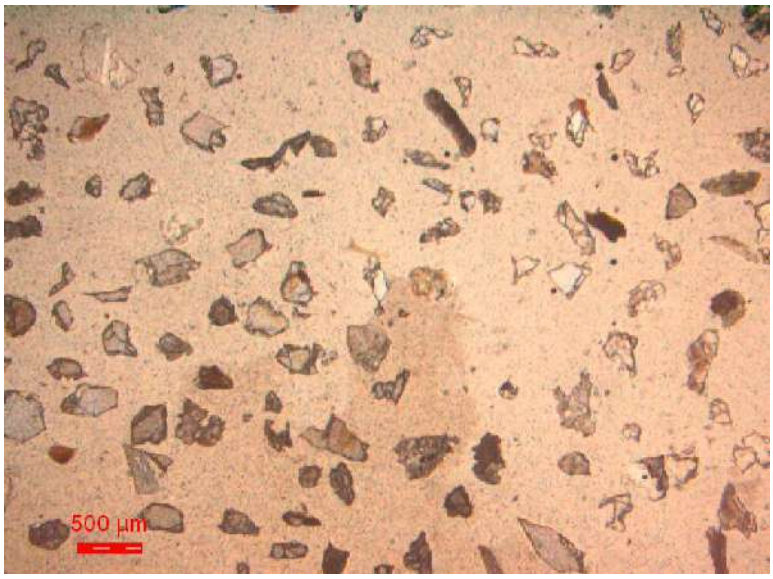


Photo 9. The angular to sub angular shape of the grains.

Sample No. FA-43 PPL

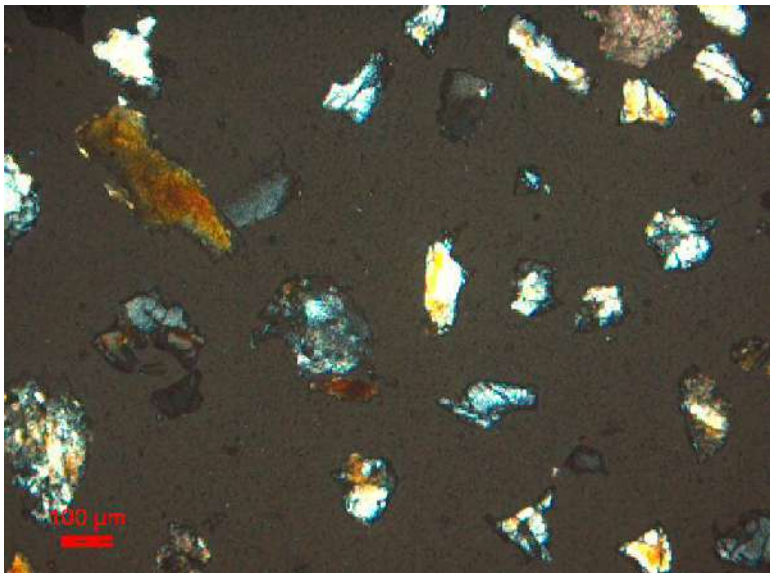


Photo 10. Sub angular lithic fragments and the angular quartz grains.

Sample No. FA-43 XPL

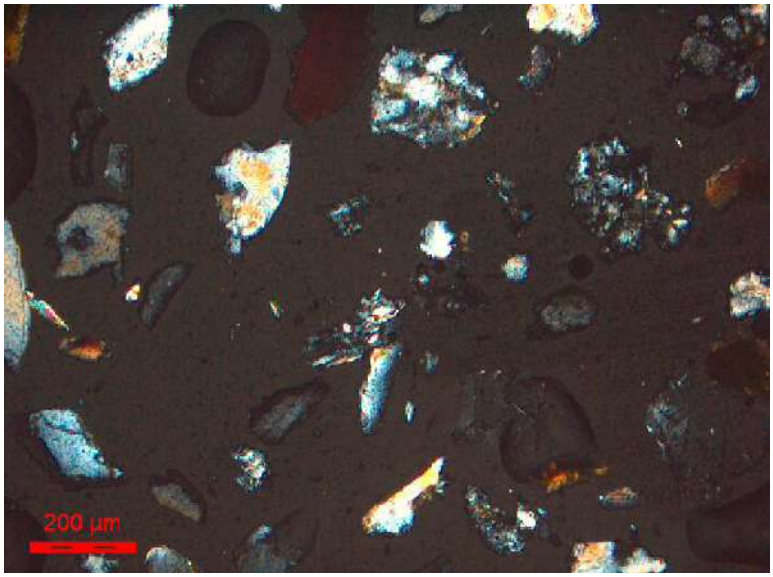


Photo 11. Polycrystalline quartz grain at the centre top position of the photograph. Other lithic fragments and quartz grains also present.
Sample No. FA-44 XPL

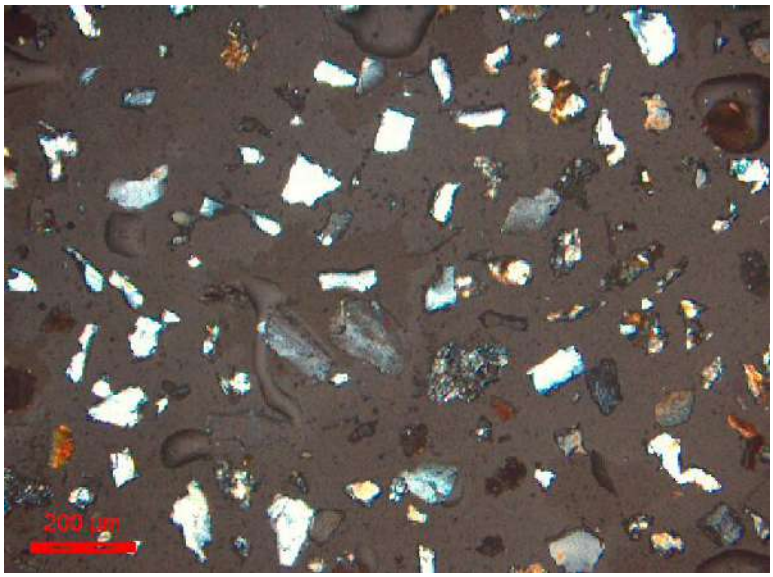


Photo 12. The angular quartz dominated sample. A lithic fragment in the centre of the photograph.
Sample No. FA-44 XPL

ANNEXURE-IX

INTERIM REPORT ON LABORATORY INVESTIGATION OF ROCK AND SAND SAMPLES

SJVN LIMITED
(A Joint Venture of Govt. of India & Govt. of H.P.)
A Mini Ratna & Schedule 'A' PSU

Ref No. SJVN/BD&MS/EG/2014-250-54 Dated: 28.02.2014

Director (CSMRS),
Central Soil & Materials Research Station,
Olf Palme Marg, Hauz Khas,
New Delhi-62

Subject: Detailed Project Report (DPR) of Wangchu HEP (570 MW), Bhutan.

Sir,
This is in reference to CSMRS letter No. 29/36/Compl. Wangchhu/RM-1/CSMRS/2012/306 dated 17.10.2013 vide which it was advised to get testing of rock samples from quarry No.4 and Rock quarry on left bank of river Wangchhu, 700 m u/s of dam axis.
Coarse Aggregates: In this context it is submitted that samples from rock quarry No. 4 have got been conducted from CSMRS and the material have been found to be suitable for wearing as well as Non Wearing surfaces and also acceptable based on ASR as per CSMRS report enclosed herewith. It has been advised to use PPC containing not less than 25% fly ash or PSC containing not less than 50% slag by weight and the same shall be complied during construction.
Fine Aggregates: in this context the requisite sample have got been tested from CSMRS (Report enclosed) and advice for washing of fine aggregate and use of PPC/PSC with required quantity of fly ash and slag shall be complied as suggested in the report.
The quantity of wearing surface aggregate as worked out by TCD, CEA (copy of letter enclosed) inclusive of 38% wastage comes out to be 4,10,197 cubic-meter and the same is available from Dam Area and Quarry No. 4. Regarding testing of rock samples from quarry on left bank of river Wangchhu, 700 m u/s of dam axis is concerned, it is submitted that the site is still inaccessible and samples will be sent subsequently during pre-construction stage.

In view of the above it is hereby requested that necessary clearance may please be accorded.

Yours Faithfully,

28.02.14

(S P Bansal)
DGM (Expediting Group), BD&MS, SJVN Ltd.
C/o Bhanot House, 205-206, Yusuf Sarai,
New Delhi

...ology), SJVN Ltd. 8435 3/3/14 New Shimla

CC: For kind information please:
Director (PAC), CEA
Director (HPA), CEA
Director (PA-S), CWC

Received by hand from Sh. Lalit Verma AGM (FP) on 3/3/2014.

3/3/2014

Registered & Corporate Office: Himfed Building, New Shimla-171009, H.P.
BD&MS Office: C-4, IRCON Building, Ground Floor, District Centre, Saket, New Delhi – 110 017.
Tel.: 011-41659207, EPABX: 011 – 41659210, Fax: 011- 41659204

SJVN LIMITED
(A Joint Venture of Govt. of India & Govt. of H.P.)
A Mini Ratna & Schedule 'A' PSU

NOO: For information please:

ED (BD&MS), SJVN, New Delhi
GM (Geology), SJVN, Shimla
GM (Civil Design), SJVN, Shimla
HOP (WHEP), Bhutan

The letter has been finalized in consultation with the Design Foreign Projects.

Registered & Corporate Office: Himfed Building, New Shimla-171009, H.P.
BD&MS Office: C-4, IRCON Building, Ground Floor, District Centre, Saket, New Delhi – 110 017.
Tel.: 011-41659207, EPABX: 011 – 41659210, Fax: 011- 41659204

सत्यमेव जयते

केंद्रीय मृदा एवं सामग्री अनुसंधानशाला, नई दिल्ली

CENTRAL SOIL AND MATERIALS RESEARCH STATION

Report No. 03/SSC/CSMRS/E/02/2014

INTERIM REPORT ON LABORATORY INVESTIGATIONS OF ROCK AND SAND SAMPLES FOR USE AS COARSE AGGREGATE AND FINE AGGREGATE IN CONCRETE FOR WANGCHU HYDRO ELECTRIC PROJECT, BHUTAN

February, 2014

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DIRECTOR

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Team deputed for Field Investigation Work

Samples collected by project officials

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INTERIM REPORT ON LABORATORY INVESTIGATIONS OF ROCK AND SAND SAMPLES FOR USE AS COARSE AGGREGATE AND FINE AGGREGATE IN CONCRETE FOR WANGCHU HYDRO ELECTRIC PROJECT, BHUTAN

1.0 INTRODUCTION

The Manager (Geology), Wangchu H.E. Project, Bhutan had requested CSMRS vide his letter no. Geo /SJVNL/WHEP/11-221-30 dated the 2nd May, 2011 to take up the work of Construction Materials Survey and Laboratory Investigations of Rock and Natural Riverbed materials for assessing their suitability for use as coarse aggregate and fine aggregate respectively in concrete for the proposed Wangchu H.E.Project, Bhutan. Subsequently CSMRS submitted Report No. 5/C-II/CSMRS/G/2012 titled "REPORT ON THE CONSTRUCTION MATERIALS SURVEY AND LABORATORY INVESTIGATIONS OF ROCK AND SAND SAMPLES FOR USE AS COARSE AGGREGATE AND FINE AGGREGATE IN CONCRETE FOR WANGCHU HYDRO ELECTRIC PROJECT, BHUTAN" to the project authority vide this office letter no. No. 29/49/CSMRS/2010/C-II dated January 7, 2013. General Manager (Bhutan Projects), SJVNL vide office letter no. SJVN/WHEP/Geo/2013-1041-42 dated December13, 2013 has further requested CSMRS to carry out some additional tests on previous samples in addition to three fresh samples of coarse aggregate from quarry no. 4. Due to paucity of time samples has been collected by project official itself. Since report of petrogaphic analysis from GSI and result of one test of ASR with OPC is still awaited, for the time being an interim report is being submitted. The final report shall be submitted after getting petrographic analysis report from GSI and completion of one test of ASR.

2.0 SALIENT FEATURES OF THE PROJECT(provided by project authority)

The scheme consists of construction of a 140 m high concrete gravity dam across the river Wangchu near Silli village about 25 km upstream of Piping confluence. The length of HRT is 12.5 km and the diameter of circular shaped head race tunnel is 8.5 m. A surface powerhouse with an installed capacity of 4 x 150 MW (600 MW) is proposed near Piping village on the left bank of Wangchu river. M/s SJVNL has been entrusted with the preparation of Detailed Project Report (DPR) for this project.

3.0 FIELD INVESTIGATION

Samples have been collected by the project officials and have been delivered at CSMRS for testing. Results are valid only for the samples supplied.

3.1 Coarse Aggregate

In all, a total number of 7 representative rock samples (3 representative samples from river shoal deposits and 4 representative samples from rock quarry) have been supplied to CSMRS which is supposed to represent three prospective rock quarries. The project authorities are responsible for representative nature of samples. The details of rock samples/RBM collected from different prospective rock quarries are furnished in Annexure-I. **Three coarse aggregate samples have been collected from quarry no. 4 but exact location has not been mentioned.**

3.2 Fine Aggregate

In all, a total number of 3 representative fine aggregate samples collected from river shoal deposits have been supplied to CSMRS which is supposed to represent aggregate quarry only. The project authorities are responsible for representative nature of samples. The details of fine aggregate samples collected from prospective sand quarry are also furnished in Annexure-I.

4.0 LABORATORY INVESTIGATIONS

4.1 Coarse Aggregate

The following physical and chemical tests were conducted on the 3 nos. representative rock samples from quarry no. 4 as per IS: 2386-1963 (Reaffirmed 1997) and their suitability for use as coarse aggregate in concrete for both wearing as well as non-wearing surfaces was assessed as per IS: 383-1970 (Reaffirmed 1997).

- Specific gravity
- Water absorption
- Soundness (5 cycles with Na_2SO_4)
- Aggregate impact value
- Aggregate crushing value
- Aggregate abrasion value (Los Angeles)
- Mica Content (crushed sand)

- Petrographic analysis

Physical and chemical tests for other coarse aggregate samples have not been carried out this time as report on the same has already been submitted to the project authority in January 2013. The results of physical and chemical tests of coarse aggregate samples from quarry no. 4 are presented in Annexure-II. The results of ASR in respect of all five samples by accelerated mortar bar test as per ASTM 1567 with PPC and PSC are placed in Annexure-III and IV, respectively.

One representative rock samples which form a part of the identified rock quarry no.4 were sent to Geological Survey of India, Faridabad for a detailed Petrographic analysis for determination of various mineral constituents and to assess their potential in Alkali Aggregate Reaction. The report of Petrographic analysis by Geological Survey of India, Faridabad is still awaited.

4.2 Fine Aggregate

The physical and chemical tests were conducted on the representative sand samples as per IS: 2386-1963(Reaffirmed 1997) and report on their suitability for use as Fine aggregate in concrete as per IS: 383-1970 (Reaffirmed 1997) and ASTM C 1260 was submitted earlier to project authority in January 2013. However on request of project authority the following special tests has been conducted:

- ASR with PPC and PSC as per ASTM C 1567
- Mica content

The results of ASR with PPC and PSC as per ASTM C 1567 are presented in Annexure-V and VI, respectively. The results of mica content test are presented in Annexure-VII.

5.0 DISCUSSION OF TEST RESULTS

5.1 Coarse Aggregate

Two coarse aggregate samples collected from both the drifts located near the dam area were found conforming to the specification requirements as per IS:383-1970 (Reaffirmed 1997) for use as coarse aggregate for both wearing and non-wearing surfaces in concrete, however coarse

aggregate samples collected from river shoal deposits near power house were found conforming to the specification requirements as per IS:383-1970 (Reaffirmed 1997) for use as coarse aggregate for non-wearing surfaces only in concrete as per CSMRS report submitted in January 2013.

In the fresh lot of coarse aggregate samples provided from quarry no. 4, samples from loc. 1 & 3 were found conforming to the specification requirements as per IS:383-1970 (Reaffirmed 1997) for use as coarse aggregate for both wearing and non-wearing surfaces in concrete, however coarse aggregate samples collected from loc. 2 were found conforming to the specification requirements as per IS:383-1970 (Reaffirmed 1997) for use as coarse aggregate in concrete for non-wearing surfaces only. **Since there is a lot of variation in the physical behavior in the three samples from quarry no. 4 therefore project authority is requested to provide exact location of the three locations.**

Results of ASR test placed at Annexure-III and IV indicate that percentage expansions of mortar bar for all the coarse aggregate samples are less than 0.10% at 14 days (i.e. 16 days after casting), the rock sample shows innocuous behaviorwith PPC and PSC as per ASTM C-1565, however most of these samples were found innocuous and deleterious with OPC as per ASTM C-1260.

5.2 Fine aggregate

The physical test results of these riverbed materials were furnished in CSMRS report submitted to project authority in January 2013. The physical test results indicate that the sand samples fall in the grading zone II and III and their silt content were found to be less than 3%. Sand samples were found to conform to the specification requirements of IS: 383-1970 for use as fine aggregate in concrete.

Results of ASR test placed at Annexure-V and VI, indicate that percentage expansions of mortar bar at 14 days (i.e. 16 days after casting) are less than 0.10%, hence all the fine aggregate samples are innocuous with PPC and PSC as per ASTM 1567.

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Coarse Aggregate

In all, a total number of seven representative rock samples (three representative samples

from river boulders samples and four representative samples from rock mass) were collected from three prospective rock quarries by the project authority. The above samples were tested in the laboratory for evaluation of its physical properties for assessing their suitability for use as coarse aggregate in concrete. Based on the results of physical tests conducted on the representative rock samples collected from the above mentioned quarries, the suitability of different rock quarries for use as coarse aggregate in concrete to be used in concrete is indicated below:

6.1.1 Suitability of coarse aggregate for use in wearing as well as non-wearing surfaces of concrete structures.

Dam axis area: Rock samples collected from both the drifts along the dam axis have been found to conform their suitability for use as coarse aggregates in concrete for both wearing and non-wearing surfaces. The excavated materials found from excavation of intake structures, desilting chambers and Head Race Tunnel can be a potential source for use as aggregates in concrete for both wearing and non-wearing surfaces.

Quarry no. 4: Rock samples collected from quarry no.4(loc.1 and loc. 3) have been found to confirm their suitability for use as coarse aggregates in concrete for both wearing and non-wearing surfaces.

6.1.2 Suitability of coarse aggregate for use in non-wearing surfaces of concrete structures only

River shoal deposit materials collected from the power house area have been found to be suitable for use as coarse aggregates in concrete for non-wearing surfaces only. Since ample quantity of riverbed materials are getting deposited during every monsoon, this area can be considered as a potential source of RBM for exploitation every year till the completion of the project. In addition to above sample collected from loc. 2 of quarry no. 4 has also been found to be suitable for use as coarse aggregates in concrete for non-wearing surfaces only.

6.2 Fine Aggregate

Based on the results of physical and chemical tests conducted on three sand samples collected from river bed materials, the sand pockets in the riverbed materials at power house site satisfy the requirements as given in BIS: 383-1970 and can be used as fine

aggregate in concrete. In few samples, presence of deleterious materials such as silt and clay fractions has been found to be in higher side and it is suggested to wash these sand with clear water to separate silt and clay fractions from sand which may reduce the compressive strength of concrete. Fineness Modulus of few sand samples has been found to be low and falls in grading zone III. Such sand needs to be blended in appropriate proportion with coarser sand. In case of shortage of natural fine aggregates, crusher sand produced from the riverbed can also be considered after meeting the specification requirements. Presence of mica content in these natural sand samples varies from 6 to 8.3%. IS : 383 1970 does not specify upper limit of mica content but a cautionary note is added. Even one to two percent of mica may adversely affect the properties of concrete. Generally more than 5 % of mica content is not advisable to be used in concrete as it reduces strength of concrete and increases water demand, significantly. Thus it is necessary to carry out trial mixes with such sand and adjust the mix proportions so as to result in satisfactory compressive strength, adequate workability and permeability of concrete. Therefore good quality control is necessary at the time of construction.

6.3. Conclusions and recommendations in respect of Coarse Aggregate and Fine Aggregate are tabulated below:

Sample No.	Suitability based on Physical tests	Suitability based on ASR
Coarse aggregates		
Dam Area WHEP/DA/DRR & WHEP/DA/DRL	**Suitable for use in both wearing and non-wearing surfaces**	Accelerated mortar bar test with OPC as per ASTM C1260 confirm their susceptibility for AAR, however in accelerated mortar bar test with PPC and PSC as per ASTM 1567, these coarse aggregate samples were found to exibit innocuous behaviour. Pozolana content in PPC and PSC were not given. It is therefore, advised to use PPC containing not less than 25% fly ash or PSC containing not less than 50% slag by weight to avoid ASR cracks and to improve durability performance
Quarry no. 4 WHEP/PH/Left Bank-Trititar(loc. 1) WHEP/PH/Left Bank-Trititar(loc. 3)		

Power House Area WHEP/PH/RBM-1 WHEP/PH/RBM-2 WHEP/PH/RBM-3	**Suitable for use in non-wearing surfaces only**	of concrete.
Quarry no. 4 WHEP/PH/Left Bank-Trititar(loc. 2)		
Fine aggregates		
Power House Area (Separated from Composite RBM) WHEP/PH/FA-1 WHEP/PH/FA-2 WHEP/PH/FA-3	All the samples satisfy the requirements as given in BIS: 383-1970 and can be used as fine aggregate in concrete. In few samples, presence of deleterious materials such as silt and clay fractions have been found to be in higher side. It is therefore, suggested to wash these sand with water to separate silt and clay fractions from sand which otherwise would aid in reducing the strength of concrete. Fineness of few sand samples has been found to be very high and falls in grading zone III. Such sand needs to be blended in appropriate proportion with coarser sand.	Accelerated mortar bar test with OPC as per ASTM C1260 confirm their susceptibility for AAR, however in accelerated mortar bar test with PPC and PSC as per ASTM 1567, these fine aggregate samples were found to exibit innocuous behaviour. Pozolana content in PPC and PSC were not given. It is therefore, advised to use PPC containing not less than 25% fly ash or PSC containing not less than 50% slag by weight to avoid ASR cracks and to improve durability performance of concrete.

Annexure-I

Details of Rock, Riverbed Materials and Natural Sand Samples collected from the site and its adjoining areas of Wangchu Hydroelectric Project, Bhutan.

Sl.No	Description of samples	Sample designation	
		Field No.	Lab. No.
Rock Quarry and Riverbed Deposits for Coarse & Fine Aggregates			
1	Rock sample (Coarse aggregate)-Power House Site(Quarry No. 4)	WHEP/PH/Left Bank-Trititar(loc. 1)	CA-14/01
2	Rock sample (Coarse aggregate)-left bank of Wangchu river near Trititar(Quarry No. 4)	WHEP/PH/Left Bank-Trititar(loc. 2)	CA-14/15
3	Rock sample (Coarse aggregate)-Power House Site(Quarry No. 4)	WHEP/PH/Left Bank-Trititar(loc. 3)	CA-14/16
4	Mixed samples of right and left bank drifts at dam site	WHEP-Right/Left bank	CA-14/02
5	Shoal deposit (coarse aggregate)-Power House site	WHEP/PH/CA-4(pit -1)	CA-14/03
6	Shoal deposit (coarse aggregate)-Power House site	WHEP/PH/CA-5(pit -2)	CA-14/04
7	Shoal deposit (coarse aggregate)-Power House site	WHEP/PH/CA-6(pit -3)	CA-14/05
8	Shoal deposit (Fine aggregate)-Power House site	WHEP/PH/FA-4(pit -1)	FA-14/06
9	Shoal deposit (Fine aggregate)-Power House site	WHEP/PH/FA-5(pit -2)	FA-14/07
10	Shoal deposit (Fine aggregate)-Power House site	WHEP/PH/FA-6(pit -3)	FA-14/08

Annexure – II

Central Soil and Materials Research Station
Wangchu Hydroelectric Project, Bhutan

Test Results showing Physical Properties of Rock and River bed materials collected from different quarries for use as Coarse Aggregate in Concrete

S. No	Name of Quarry	Sample Designation		Specific Gravity	Aggregate Impact Value (%)	Aggregate Abrasion Value (%)	Aggregate Crushing Value (%)	Soundness (%)	Water Absorption (%)
		Field No.	Lab. No.						
1	Quarry No. 4	WHEP/PH/Left Bank-Trititar	CA-14/01	2.59	19.72	28.95	19.88	2.0	0.4
2	Quarry No. 4	WHEP/PH/Left Bank-Trititar	CA-14/15	2.62	27.79	34.05	23.08	1.7	0.4
3	Quarry No. 4	WHEP/PH/Left Bank-Trititar	CA-14/16	2.57	22.1	25.9	20.68	2.3	0.4

Annexure-III

Central Soil and Materials Research Station
Wangchu Hydroelectric Project, Bhutan

Statement showing test results of Accelerated Alkali Aggregate Reactivity Test on Coarse Aggregate samples

Testing Regime — Accelerated Method in 1 N NaOH solution at 80 deg temp

Cement used — PPC

Age (in days)	Percentage Expansion of Samples				
Sample No →	*CA-14/01*	*CA-14/02*	*CA-14/03*	*CA-14/04*	*CA-14/05*
INITIAL	*0*	*0*	*0*	*0*	*0*
1	*0.003*	*0.006*	*0.001*	*0.007*	*0.002*
2	*0.005*	*0.006*	*0.002*	*0.014*	*0.003*
3	*0.007*	*0.009*	*0.004*	*0.017*	*0.009*
4	*0.009*	*0.012*	*0.006*	*0.019*	*0.013*
5	*0.012*	*0.015*	*0.007*	*0.023*	*0.016*
6	*0.015*	*0.018*	*0.01*	*0.025*	*0.019*
7	*0.017*	*0.022*	*0.013*	*0.029*	*0.021*
8	*0.02*	*0.025*	*0.017*	*0.033*	*0.024*
9	*0.023*	*0.029*	*0.019*	*0.035*	*0.027*
10	*0.026*	*0.032*	*0.02*	*0.038*	*0.031*
11	*0.031*	*0.034*	*0.023*	*0.04*	*0.035*
12	*0.034*	*0.036*	*0.025*	*0.042*	*0.038*
13	*0.037*	*0.041*	*0.027*	*0.045*	*0.041*
14	***0.04***	***0.046***	***0.029***	***0.05***	***0.046***

xpansion criteria:

Expansion of less than 0.10% at 14 days (i.e. 16 days after casting) *is indicative of innocuous behavior.*
Expansion of more than 0.20% at 14 days (i.e. 16 days after casting) *is indicative of potentially deleterious expansion.*
Expansion between 0.10% and 0.20% at 14 days (i.e. 16 days after casting) *include both aggregates that are known to be innocuous and deleterious. However, in this situation it may also useful to take comparator reading until 28 days.*

ote: Refer ASTM C 1567 for testing procedure.
Demoulding of sample after 24 hrs (1 day)
Take Zero Reading after immersion in water after 24 hrs (1day)
Take subsequent reading after immersion in 1 N NaOH soln. every 24 hours for 14 days (i.e. 16 days after casting)

Annexure-IV

Central Soil and Materials Research Station
Wangchu Hydroelectric Project, Bhutan

Statement showing test results of Accelerated Alkali Aggregate Reactivity Test on Coarse Aggregate samples

Testing Regime — Accelerated Method in 1 N NaOH solution at 80 deg temp
Cement used — PSC

Age (in days)	Percentage Expansion of Samples				
Sample No →	*CA-14/01*	CA-14/02	CA-14/03	*CA-14/04*	*CA-14/05*
INITIAL	0	0	0	0	0
1	0.007	0.01	0.007	0.007	0.006
2	0.014	0.022	0.014	0.014	0.012
3	0.019	0.026	0.02	0.022	0.018
4	0.026	0.03	0.027	0.029	0.025
5	0.033	0.034	0.033	0.038	0.031
6	0.037	0.037	0.04	0.045	0.037
7	0.042	0.039	0.047	0.046	0.042
8	0.046	0.042	0.05	0.048	0.047
9	0.051	0.044	0.057	0.155	0.053
10	0.057	0.049	0.061	0.32	0.056
11	0.062	0.053	0.066	0.058	0.059
12	0.064	0.056	0.069	0.865	0.062
13	0.065	0.058	0.072	0.067	0.068
14	**0.067**	**0.061**	**0.074**	**0.07**	**0.074**

Expansion criteria:

Expansion of less than 0.10% at 14 days (i.e. 16 days after casting) *is indicative of innocuous behavior.*
Expansion of more than 0.20% at 14 days (i.e. 16 days after casting) *is indicative of potentially deleterious expansion.*
Expansion between 0.10% and 0.20% at 14 days (i.e. 16 days after casting) *include both aggregates that are known to be innocuous and deleterious. However, in this situation it may also useful to take comparator reading until 28 days.*

Note: Refer ASTM C 1567 for testing procedure.
Demoulding of sample after 24 hrs (1 day)
Take Zero Reading after immersion in water after 24 hrs (1day)
Take subsequent reading after immersion in 1 N NaOH soln every 24 hours for 14 days (i.e. 16 days after casting)

Annexure-V

Central Soil and Materials Research Station
Wangchu Hydroelectric Project, Bhutan

tatement showing test results of Accelerated Alkali Aggregate Reactivity Test on Fine Aggregate samples

ting Regime — Accelerated Method in 1 N NaOH solution at 80 deg temp
nent used — PPC

Age (in days)	Percentage Expansion of Samples		
ıple No →	*FA-14/06*	*FA-14/07*	*FA-14/08*
NITIAL	*0*	*0*	*0*
1	*0.002*	*0.005*	*0.007*
2	*0.004*	*0.01*	*0.013*
3	*0.005*	*0.015*	*0.018*
4	*0.006*	*0.02*	*0.022*
5	*0.008*	*0.023*	*0.025*
6	*0.01*	*0.026*	*0.028*
7	*0.013*	*0.029*	*0.03*
8	*0.014*	*0.032*	*0.033*
9	*0.016*	*0.033*	*0.035*
10	*0.018*	*0.036*	*0.038*
11	*0.021*	*0.039*	*0.042*
12	*0.104*	*0.041*	*0.045*
13	*0.025*	*0.044*	*0.047*
14	***0.027***	***0.045***	***0.049***

pansion criteria:

Expansion of less than 0.10% at 14 days (i.e. 16 days after casting) *is indicative of innocuous behavior.*
Expansion of more than 0.20% at 14 days (i.e. 16 days after casting) *is indicative of potentially deleterious expansion.*
Expansion between 0.10% and 0.20% at 14 days (i.e. 16 days after casting) *include both aggregates that are known to be innocuous and deleterious. However, in this situation it may also useful to take comparator reading until 28 days.*

ıte: Refer ASTM C 1567 for testing procedure.
Demoulding of sample after 24 hrs (1 day)
Take Zero Reading after immersion in water after 24 hrs (1day)
Take subsequent reading after immersion in 1 N NaOH soln every 24 hours for 14 days (i.e. 16 days after casting)

Central Soil and Materials Research Station
Wangchu Hydroelectric Project, Bhutan

Statement showing test results of Accelerated Alkali Aggregate Reactivity Test on Fine Aggregate samples

Testing Regime — Accelerated Method in 1 N NaOH solution at 80 deg temp
Cement used — PSC

Age (in days)	Percentage Expansion of Samples		
Sample No →	FA-14/06	FA-14/07	FA-14/08
INITIAL	0	0	0
1	0.007	0.001	0.01
2	0.011	0.005	0.013
3	0.016	0.009	0.018
4	0.022	0.013	0.023
5	0.027	0.016	0.027
6	0.033	0.019	0.031
7	0.04	0.022	0.034
8	0.046	0.026	0.038
9	0.049	0.028	0.042
10	0.052	0.03	0.045
11	0.053	0.034	0.05
12	0.057	0.039	0.053
13	0.061	0.045	0.056
14	**0.063**	**0.049**	**0.059**

Expansion criteria:

Expansion of less than 0.10% at 14 days (i.e. 16 days after casting) *is indicative of innocuous behavior.*
Expansion of more than 0.20% at 14 days (i.e. 16 days after casting) *is indicative of potentially deleterious expansion.*
Expansion between 0.10% and 0.20% at 14 days (i.e. 16 days after casting) *include both aggregates that are known to be innocuous and deleterious. However, in this situation it may also useful to take comparator reading until 28 days.*

Note: Refer ASTM C 1567 for testing procedure.
Demoulding of sample after 24 hrs (1 day)
Take Zero Reading after immersion in water after 24 hrs (1day)
Take subsequent

Annexure-VII

Central Soil and Materials Research Station
Wangchu Hydroelectric Project, Bhutan

Statement showing test results of Mica content test on Fine Aggregate samples from River shoal deposits

Sl. No	Sample Identification		Mica content (%)
	Field Identification	CSM No	
1.	Shoal deposit (Fine aggregate)-Power House site WHEP/PH/FA-4(Pit -1)	FA-14/06	8.3
2.	Shoal deposit (Fine aggregate)-Power House site WHEP/PH/FA-5(Pit -2)	FA-14/07	6.0
3.	Shoal deposit (Fine aggregate)-Power House site WHEP/PH/FA-6(Pit -3)	FA-14/08	7.7
4.	Crushed Sand	CA-14/01	1.67

ANNEXURE-X

GEO-MECHANICAL PROPERTIES OF SOIL

GEO-MECHANICAL PROPERTIES OF SOILS

Submitted to :

Wangchhu Hydro-Electrical Project

Bhutan

Prof. T.N. Singh

DEPARTMENT OF EARTH SCIENCES,

INDIAN INSTITUTE OF TECHNOLOGY, BOMBAY

POWAI, MUMBAI – 400 076

2012

GEO-MECHANICAL PROPERTIES OF SOILS PROVIDED BY M/S WANGCHHU HYDRO-ELECTRICAL PROJECT, BHUTAN

The soil samples were sent by the client to Department of Earth Sciences, Indian Institute of Technology Bombay, Powai, Mumbai, Maharashtra-400076. The test was performed as per Standard code.

The following laboratory tests have been done as per required:

1) Particle Size Distribution (Sieve Analysis)

2) Liquid and Plastic Limits

3) Bulk Density

4) Specific Gravity

5) Natural Moisture Contents

6) Cohesion and Angle of Internal Friction

7) Consolidation Characteristics

8) Permeability

9) Swelling Test

First the methodologies of each test have been described followed by results in the tabular forms.

1. **Grain Size Analysis of soils**

   Usually soils consist of grains of different sizes in varying quantities. The particle sizes and their distribution in a soil influence the engineering properties of the soils. The method by which different particle size and distribution are determined is known as "Mechanical Analysis". The results of grain size analysis are widely used in soil classification, filter design for earth dams, soil stabilization, soil compaction etc.

   Grain size distribution of coarser particles like sand and gravel can be easily obtained by sieving the soil through a set of sieves. Particle size distribution of finer fractions like silt and clays determined by sedimentation method using stoke's law.

   The experiment was conducted for the mechanical analysis tests of a given soil sample, to plot the grain size distribution curves of the soils, to classify and describe the soils on the basis of grain size distribution. Sieve analysis of cohesion less soil retained on ASTM sieve apparatus. The test was performed as per code **ASTM D422**.

2. **Determination of Liquid Limit of the Soils**

   The liquid limit of a soil is the moisture content, expressed as a percentage of the mass of the oven-dried soil, at the boundary between the liquid and plastic states. The moisture content at this boundary is arbitrari1y defined as the liquid limit and is the moisture content at a consistency as determined by means of the standard liquid limit apparatus (ASTM D4318).

Procedure :

- Adjust the drop of the cup of the liquid limit device by releasing the two screws at the top and by using the handle of the grooving tool or a gauge. The drop should be exactly 1cm at the point of contact on the base. Tighten the screw after adjustment.
- Take about 120g of the air-dried soil sample passing 425 μ IS sieve.
- Mix the sample thoroughly with distilled water in an evaporating dish or a glass plate to form a uniform paste. Mixing should be continued for about 15 to 30 min, till a uniform mix is obtained.
- Keep the mix under humid conditions for obtaining uniform moisture distribution for sufficient period. For some fat clays. This maturing time may be up to 24 hours.
- Take a portion of the matured paste and remix it thoroughly. Place it in the cup of the device by a spatula and level it by a spatula or a straight edge to have a minimum

depth of the soil as 1cm at the point of the maximum thickness. The excess soil, if any should be transferred to the evaporating dish.

- Cut a groove in the sample in the cup by using the appropriate tool. Draw the grooving tool through the paste in the cup along the symmetrical axis, along the diameter through the centre line of the cup. Hold the tool perpendicular to the cup.
- Turn the handle of the device at a rate of 2 revolutions per second. Count the number of blows until the two halves of the soil specimen come in contact at the bottom of the groove along a distance of 12mm due to flow and not by sliding.
- Collect a representative sample of the soil by moving spatula width-wise from one edge to the other edge of the soil cake at right angles to the groove. This should include the portion of the groove in which the soil flowed to close the groove.
- Remove the remaining soil from the cup. Mix it with the soil left in evaporating dish.
- Change the water content of the mix in the evaporating dish either by adding more water if the water content is to be increased or by kneading the soil, if the water content is to be decreased. In no case the dry soil should be added to reduce the water content.
- Repeat the steps above and determine the number of blows (N) and the water content in each case.
- Draw the flow curve between log N and w, and determine the liquid limit corresponding to N=25

The liquid limit also calculated by the formula given below:

$$LL = W\,(N/25)^{0.12}$$

Where,

W= Moisture content (%)

N= No. of drops of the cup required to close the groove at the moisture content, W

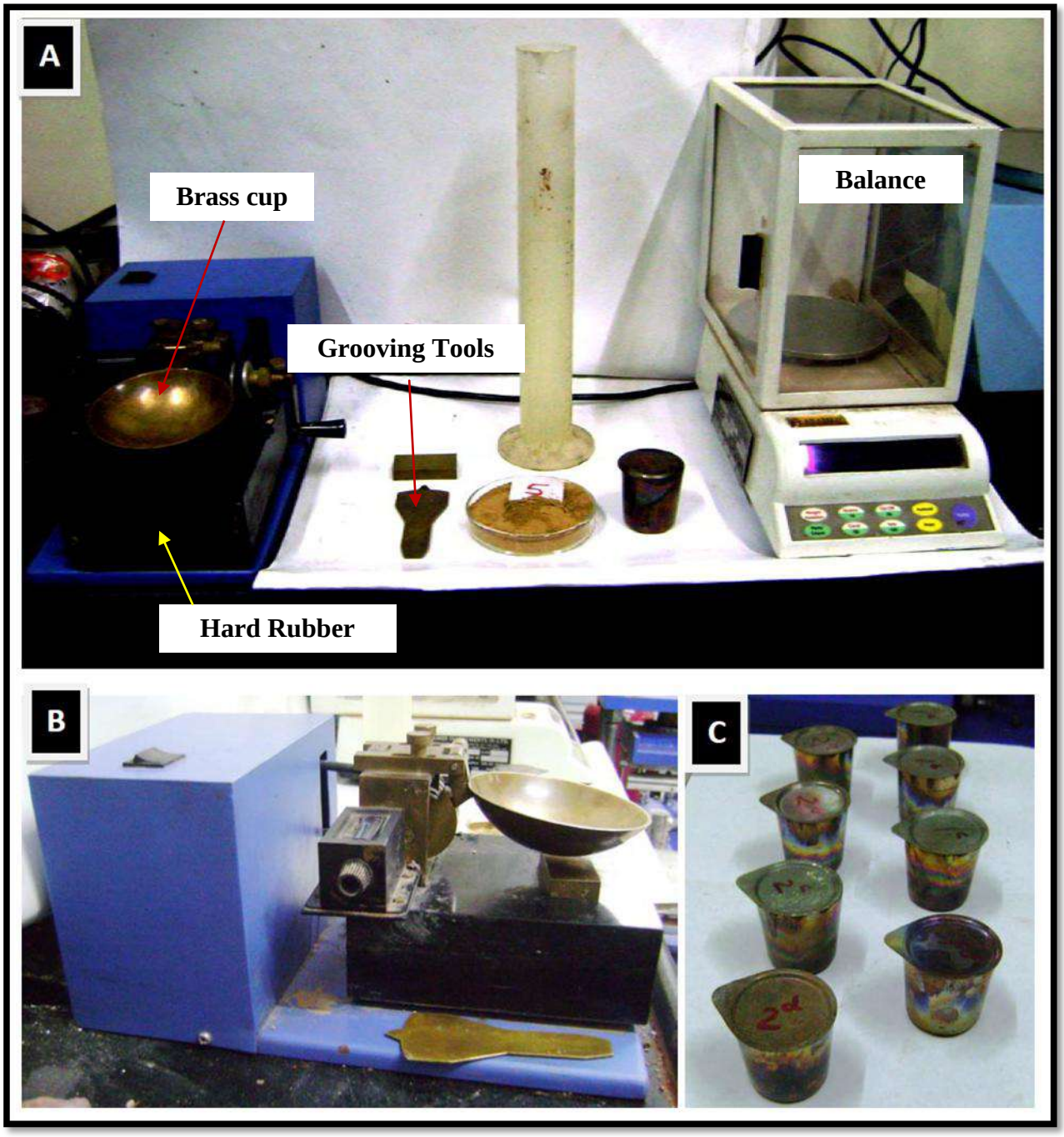


Fig.1: A) Setup for liquid limit determination; **B)** Liquid limit apparatus and **C)** Soil samples ready for oven drying

3. Determination of Plastic Limit (ASTM D4318)

This test is used to determine the plasticity index (PI) of silty and clayey soils. Commonly a PI of 15 or greater is used to distinguish a point between low and moderately expansive soil.

The plastic limit is defend as follows:

I) The water content at which a soil will just begin to crumble when rolled into a thread approximately 1/8 in. in diameter.

II) The water content corresponding to an arbitrary limit between the plastic and semisolid consistency states of a soil.

Plastic Limit (PL) (%) = (Weight of Water/Weight of Oven-dry soil) x100

Plasticity Index (PI) = Liquid Limit (LL) - Plastic Limit (PL)

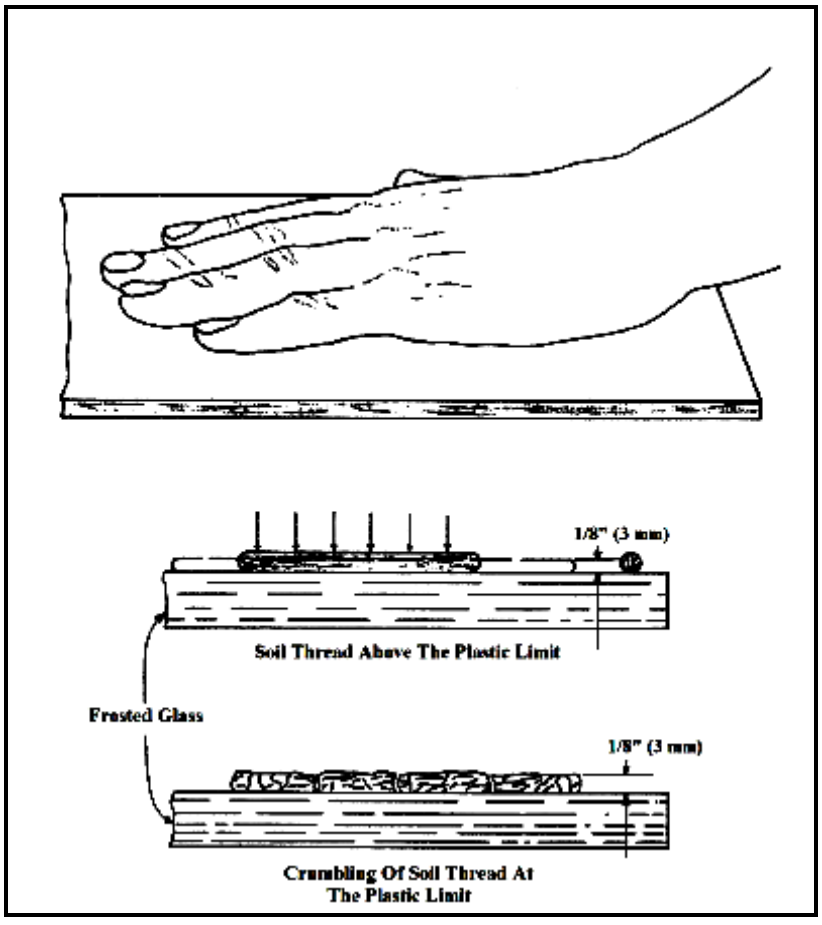


Fig.2: Diagram illustrating plastic limit

4. Determination of Dry Density (ASTM D1556)

The soil bulk or dry density, b, is the ratio of the mass of the solid phase of the soil (i.e., dried soil) to its total volume (solid and pore volumes together) and is defined as follows:

$$\rho_b = \frac{M_s}{V_t}$$

Where,

M_s = mass of solids in (g)

M_l = Mass of liquids in (g)

Bulk density values represent the density of the oven dry soil as a whole; this includes solids and pore space.

$$\rho_b = Ws/ Vt$$

Where

W_s = Oven dry mass of the sample (g)
V_t = Total volume of the sample, pore volume + solid volume (cm^3).

5. Specific Gravity

The specific gravity of soil has been determined as per **ASTM** Standard Code **D854-10.** Specific gravity is the ratio of the weight in air of a given volume of a material at a standard temperature to the weight in air of an equal volume of distilled water at the same stated temperature. Specific gravity (G_t) is determined by the formula:

$$G_t = \frac{\rho_s}{\rho_{w,t}} = \frac{M_s}{(M_{\rho_{w,t}} - (M_{\rho ws,t} - M_s))}$$

Where,

ρ_s = the density of the soil solids g/cm3,

$\rho_{w,t}$ = the density of water at the test temperature (T_t), g/cm3.

M_s = the mass of the oven dry soil solids (g), and

$M_{rws,t}$ = the mass of pycnometer, water, and soil solids at the test temperature, (Tt), g.

6. Natural Moisture Contents

This method covers the laboratory determination of the moisture content of a soil as a percentage of its oven-dried weight. This method covers the laboratory determination of the moisture content of a soil as a percentage of its oven-dried weight.

$$MC\% = \frac{W_2 - W_3}{W_3 - W_1} x\,100$$

Where:

W1 = Weight of pan (g)
W2 = Weight of moist soil + pan (g)
W3 = Weight of dried soil + pan (g)

7. Cohesion and Angle of Internal Friction

Cohesion and angle of internal friction has been calculated with the help of Mohr's circle, plotting the σ_1 and σ_3, where σ_1 and σ_2 are the maximum and minimum principle stresses respectively, obtaining from triaxial test. The method was performed as per code **ASTM D5030**

Fig. 2.a: Triaxial Test setup for soil.

8. Consolidation Characteristics of the soil

The test has been performed as per code **ASTM D2435/2435M-11**. Two alternative procedures have been done for the test as follows:

- This test method is performed with constant load increment duration of 24 h. Time-deformation readings are required on a minimum of two load increments.
- Time-deformation readings are required on all load increments. Successive load increments are applied after 100% primary consolidation is reached, or at constant time increments as described in first point.

Final formula for consolidation coefficient for each load increment is as follows:

$$c_v = \frac{TH_{D_{50}}^2}{t}$$

Where,

$\mathbf{c_v}$ = coefficient of consolidation (cm^2/s) (3 significant digits),

T = a dimensionless time factor

t = time corresponding to the particular degree of consolidation,

$\mathbf{H_{D50}}$ = length of the drainage path at 50 % consolidation, (cm)

9. Permeability of Soil

Permeability of soil is the property of soils that allows water to pass through them at some rate. The property is the product of the granular soils, although it can be affected by the other factors (such as water bonding in clays).

The permeability of soil has been performed by the constant head method as **ASTM** Standard Code **D2434.** For the calculation of coefficient of permeability (k) the formula has been used as follows:

$$k = QL/Ath$$

Where,

k = coefficient of permeability,

Q = quantity of water discharged,

L = distance between manometers,

A = cross-sectional area of specimen,

t = total time of discharge,

h = difference in head on manometers.

10. Free Swelling Index (FSI) of Soil

Free Swelling Index (FSI) is the increase in volume of soil without any external constraint when subjected to submergence in water. The test has been performed as per **IS** Code **IS 2729 (Part XL).** For the calculation of free soil index, the formula has been used as;

$$\textbf{Free swell index (FSI)} = [\ (V_d - V_k) / V_k\ ] \times 100\%$$

where,

V_d = volume of soil specimen read from the graduated cylinder containing distilled water.
V_k = volume of soil specimen read from the graduated cylinder containing kerosene.

Table. 1.1: Sieve analysis of Sample N. 1

Sieve No. (ASTM)	Size (mm)	Weight retained (g)	% retained	Cumulative % Retained	Cumulative % Pass (% Finer0
14	1.41	98.23	49.12	49.12	50.89
35	0.5	47.98	23.99	73.11	26.90
50	0.297	15.92	7.96	81.07	18.94
80	0.18	13.72	6.86	87.93	12.08
100	0.149	8.30	4.15	92.08	7.93
120	0.125	4.26	2.13	94.21	5.80
140	0.101	4.57	2.29	96.49	3.51
200	0.075	2.89	1.45	97.94	2.07
270	0.053	1.94	0.97	98.91	1.10
Pan		0.53	0.27	99.17	0.83
Total Weight (W)= 200 g				**W1= 198.34 g**	

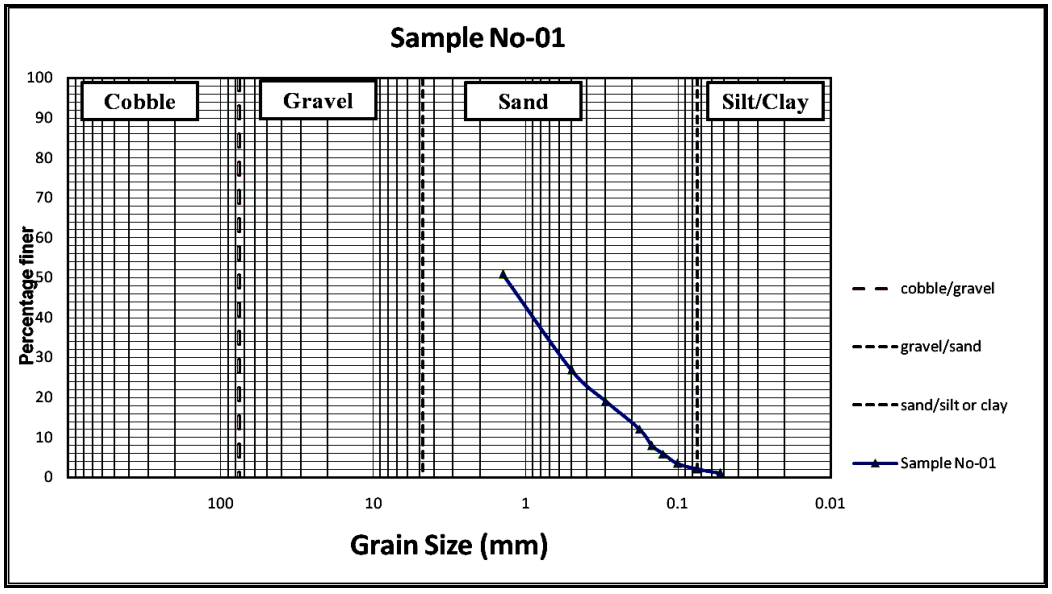


Fig. 3: Graph between grain size and percentage finer of soil no. 1

Table. 1.1: Sieve analysis of sample n. 2

Sieve No. (ASTM)	Size (mm)	Weight retained (g)	% retained	Cumulative % Retained	Cumulative % Pass (% Finer)
14	1.41	91.90	45.95	45.95	54.05
35	0.5	48.91	24.46	70.41	29.60
50	0.297	18.10	9.05	79.46	20.55
80	0.18	13.80	6.90	86.36	13.65
100	0.149	5.84	2.92	89.28	10.73
120	0.125	2.51	1.26	90.53	9.47
140	0.101	2.81	1.41	91.94	8.07
200	0.075	3.40	1.70	93.64	6.36
270	0.053	6.79	3.40	97.03	2.97
Pan		5.73	2.87	99.90	0.11
Total Weight (W)= 200 g				**W1= 199.79 g**	

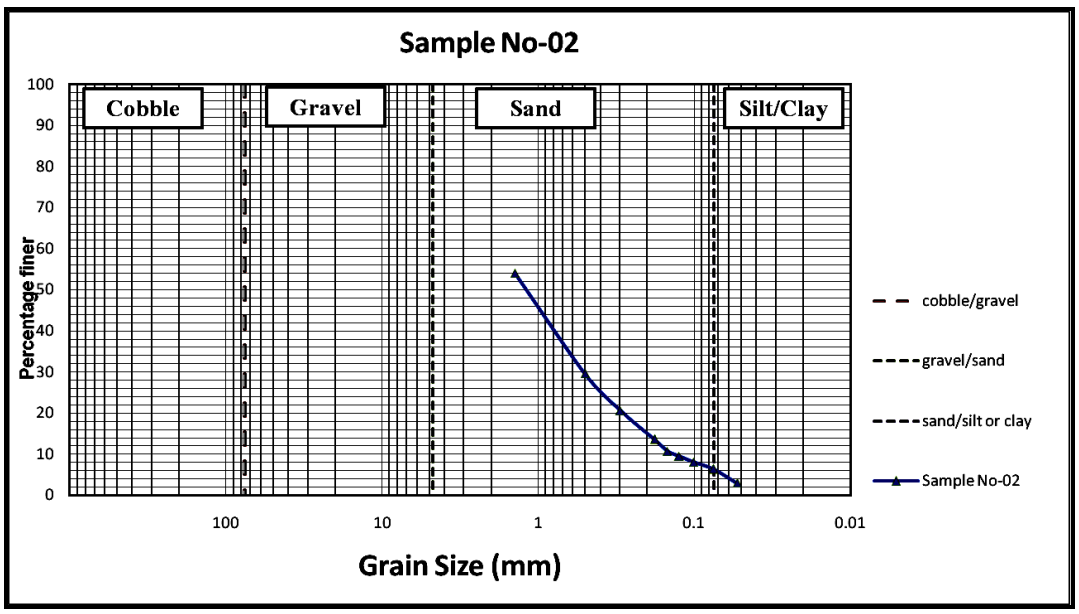


Fig. 4: Graph between grain size and percentage finer of soil no. 2

Table. 1.3: Sieve analysis of sample no. 3

Sieve No. (ASTM)	Size (mm)	Weight retained (g)	% retained	Cumulative % Retained	Cumulative % Pass (% Finer)
14	1.41	65.88	32.94	32.94	67.06
35	0.5	68.67	34.34	67.28	32.73
50	0.297	25.56	12.78	80.06	19.95
80	0.18	16.79	8.40	88.45	11.55
100	0.149	5.39	2.70	91.15	8.86
120	0.125	2.26	1.13	92.28	7.73
140	0.101	2.35	1.18	93.45	6.55
200	0.075	2.54	1.27	94.72	5.28
270	0.053	4.98	2.49	97.21	2.79
Pan		5.55	2.78	99.99	0.02
Total Weight (W)= 200 g				**W1= 199.97 g**	

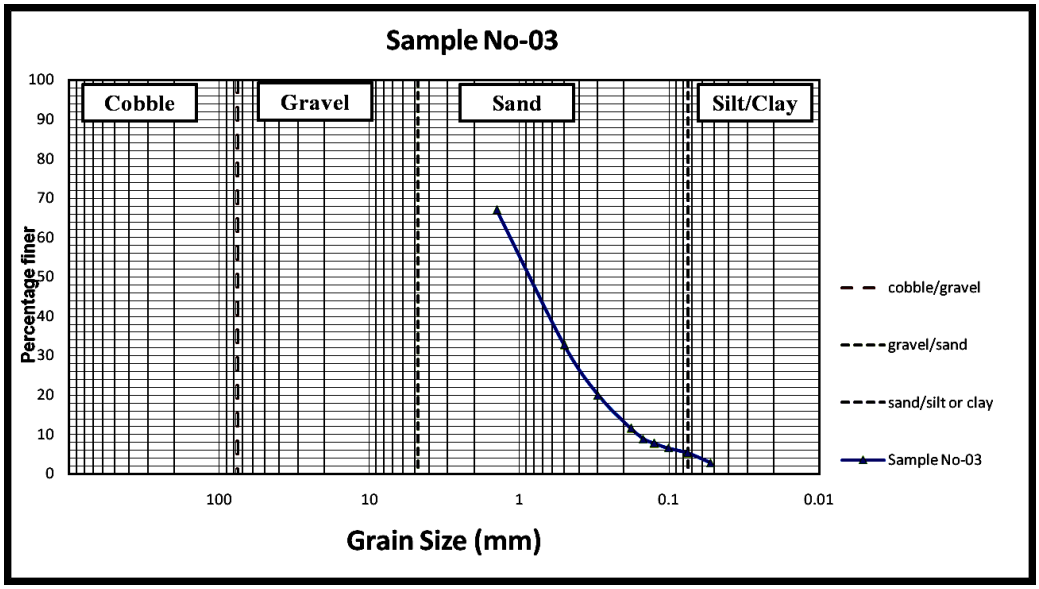


Fig. 5: Graph between grain size and percentage finer of soil smple no. 3

Table. 1.4: Sieve analysis of sample no. 4

Sieve No. (ASTM)	Size (mm)	Weight retained (g)	% retained	Cumulative % Retained	Cumulative % Pass (% Finer)
14	1.41	41.17	20.59	20.59	79.42
35	0.5	44.83	22.42	43.00	57.00
50	0.297	48.90	24.45	67.45	32.55
80	0.18	38.63	19.32	86.77	13.24
100	0.149	13.98	6.99	93.76	6.25
120	0.125	4.96	2.48	96.24	3.77
140	0.101	1.82	0.91	97.15	2.86
200	0.075	1.62	0.81	97.96	2.05
270	0.053	1.43	0.72	98.67	1.33
Pan		0.51	0.26	98.93	1.08
Total Weight (W)= 200 g				**W1= 197.85 g**	

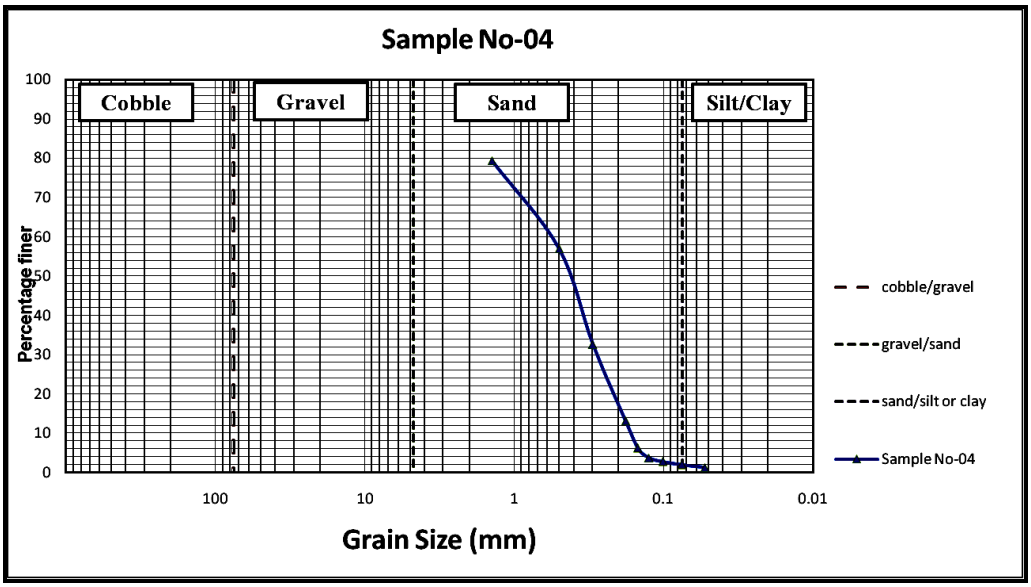


Fig. 6: Graph between grain size and percentage finer of soil smple no.4

Table. 1.5: Sieve analysis of sample n. 5

Sieve No. (ASTM)	Size (mm)	Weight retained (g)	% retained	Cumulative % Retained	Cumulative % Pass (% Finer)
14	1.41	54.20	27.10	27.10	72.90
35	0.5	57.31	28.66	55.76	44.25
50	0.297	35.13	17.57	73.32	26.68
80	0.18	25.91	12.96	86.28	13.73
100	0.149	8.71	4.36	90.63	9.37
120	0.125	3.50	1.75	92.38	7.62
140	0.101	3.77	1.89	94.27	5.73
200	0.075	3.76	1.88	96.15	3.85
270	0.053	4.31	2.16	98.30	1.70
Pan		2.61	1.31	99.61	0.39
Total Weight (W)= 200 g				**W1= 199.21 g**	

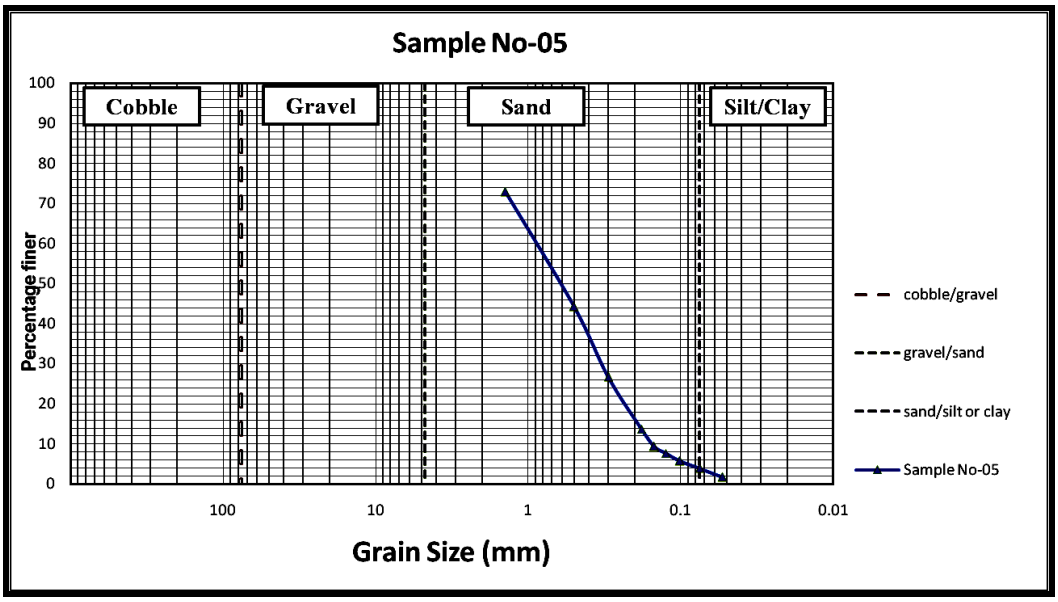


Fig. 7: Graph between grain size and percentage finer of soil smple no.5

Table. 1.6: Sieve analysis of sample n. 6

Sieve No. (ASTM)	Size (mm)	Weight retained (g)	% retained	Cumulative % Retained	Cumulative % Pass (% Finer)
14	1.41	54.20	27.10	27.10	72.90
35	0.5	57.31	28.66	55.76	44.25
50	0.297	35.13	17.57	73.32	26.68
80	0.18	25.91	12.96	86.28	13.73
100	0.149	8.71	4.36	90.63	9.37
120	0.125	3.50	1.75	92.38	7.62
140	0.101	3.77	1.89	94.27	5.73
200	0.075	3.76	1.88	96.15	3.85
270	0.053	4.31	2.16	98.30	1.70
Pan		2.61	1.31	99.61	0.39
Total Weight (W)= 200 g				**W1= 199.21 g**	

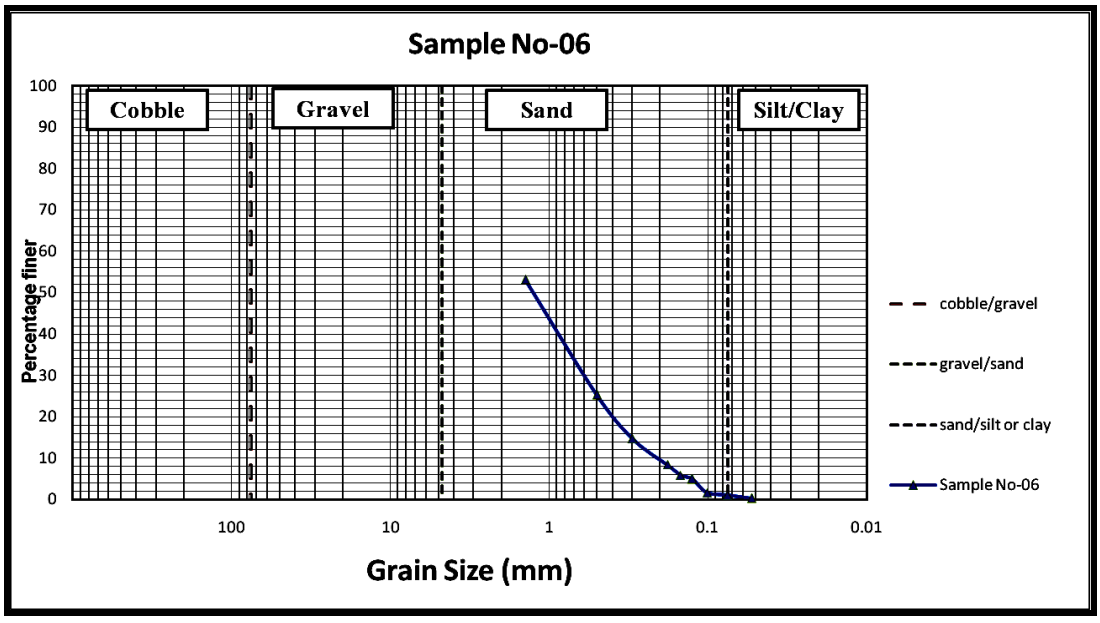


Fig. 8: Graph between grain size and percentage finer of soil smple no.6

Table. 1.7: Sieve analysis of sample n. 7

Sieve No. (ASTM)	Size (mm)	Weight retained (g)	% retained	Cumulative % Retained	Cumulative % Pass (% Finer0
14	1.41	83.00	41.50	41.50	58.50
35	0.5	48.56	24.28	65.78	34.22
50	0.297	18.21	9.11	74.89	25.12
80	0.18	15.70	7.85	82.74	17.27
100	0.149	15.12	7.56	90.30	9.71
120	0.125	6.57	3.29	93.58	6.42
140	0.101	5.67	2.84	96.42	3.59
200	0.075	2.75	1.38	97.79	2.21
270	0.053	1.63	0.82	98.61	1.40
Pan		0.55	0.28	98.88	1.12
Total Weight (W)= 200 g				**W1= 199.21 g**	

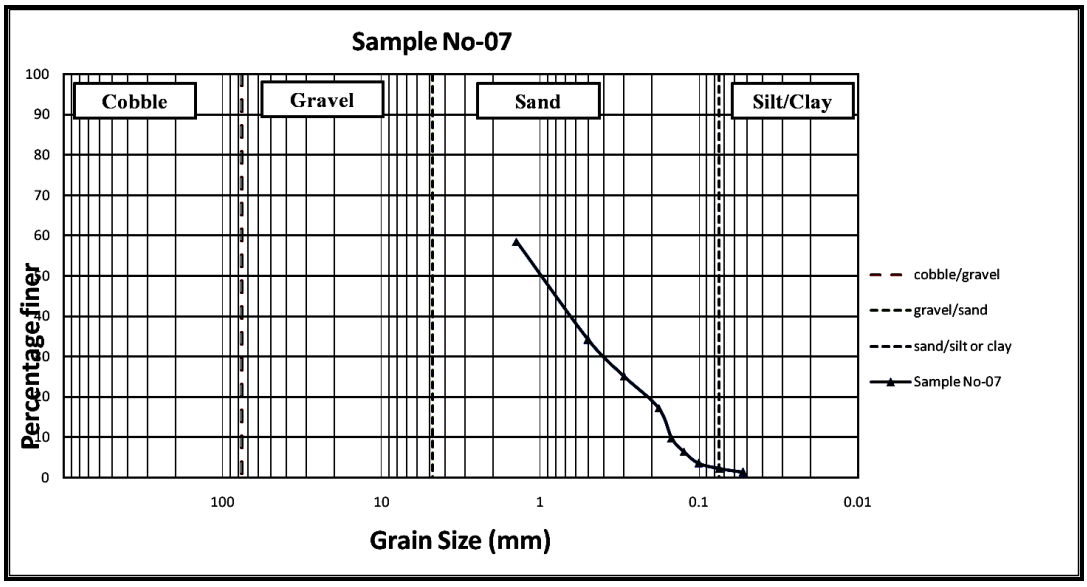


Fig.9: Graph between grain size and percentage finer of soil smple no.7

Table. 1.8: Sieve analysis of sample n. 8

Sieve No. (ASTM)	Size (mm)	Weight retained (g)	% retained	Cumulative % Retained	Cumulative % Pass (% Finer)
14	1.41	74.60	37.30	37.30	62.70
35	0.5	50.30	25.15	62.45	37.55
50	0.297	20.61	10.31	72.76	27.25
80	0.18	17.07	8.54	81.29	18.71
100	0.149	15.93	7.97	89.26	10.75
120	0.125	7.90	3.95	93.21	6.80
140	0.101	5.71	2.86	96.06	3.94
200	0.075	2.32	1.16	97.22	2.78
270	0.053	1.71	0.86	98.08	1.93
Pan		0.56	0.28	98.36	1.65
Total Weight (W)= 200 g				**W1= 196.71 g**	

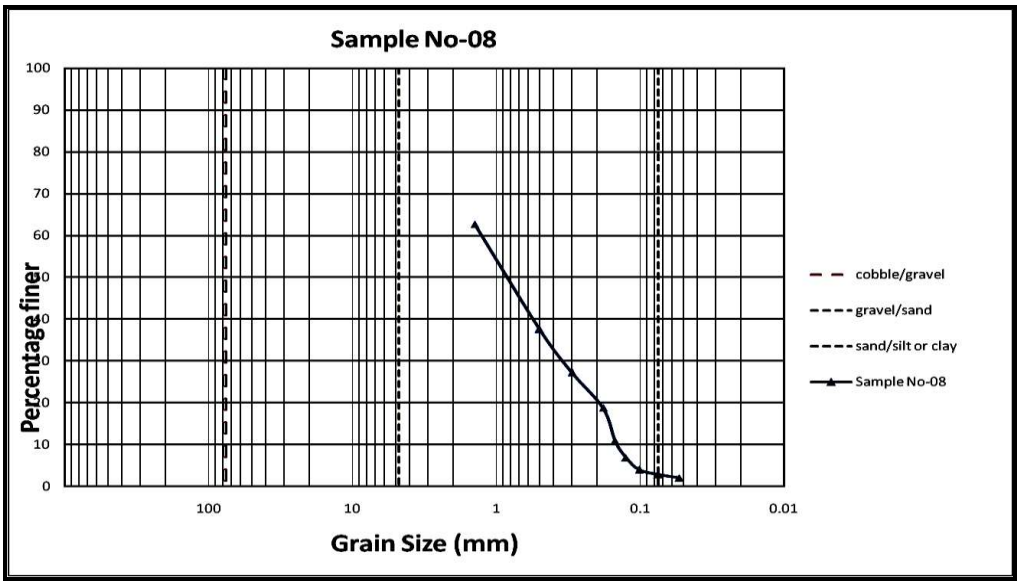


Fig. 10: Graph between grain size and percentage finer of soil smple no.8

Table. 1.9: Sieve analysis of sample n. 9

Sieve No. (ASTM)	Size (mm)	Weight retained (g)	% retained	Cumulative % Retained	Cumulative % Pass (% Finer)
14	1.41	74.60	37.30	37.30	62.70
35	0.5	50.30	25.15	62.45	37.55
50	0.297	20.61	10.31	72.76	27.25
80	0.18	17.07	8.54	81.29	18.71
100	0.149	15.93	7.97	89.26	10.75
120	0.125	7.90	3.95	93.21	6.80
140	0.101	5.71	2.86	96.06	3.94
200	0.075	2.32	1.16	97.22	2.78
270	0.053	1.71	0.86	98.08	1.93
Pan		0.56	0.28	98.36	1.65
Total Weight (W)= 200 g				**W1= 196.71 g**	

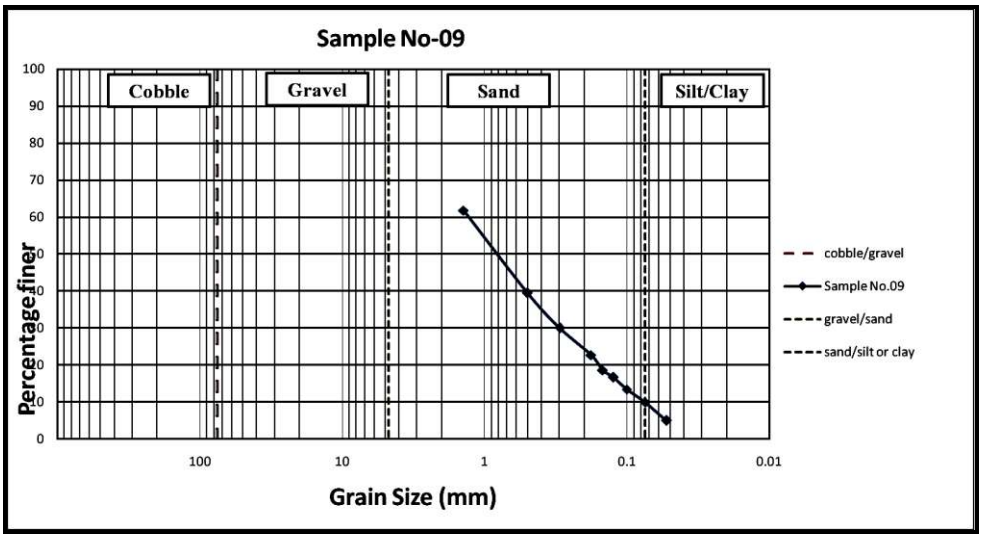


Fig. 11: Graph between grain size and percentage finer of soil smple no.9

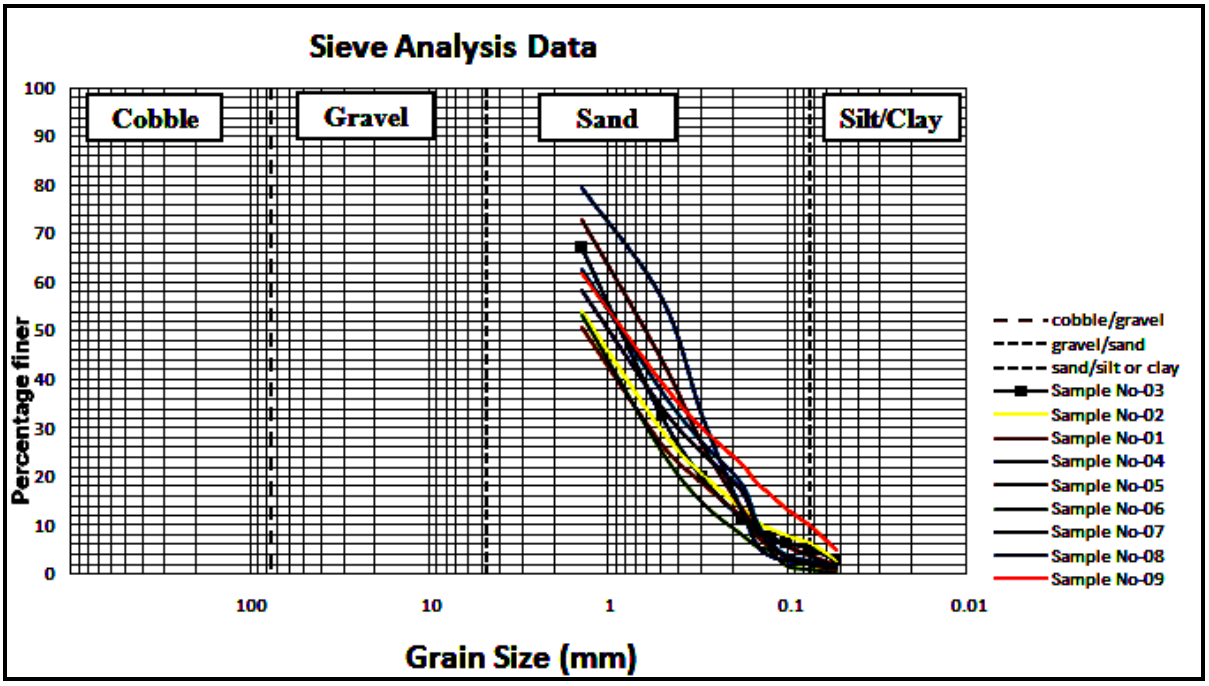
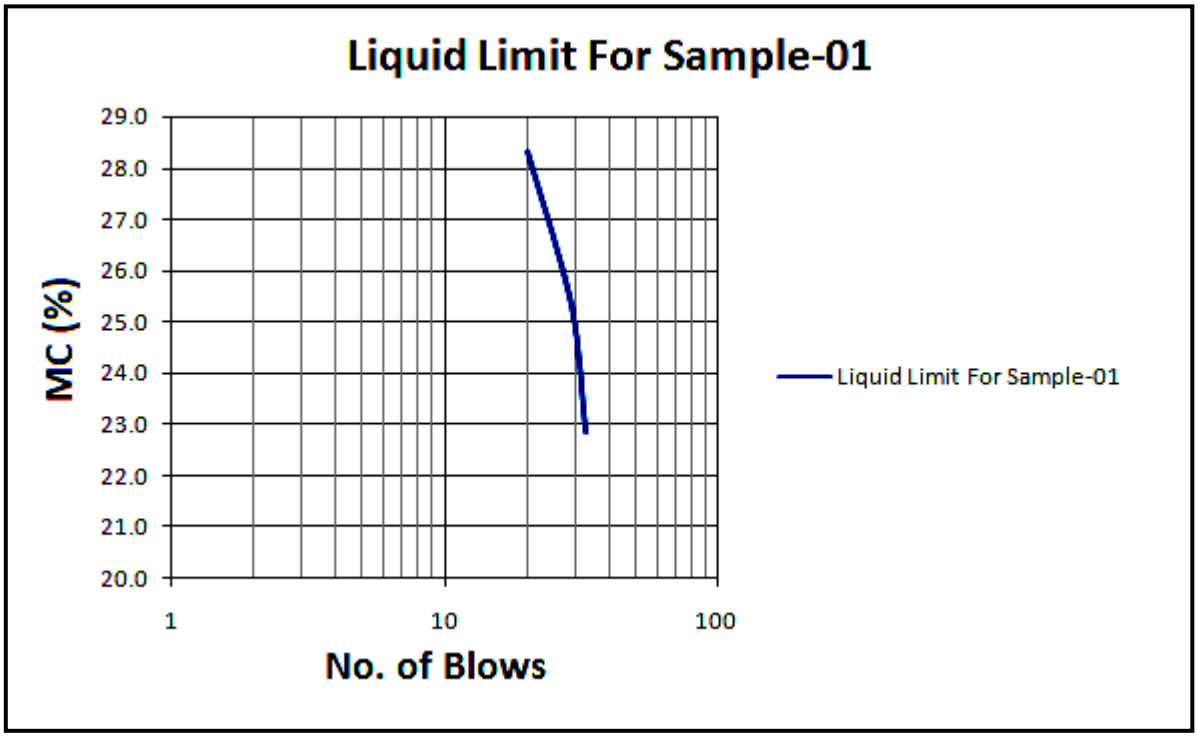
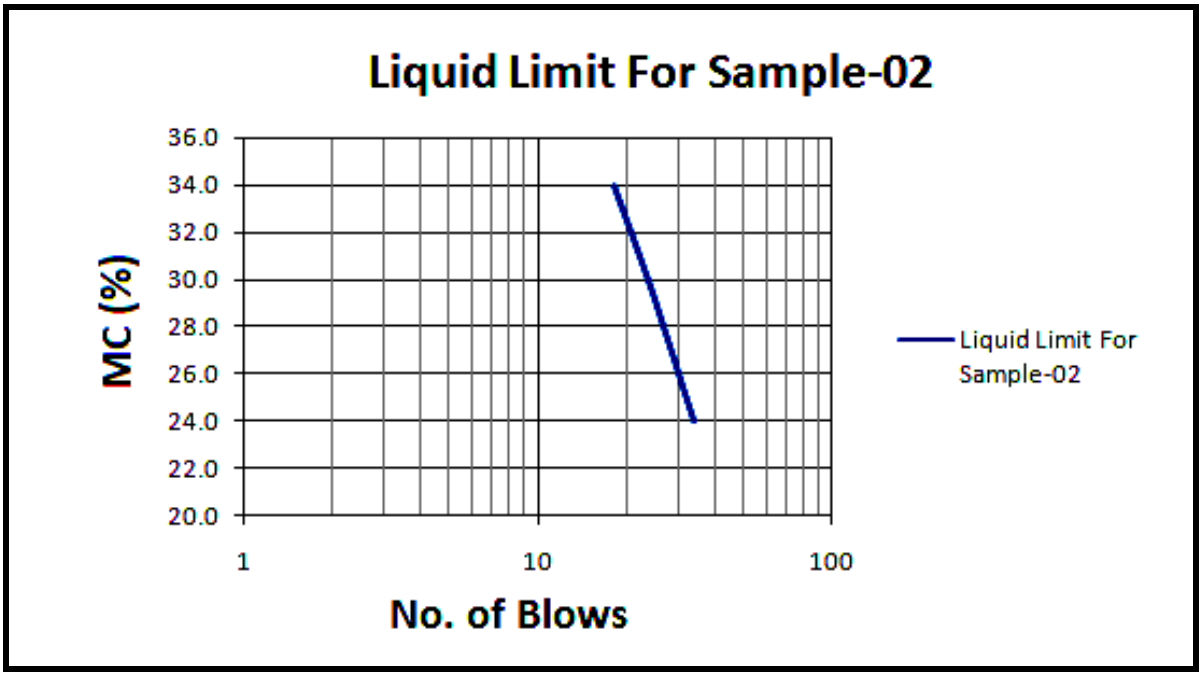


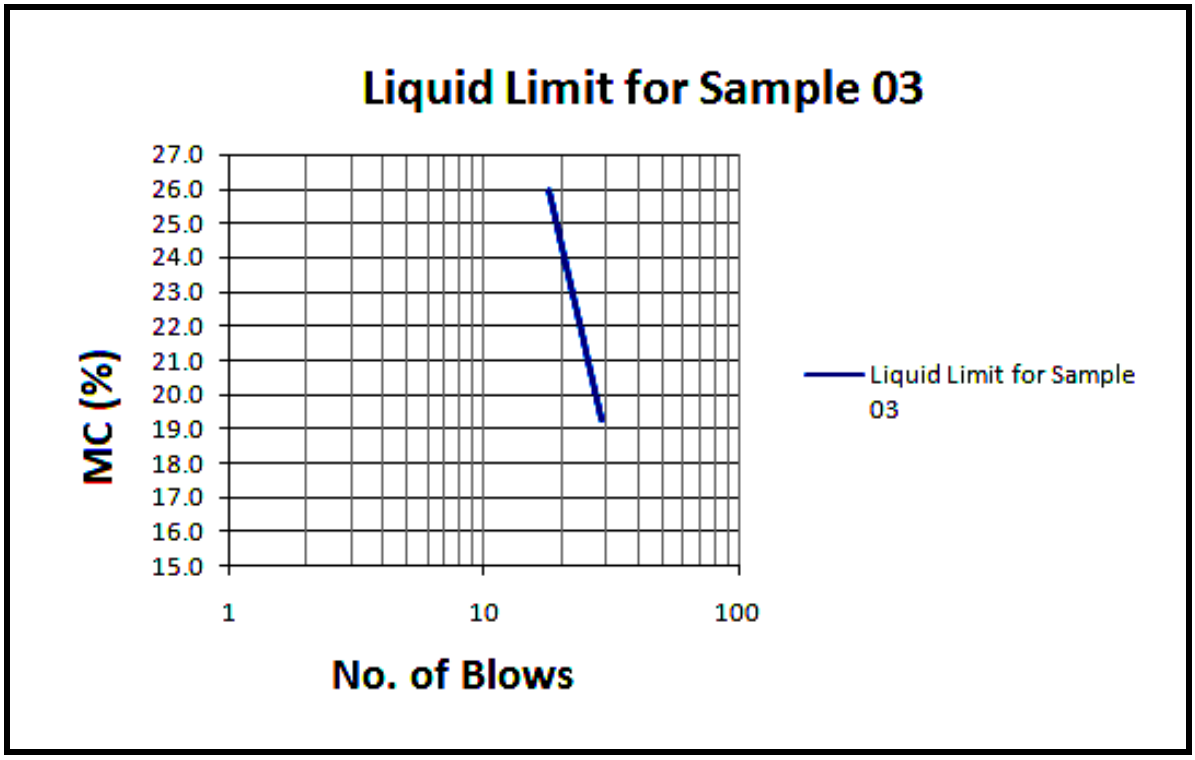
Fig. 12: Graph between grain size and percentage finer for all nine samples.

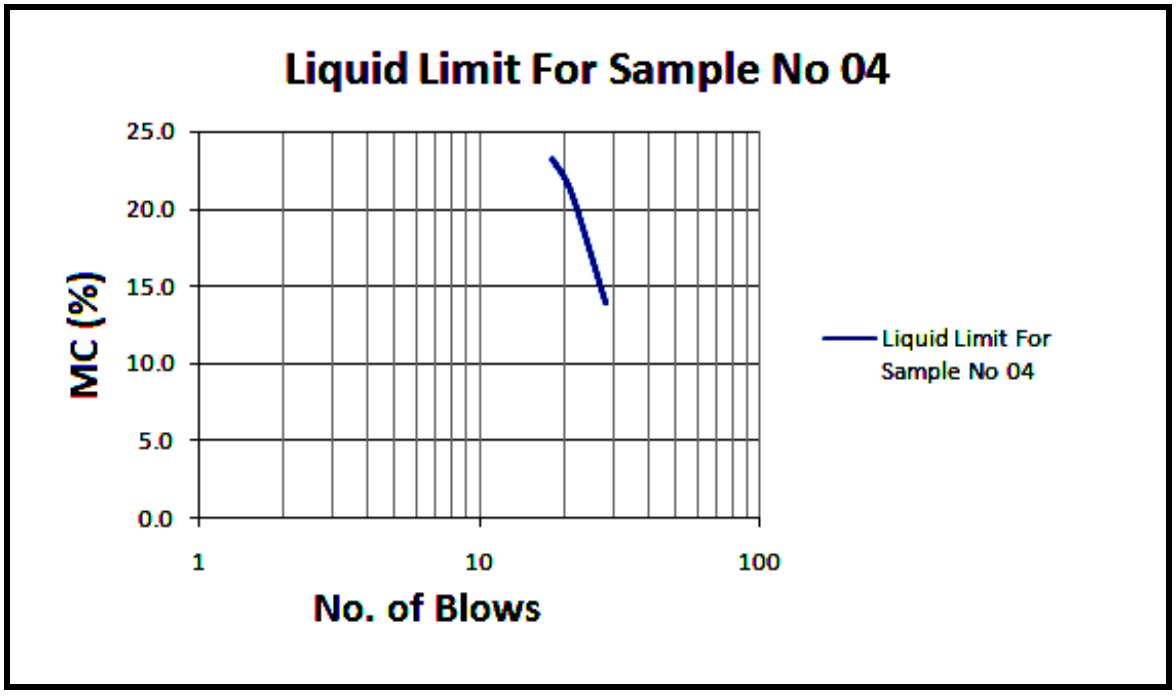
Table.2: LL, PL and PI

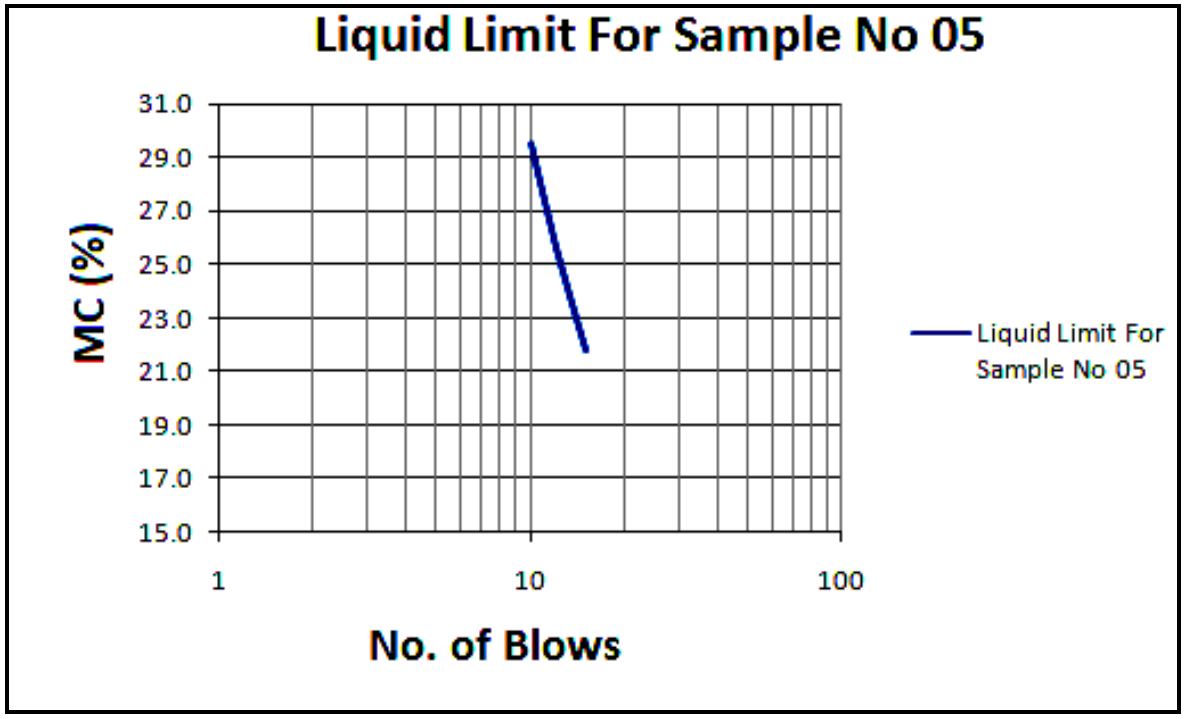
Sample No.	Liquid Limit (LL) (%)	Plastic Limit (PL) (%)	Plasticity Index (PI)
1	26.3	16.5	9.8
2	29.1	17.0	12.1
3	21.2	16.0	5.2
4	20.9	6.0	14.9
5	23.1	10.5	12.6
6	20.2	5.5	14.7
7	23.3	15.5	7.8
8	25.5	16.0	9.5
9	32.7	17.0	15.7

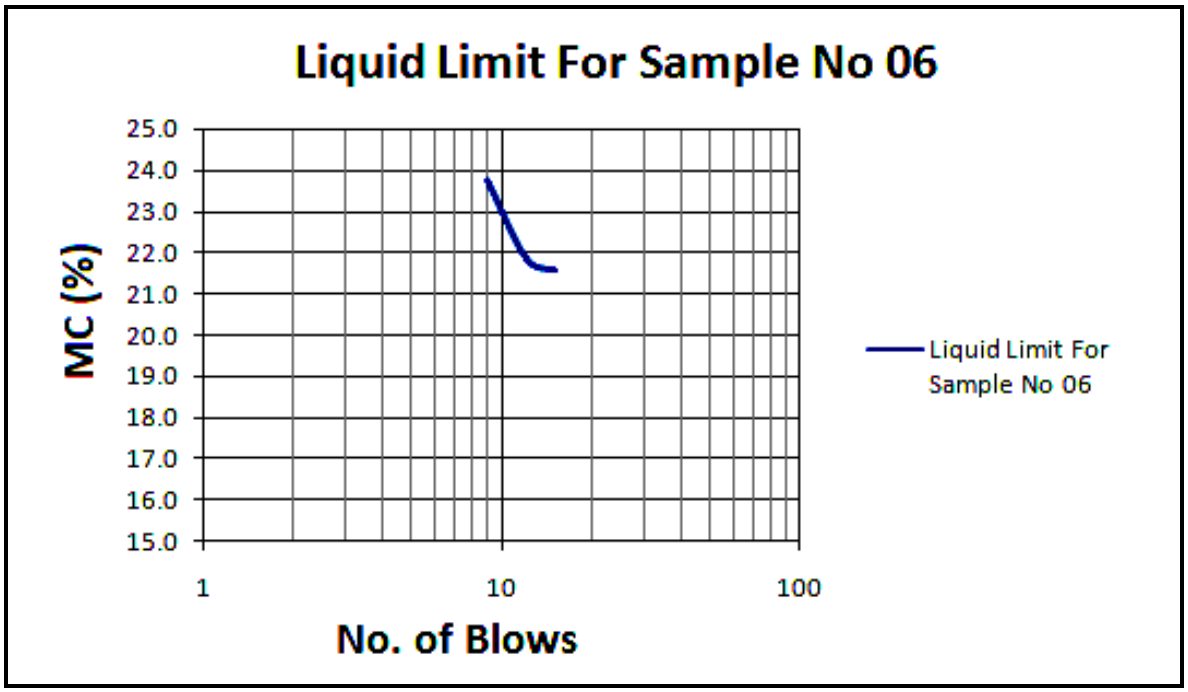

Liquid Limit For Sample-01
29.0
28.0
27.0
26.0
25.0
24.0
23.0
22.0
21.0
20.0
MC (%)
1
10
100
No. of Blows
Liquid Limit For Sample-01

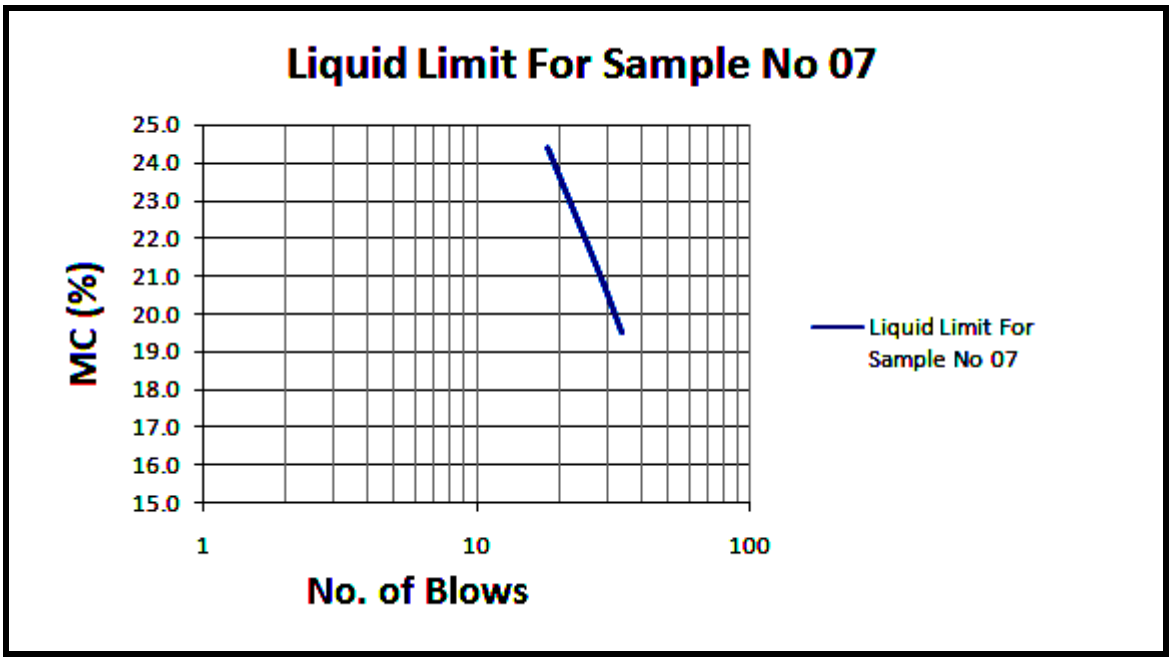

Liquid Limit For Sample-02
36.0
34.0
32.0
30.0
28.0
26.0
24.0
22.0
20.0
MC (%)
1
10
100
No. of Blows
Liquid Limit For Sample-02

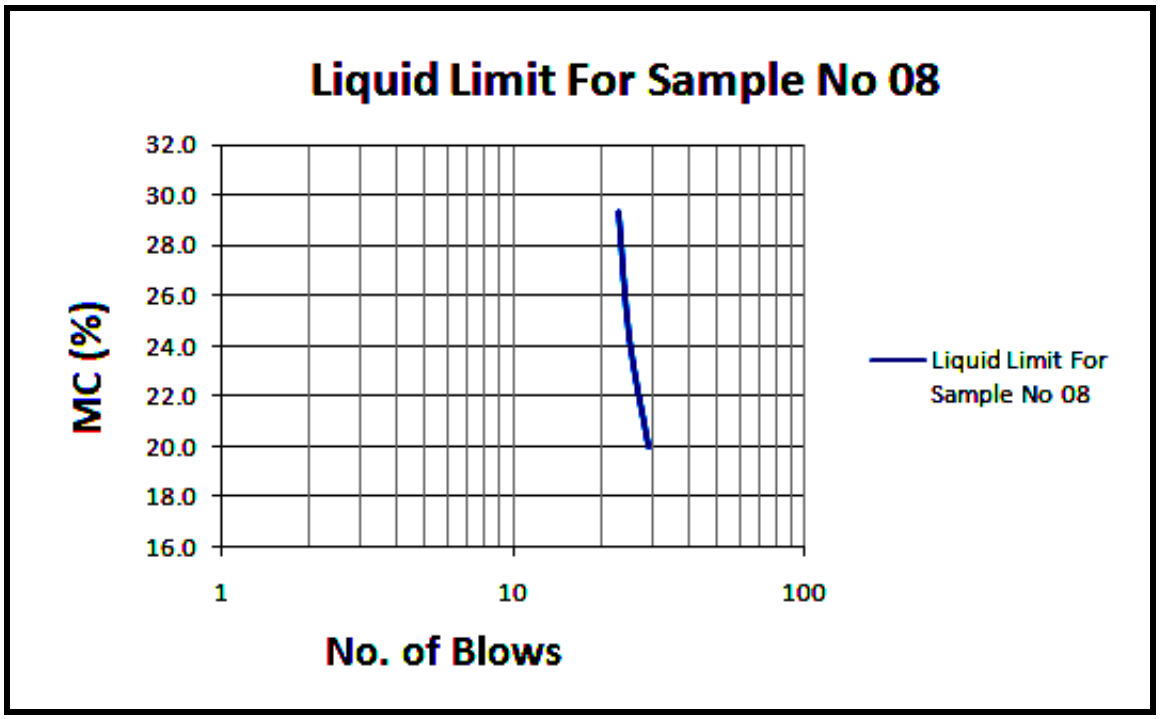

Liquid Limit for Sample 03
27.0
26.0
25.0
24.0
23.0
22.0
21.0
20.0
19.0
18.0
17.0
16.0
15.0
MC (%)
1
10
100
No. of Blows
Liquid Limit for Sample 03


Liquid Limit For Sample No 04
25.0
20.0
15.0
10.0
5.0
0.0
MC (%)
1
10
100
No. of Blows
Liquid Limit For Sample No 04


Liquid Limit For Sample No 05
31.0
29.0
27.0
25.0
23.0
21.0
19.0
17.0
15.0
MC (%)
1
10
100
No. of Blows
Liquid Limit For Sample No 05


Liquid Limit For Sample No 06
25.0
24.0
23.0
22.0
21.0
20.0
19.0
18.0
17.0
16.0
15.0
MC (%)
1
10
100
No. of Blows
Liquid Limit For Sample No 06


Liquid Limit For Sample No 07
25.0
24.0
23.0
22.0
21.0
20.0
19.0
18.0
17.0
16.0
15.0
MC (%)
1
10
100
No. of Blows
Liquid Limit For Sample No 07


Liquid Limit For Sample No 08
32.0
30.0
28.0
26.0
24.0
22.0
20.0
18.0
16.0
MC (%)
1
10
100
No. of Blows
Liquid Limit For Sample No 08

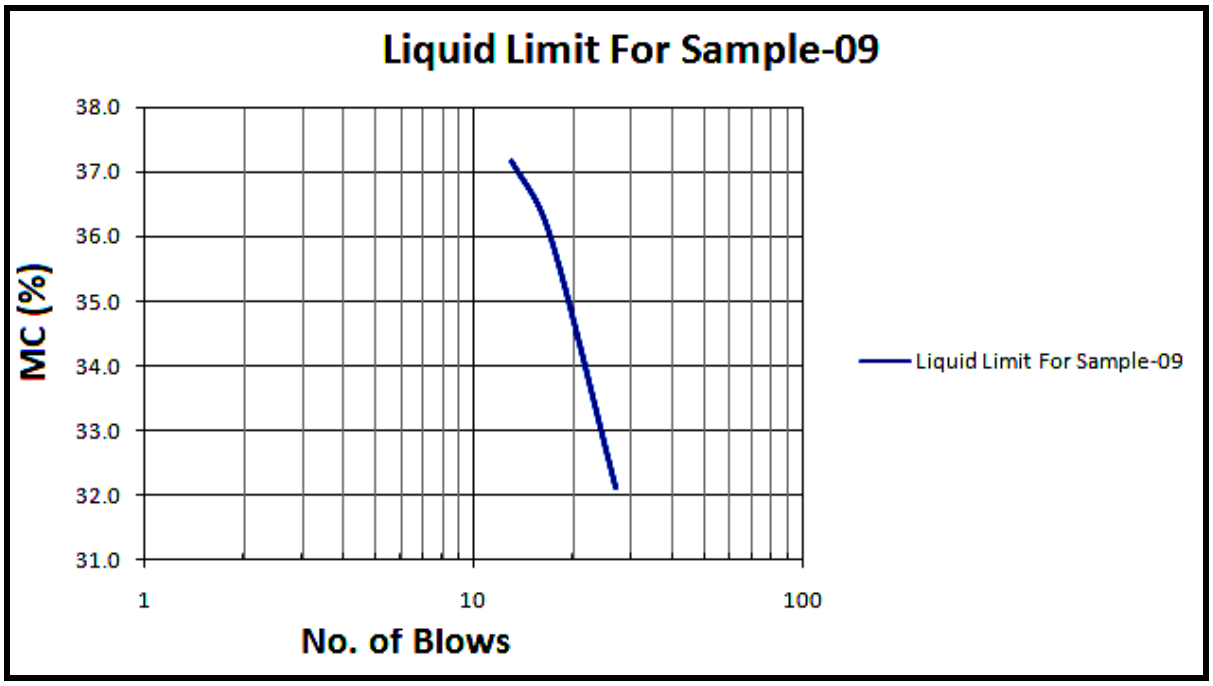


Table No.3: Properties of soils

Sample No.	Natural Moisture Contents (%)	Dry Density (gm/cc)	Specific Gravity	Cohesion (kg/sq.cm)	Angle of Internal Friction (°)
1	8.88	1.51	1.42	0.197	27.0
2	9.96	1.47	1.39	0.187	28.3
3	11.33	1.45	1.39	0.150	27.9
4	6.00	1.54	1.48	0.108	30.3
5	5.80	1.44	1.56	0.106	31.1
6	9.50	1.65	1.49	0.153	27.9
7	8.50	1.59	1.52	0.142	29.0
8	8.90	1.62	1.53	0.107	26.9
9	8.44	1.62	1.51	0.106	29.5

Table No. 4: Characteristics of soils

Sample No.	Consolidation coefficient (C_v) (cm^2/sec)	Coefficient of Permeability (k)	Free Swelling Index(%)
1	0.005	$3.2*10^{-6}$	0.001
2	0.008	$2.9*10^{-7}$	0.003
3	0.003	$3.6*10^{-5}$	Nil
4	0.003	$3.6*10^{-5}$	Nil
5	0.003	$3.5*10^{-5}$	Nil
6	0.003	$3.7*10^{-5}$	Nil
7	0.003	$3.4*10^{-5}$	Nil
8	0.005	$3.1*10^{-6}$	0.001
9	0.008	$2.8*10^{-7}$	0.003