भारत हेवी इलेक्ट्रिकल्स लिमिटेड
(भारत सरकार का उपक्रम)
BHARAT HEAVY ELECTRICALS LIMITED
(A Govt. of India Undertaking)

TCN - 06

Ref: PSER:SCT:RKL-M1779:TCN-06 Date: 11-11-2016

Sub	TCN-06	
Job	DESIGN, ENGINEERING, MANUFACTURING, SUPPLY, ERECTION & COMMISSIONING OF INDUCED DRAFT COOLING TOWER (IDCT) FOR 1X250 MW NSPCL, PP-II EXPANSION, ROURKELA, ODISHA.	
Ref	1.0	Tender no PSER:SCT: RKL-M1779:16
	2.0	BHEL's NIT, vide reference no PSER:SCT:RKL-M1779:5264, Dated 17-10-2016.
	3.0	BHEL's TCN-01, vide reference PSER:SCT:RKL-M1779:TCN-01, dated 26-10-2016.
	4.0	BHEL's TCN-02, vide reference PSER:SCT:RKL-M1779:TCN-02, dated 28-10-2016.
	5.0	BHEL's TCN-03, vide reference PSER:SCT:RKL-M1779:TCN-03, dated 04-11-2016.
	6.0	BHEL's TCN-04, vide reference PSER:SCT:RKL-M1779:TCN-04, dated 08-11-2016.
	7.0	BHEL's TCN-05, vide reference PSER:SCT:RKL-M1779:TCN-05, dated 10-11-2016.
	8.0	All other pertinent issues till date.

With reference to above, following points/ documents, relevant to tender, may please be noted and complied with while submitting offer.

1.0 Extension of due date of submission of offer from 16-11-2016 to **22-11-2016** (15:00 hrs).

2.0 Introduction of Technical specification, RKL-IDCT-VOLUME-II-TS-7-R-00.

3.0 Technical specification, RKL-IDCT-VOLUME-II-TS-6-R-00 issued along with TCN-3 stands deleted.

4.0 Introduction of Clause no. 2.9 to Volume-ID, SCC (Service) as follow:

" In case, the design is required to be changed because of certain site conditions, encountered during execution, the bidder shall do the re-design and get approval from BHEL/Customer within the quoted price, and no extra cost shall be payable to the bidder on this account **".**

5.0 Revised `No deviation certificate' as per enclosed Annexure-2. Bidder shall submit no deviation certificate as per enclosed format only.

6.0 All other terms & conditions shall remain unchanged.

Thanking you,

Yours faithfully,
for BHARAT HYEAVY ELECTRICALS LTD

SR ENGR (SCT)

Encl : As above.

पावर सेक्टर पूर्वी क्षेत्र (मुख्यालय)
POWER SECTOR EASTERN REGION, DJ-9/1, SECTOR-II, SALT LAKE CITY, KOLKATA - 700 091
फैक्स/Fax : (033) 23211960 फोन/Phone : बोर्ड/EPABX : 23211691, 23211798, 23211796

GEOTECHNICAL INVESTIGATION REPORT

PROJECT: 1x250 MW NSPCL ROURKELA TPP-III

LOCATION: MAIN PLANT AREA (Part 1/Volume I)

DOCUMENT NO: PE-DC-427-602-C001 PART-1/Volume-I
(REVISION: 1)

Customer

NTPC – SAIL POWER CORPORATION LIMITED (NSPCL)

Submitted by

PROJECT ENGINEERING MANAGEMENT

POWER PROJECT ENGINEERING INSTITUTE

HRD & ESI COMPLEX

PLOT NO.: 25, SECTOR-16A

NOIDA (U.P.) - 201 301

Job No: 3766

REPORT ON
GEOTECHNICAL INVESTIGATION WORK
AT 1 X 250MW NSPCL ROURKELA TPP-III
ODISHA

PART 1 : MAIN PLANT AREA
(*Volume I* : *Methodology, Analysis & Recommendations*)

Client:

M/s. Bharat Heavy Electricals Limited
9/1, D.J. Block, Sector-II,
Salt Lake City, Kolkata – 700 091

Foundation Consultants:

C. E. Testing Company Pvt. Limited
An ISO 9001, 14001& OHSAS 18001 Certified Company
NABL Accredited Laboratory
124A, N.S.C. Bose Road : Kolkata - 700 092
Phones: 2428-6221/6222/6223 Fax: (033) 2428-6220
Email: cetest@cetestindia.com

September – 2016
(Revised on 19.10.2016)

LIST OF CONTENTS

REPORT ON
GEOTECHNICAL INVESTIGATION WORK
AT 1 X 250MW NSPCL ROURKELA TPP-III
ODISHA.

1. INTRODUCTION

M/s. NTPC-SAIL Power Company (P) Limited has proposed 1 x 250MW Expansion Project at Rourkela, Odisha and the job of civil work was awarded to **M/s. Bharat Heavy Electricals Limited**. For layout plan and designing various foundation structures coming under this project, it was necessary to conduct a detail Geotechnical Investigation Work to obtain engineering properties of the underlying soil and the job was awarded to **M/s. C. E. Testing Company Pvt. Ltd.,** Kolkata.

This is a part of the whole project and deals with soil investigation around BTG Area**.** The scope of the work comprises of sinking 47 nos. boreholes, TP (Trial Pits – 5 Nos.), PLT (Plate Load Tests – 5 Nos.), CPLT (Cyclic Plate Load Tests – 3 Nos.), PMT (Pressure Meter Test – 3 Nos), ERT (Electrical Resistivity Tests – 19 Nos.), CST (Cross Hole Shear Tests – 3 Nos.), DCPT (Dynamic Cone Penetration Tests – 4 Nos.), SCPT (Static Cone Penetration Tests – 4 Nos.), FPT(Field Permeability Tests – 10 Nos.) and Field CBR Tests – 5 Nos.

The boreholes of 150 mm diameter were advanced by Shell and Auger method in soil. In rock, rotary core drilling of “NX” size was adopted. The scope also included conducting Standard Penetration Tests, collecting disturbed samples at regular intervals for identification and logging purposes, collecting undisturbed tube samples at suitable intervals or at change of strata whichever is earlier and testing these in the laboratory.

Based on the above, this report presents the Bore Logs, Soil Profile, laboratory and field Test Results. On the basis of field tests and laboratory test results and their analysis thereof, the most suitable type of foundation is suggested. The field profile is sometimes changed in the light of laboratory test results.

The subsoils is characterised by a filled up soil followed by stiff silty clay / clayey silt layer. Below this very stiff to hard silty clay / clayey silt layer was observed. After that weathered

rock layer was struck and that continues upto the terminating depth of all the boreholes. However around some borehole locations, soft to medium silty clay and very dense silty sand layer was observed.

Considering the nature of the subsoil as revealed from field tests, shallow foundation is recommended. However, this is discussed in details later.

The Geotechnical report has been divided into three parts as detailed below.

Part – 1: Main Plant Area

Volume-I: Methodology, Analysis & Recommendations

Volume-II: Bore logs, Field & Laboratory Test Results

Volume-III: Plate load Test (PLT), Cyclic Plate Load Test (CPLT), Standard Proctor Compaction & CBR Test Results

Part-2: Coal Handling Plant (CHP) & Ash Handling Plant (AHP) Area

Volume-I: Methodology, Analysis & Recommendations

Volume-II: Bore logs, Field & Laboratory Test Results

Volume-III: Plate load Test (PLT), Cyclic Plate Load Test (CPLT), Standard Proctor Compaction & CBR Test Results

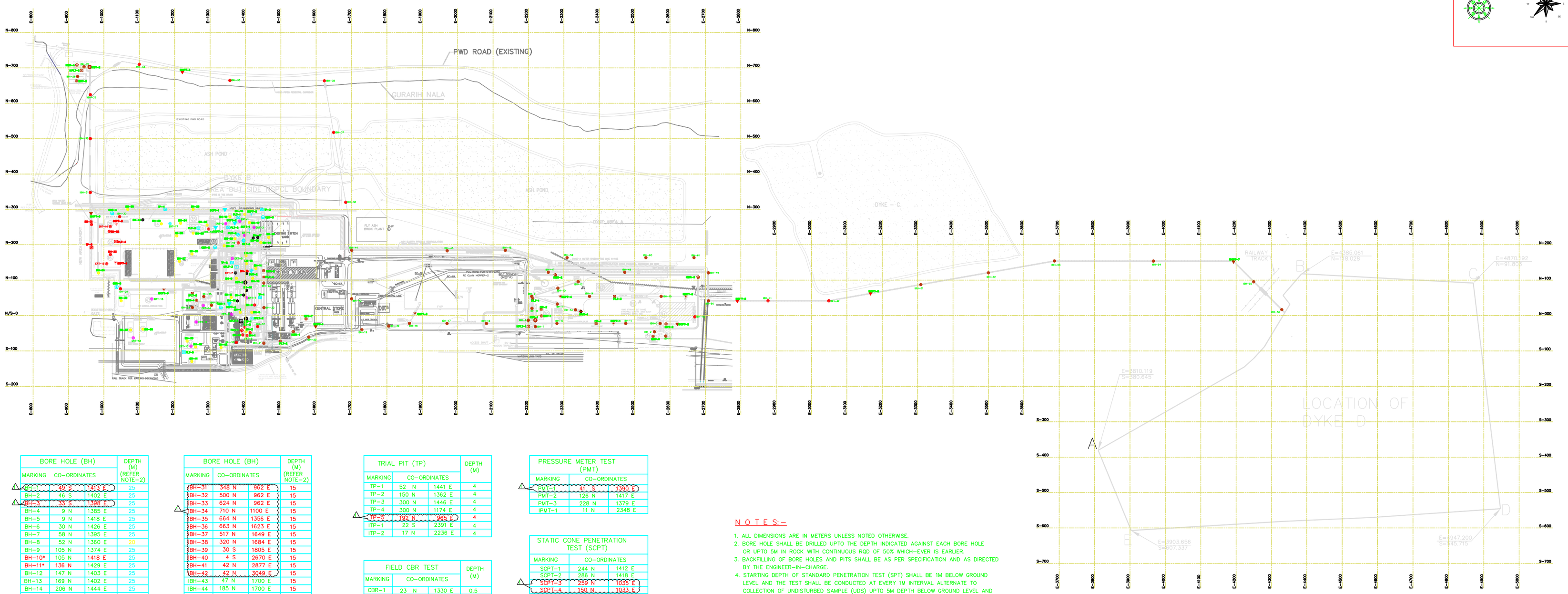
Part-3: River Water Intake pipe line & Pump House Area

Volume-I: Methodology, Analysis & Recommendations

Volume-II: Bore logs, Field & Laboratory Test Results

DRAWING No. PE-DG-427-602-C001

CUSTOMER'S DRAWING No.



BORE HOLE (BH)			DEPTH (M) (REFER NOTE-2)
MARKING	CO-ORDINATES		
BH-1	48 S	1403 E	25
BH-2	46 S	1402 E	25
BH-3	33 S	1398 E	25
BH-4	9 N	1385 E	25
BH-5	9 N	1418 E	25
BH-6	30 N	1426 E	25
BH-7	58 N	1395 E	25
BH-8	52 N	1360 E	20
BH-9	105 N	1374 E	25
BH-10*	105 N	1418 E	25
BH-11*	136 N	1429 E	25
BH-12	147 N	1403 E	25
BH-13	169 N	1402 E	25
BH-14	206 N	1444 E	25
BH-15*	221 N	1448 E	20
BH-16	219 N	1422 E	25
BH-17	263 N	1411 E	20
BH-18*	283 N	1398 E	20
BH-19	279 N	1356 E	20
BH-20	217 N	1370 E	25
BH-21	197 N	1340 E	15
BH-22	256 N	1292 E	20
BH-23	300 N	1252 E	15
BH-24*	261 N	1214 E	25
BH-25	233 N	1252 E	20
BH-26	174 N	1249 E	20
BH-27	153 N	1213 E	20
BH-28	225 N	1206 E	20
BH-29	259 N	1162 E	25
BH-30	300 N	1067 E	15
BH-31	257 N	985 E	15
BH-32	238 N	1015 E	20
BH-33	173 N	1018 E	20
BH-34	120 N	985 E	20
BH-35	119 N	1403 E	25
BH-36*	39 N	1045 E	20
BH-37	41 S	1075 E	20
BH-38	38 S	1110 E	20
BH-39	72 S	1235 E	15
BH-40*	92 S	1259 E	20
BH-41	130 S	1249 E	20
BH-42	90 S	1331 E	15
BH-43	55 S	1392 E	25
BH-44	270 S	1110 E	25
BH-45	41 N	1377 E	25
BH-46	71 N	1403 E	25
BH-47	221 N	1435 E	25
IBH-1	50 S	2581 E	25
IBH-2	46 S	2556 E	25
IBH-3	22 S	2572 E	25
IBH-4	22 S	2475 E	20
IBH-5	33 S	2280 E	20
IBH-6	13 S	2199 E	25
IBH-7	31 S	2229 E	25
IBH-8	20 N	2210 E	20
IBH-9	54 N	2209 E	20
IBH-10	78 N	2283 E	20
IBH-11	33 N	2281 E	20
IBH-12	96 N	2340 E	25
IBH-13	16 N	2333 E	25
IBH-14	54 N	2373 E	20
IBH-15	54 N	2575 E	20
IBH-16	22 S	2081 E	20
IBH-17	22 S	1970 E	20
IBH-18	22 S	1864 E	20
IBH-19	40 S	1729 E	20
IBH-20	61 S	1579 E	20
IBH-21	78 S	1452 E	20
IBH-22	23 N	1452 E	20
IBH-23	92 N	1452 E	20
IBH-24	23 N	1407 E	20
IBH-25	54 N	1282 E	20
IBH-26	29 N	1304 E	20
IBH-27	703 N	952 E	25
IBH-28	676 N	926 E	20
IBH-29	76 N	1047 E	15
IBH-30	290 N	1045 E	15

BORE HOLE (BH)			DEPTH (M) (REFER NOTE-2)
MARKING	CO-ORDINATES		
IBH-31	348 N	962 E	15
IBH-32	500 N	962 E	15
IBH-33	624 N	962 E	15
IBH-34	710 N	1100 E	15
IBH-35	664 N	1356 E	15
IBH-36	663 N	1623 E	15
IBH-37	517 N	1649 E	15
IBH-38	320 N	1684 E	15
IBH-39	30 S	1805 E	15
IBH-40	4 S	2670 E	15
IBH-41	42 N	2877 E	15
IBH-42	42 N	3049 E	15
IBH-43	47 N	1700 E	15
IBH-44	185 N	1700 E	15
IBH-45	184 N	1970 E	15
IBH-46	184 N	2135 E	15
IBH-47	122 N	2256 E	15
IBH-48	122 N	2472 E	15
IBH-49	121 N	2708 E	15
IBH-50	42 N	2709 E	20
IBH-51	87 N	3309 E	20
IBH-52	3500 E	121 N	15
IBH-53	3687 E	154 N	15
IBH-54	3966 E	154 N	15
IBH-55	4250 E	96 N	15
IBH-56	4329 E	17 N	15
IBH-57	1434 E	31 S	20
IBH-58	1374 E	76 S	20
IBH-59	2309 E	164 N	15
IBH-60	2532 E	164 N	15
IBH-61	3688 E	164 N	15

CYCLIC PLATE LOAD TEST (CPLT)			DEPTH (M)
MARKING	CO-ORDINATES		
CPLT-1	16 S	1388 E	3
CPLT-2	9 S	1418 E	3
CPLT-3	137 N	1375 E	3
ICPLT-1	31 S	2199 E	3
ICPLT-2	692 N	937 E	3

PLATE LOAD TEST (PLT)			DEPTH (M)
MARKING	CO-ORDINATES		
PLT-1	278 N	1380 E	3
PLT-2	249 N	1351 E	3
PLT-3	247 N	1267 E	3
PLT-4	209 N	1034 E	3
PLT-5	103 S	1228 E	3
IPLT-1	48 N	2211 E	3
IPLT-2	72 S	1498 E	3
IPLT-3	54 N	2443 E	3
IPLT-4	109 N	1452 E	3
IPLT-5	63 N	1250 E	3

TRIAL PIT (TP)			DEPTH (M)
MARKING	CO-ORDINATES		
TP-1	52 N	1441 E	4
TP-2	150 N	1362 E	4
TP-3	300 N	1446 E	4
TP-4	300 N	1174 E	4
TP-5	192 N	953 E	4
ITP-1	22 S	2391 E	4
ITP-2	17 N	2236 E	4

FIELD CBR TEST			DEPTH (M)
MARKING	CO-ORDINATES		
CBR-1	23 N	1330 E	0.5
CBR-2	193 N	1314 E	0.5
CBR-3	278 N	1449 E	0.5
CBR-4	289 N	1023 E	0.5
CBR-5	81 N	1036 E	0.5
ICBR-1	46 N	1535 E	0.5
ICBR-2	115 N	2275 E	0.5
ICBR-3	109 N	2680 E	0.5
ICBR-4	705 N	924 E	0.5

DYNAMIC CONE PENETRATION TEST (DCPT)		
MARKING	CO-ORDINATES	
DCPT-1	300 N	1342 E
DCPT-2	262 N	1370 E
DCPT-3	249 N	1316 E
DCPT-4	34 N	1354 E
IDCPT-1	31 S	1598 E
IDCPT-2	24 S	2621 E
IDCPT-3	289 N	964 E
IDCPT-4	698 N	1222 E
IDCPT-5	41 N	2790 E
IDCPT-6	62 N	3167 E
IDCPT-7	152 N	4103 E

CROSSHOLE SHEAR TEST (CST)		
MARKING	CO-ORDINATES	
CST-1	72 S	1402 E
CST-2	93 N	1400 E
CST-3	212 N	1395 E
ICST-1	13 S	2220 E
ICST-2	703 N	960 E

PRESSURE METER TEST (PMT)		
MARKING	CO-ORDINATES	
PMT-1	31 S	1390 E
PMT-2	126 N	1417 E
PMT-3	228 N	1379 E
IPMT-1	11 N	2348 E

STATIC CONE PENETRATION TEST (SCPT)		
MARKING	CO-ORDINATES	
SCPT-1	244 N	1412 E
SCPT-2	286 N	1418 E
SCPT-3	259 N	1035 E
SCPT-4	150 N	1033 E
ISCPT-1	22 S	2440 E
ISCPT-2	54 N	2644 E
ISCPT-3	7 N	1880 E
ISCPT-4	54 N	2290 E
ISCPT-5	74 N	1169 E

EART RESISTIVITY POINT (ERT)		
MARKING	CO-ORDINATES	
ERT-1	266 N	1384 E
ERT-2	260 N	1344 E
ERT-3	249 N	1424 E
ERT-4	226 N	1398 E
ERT-5	161 N	1362 E
ERT-6	121 N	1372 E
ERT-7	50 N	1402 E
ERT-8	4 N	1361 E
ERT-9	56 S	1404 E
ERT-10	88 S	1246 E
ERT-11	17 S	1260 E
ERT-12	63 S	1083 E
ERT-13	47 N	1135 E
ERT-14	28 N	1281 E
ERT-15	146 N	1008 E
ERT-16	251 N	1018 E
ERT-17	260 N	1186 E
ERT-18	245 N	1296 E
ERT-19	205 N	1380 E
IERT-1	1 S	2237 E
IERT-2	23 S	2589 E
IERT-3	127 N	1451 E
IERT-4	43 N	1282 E
IERT-5	663 N	922 E
IERT-6	59 S	2552 E
IERT-7	9 S	1571 E

NOTES:-

1. ALL DIMENSIONS ARE IN METERS UNLESS NOTED OTHERWISE.
2. BORE HOLE SHALL BE DRILLED UPTO THE DEPTH INDICATED AGAINST EACH BORE HOLE OR UPTO 5M IN ROCK WITH CONTINUOUS RQD OF 50% WHICH-EVER IS EARLIER.
3. BACKFILLING OF BORE HOLES AND PITS SHALL BE AS PER SPECIFICATION AND AS DIRECTED BY THE ENGINEER-IN-CHARGE.
4. STARTING DEPTH OF STANDARD PENETRATION TEST (SPT) SHALL BE 1M BELOW GROUND LEVEL AND THE TEST SHALL BE CONDUCTED AT EVERY 1M INTERVAL ALTERNATE TO COLLECTION OF UNDISTURBED SAMPLE (UDS) UPTO 5M DEPTH BELOW GROUND LEVEL AND AT EVERY 1.5M INTERVAL ALTERNATE TO COLLECTION OF UDS BEYOND 5M DEPTH, AT CHANGE OF STRATA & AT DEPTHS WHEREVER UDS COULD NOT BE COLLECTED.
5. STARTING DEPTH OF COLLECTION OF UDS SHALL BE 2M BELOW GROUND LEVEL AND UDS SHALL BE COLLECTED AT 1M INTERVAL ALTERNATE TO CONDUCTING SPT UPTO 5M DEPTH BELOW GROUND LEVEL & AT EVERY 1.5M INTERVAL ALTERNATE TO CONDUCTING SPT BEYOND 5M DEPTH.
6. PUMP IN TYPE FIELD PERMEABILITY TEST SHALL BE CARRIED OUT AT 2M & 4M DEPTH BELOW GROUND LEVEL IN BH-1, BH-10, BH-18, BH-27, BH-29, IBH-6, IBH-7, & IBH-12.
7. ELECTRICAL RESISTIVITY TEST SHALL BE CARRIED OUT AS PER WENNER'S METHOD.
8. PRESSURE METER TEST SHALL BE CARRIED OUT AT 1M, 3M, 5M, 7M, 9M, 12M, 15M, 18M 20M & 25M DEPTH BELOW GROUND LEVEL.
9. GROUND WATER SAMPLE SHALL BE COLLECTED FROM BH-2, BH-9, BH-19, BH-24, BH-36 IBH-6 IBH-7, IBH-12, IBH-13 & IBH-27.
10. CROSS HOLE SHEAR WAVE TEST SHALL BE CARRIED OUT AT 2M, 4M, 6M, 8M, 10M, 12M, 15M, 18M, 20M, 23M & 25M DEPTH BELOW GROUND LEVEL.
11. GEOTECHNICAL INVESTIGATION SHALL BE CARRIED OUT AS PER SPECIFICATION NO. PE-TS-999-603-002 AND SOQ SPECIFICATION NO. PE-DC-K28-602-C002.
12. DO NOT SCALE THIS DRAWING.

REF DRG :

PE-DG-427-100-M001, REV-01 "PLOT PLAN".

Note :

* - Location shifted due to local obstruction in consultation with Engineer-in-Charge.

GEOTECHNICAL INVESTIGATION LEGEND:

1. BOREHOLE (BH / IBH) . . . . . ●
2. PLATE LOAD TEST (PLT / IPLT) . . . . . ⊠
3. CYCLIC PLATE LOAD TEST (CPLT / ICPLT) . . . . . ⊡
4. DYNAMIC CONE PENETRATION TEST (DCPT / IDCPT) . . . . . ▼
5. STATIC CONE PENETRATION TEST (SCPT / ISCPT) . . . . . ▽
6. TRIAL PIT (TP / ITP) . . . . . ▨
7. FIELD CBR TEST (CBR / ICBR). . . . . ⊛
8. PRESSURE METER TEST (PMT / IPMT). . . . . ✦
9. CROSSHOLE SHEAR TEST (CST / ICST). . . . . ⊙
10. ELECTRICAL RESISTIVITY TEST (ERT / IERT) . . . . . ◍

GEOTECHNICAL INVESTIGATION LAYOUT FOR RIVER WATER INTAKE PIPE LINE OUTSIDE PLANT BOUNDARY SHALL BE SUBMITTED SEPARATELY.

LEGENDS:-

01	TG BUILDING	07	CHIMNEY	13	AHP COMPRESSOR CUM WATER PUMP HOUSE	19	COAL STOCK PILE	25	FIRE WATER P/H & MAKE-UP WATER P/H	31	DELETED	35	CW TREATMENT PLANT	41	CHP MATERIAL STORAGE YARD
02	TRANSFORMER YARD	08	ESP CONTROL ROOM	14	COOLING TOWER	20	CHP CONTROL ROOM	26	SPACE FOR F.G.D.			36	CHLORINE DIOXIDE DOSING SYSTEM	42	STACKER RECLAIMER MATERIAL STORAGE/ ASSEMBLY YARD
03	GIS SWITCHYARD	09	NEW ADMINISTRATIVE BUILDING	15	CWPH	21	COAL SETTLING POND	27	AIR WASHER ROOM (ON ROOF OF ACW PH)	32	FLY ASH SILO, DECANTING SYSTEM & HCSD PUMP HOUSE AREA	37	DELETED	43	AHP MATERIAL STORAGE YARD
04	BOILER HOUSE	10	INTERMIDIATE ASH SILO	16	CLARIFIED WATER STORAGE TANK	22	WAGON TIPPLER	28	PT PLANT			38	RAIN WATER HARVESTING POND	44	PLANT COMPRESSOR ROOM
05	MILL BAY	11	ASH SLURRY PUMP HOUSE	17	STP (IN DMP & CHP AREA)	23	WAGON TIPPLER CONTROL ROOM	29	O&M STORE	33	SERVICE BUILDING (EXISTING)	39	SERVICE WATER TANK & P/H	45	CENTRAL LUBE OIL BUILDING
06	ELECTROSTATIC PRECIPITATOR	12	EMERGENCY DG STATION	18	DM STORAGE TANK	24	ETP & GUARD POND	30	CRUSHER HOUSE	34	CONSTRUCTION STORE	40	CST & P/H		

REV	DATE	ALTD	CHD	APPD
01	02.08.2016	PK	AKV/TMSR	OPK

01 DRAWING IS REVISED THIS MARKED TO INCORPORATE THE CUSTOMER COMMENTS DATED 25.07.2016 AND DUE TO CHANGE IN PLOT PLAN.

CUSTOMER	NTPC-SAIL POWER COMPANY (P) LIMITED
CUSTOMER'S CONSULTANT	(नेवकॉन लिमिटेड) MECON LIMITED
JOB No.	427
STATUS	AS BUILT
DISTRIBUTION	
TO	
IN/OFF	

ROURKELA PP-II EXPANSION PROJECT (1X250 MW)

BHARAT HEAVY ELECTRICALS LTD
POWER SECTOR
PROJECT ENGINEERING MANAGEMENT
NOIDA

DEPT CODE		NAME	SIGN	DATE
C	DRN	S.NO	-SD-	18.07.2016
	DESN	PK	-SD-	18.07.2016
	CHD	AKV/TMSR	-SD-	18.07.2016
	APPD	OPK	-SD-	18.07.2016

TITLE: GEOTECHNICAL INVESTIGATION LAYOUT

MPL	C	MSE	I	MAX	E	DEPT.	SCALE	DRAWING No.
						SIGN		PE-DG-427-602-C001
						DATE		SHEET 01 OF 01 REV 01

SIZE-A0

COMPUTER FILE NAME:

2. FIELD INVESTIGATION

2.1. GENERAL:

In an attempt for finalisation in the design of foundation for these proposed structures to be constructed at this site, Geotechnical Investigation was envisaged. The entire Investigation programme had been divided mainly into two parts, I) Field works & II) Laboratory tests.

I) Field works unfold the sub-surface deposit types and their characteristics and

II) Laboratory tests part would help determining the relevant physical and geotechnical properties of the sub-surface deposits leading to finalisation of foundation depths of the structures and the bearing capacity with particular reference to the sub-surface types and their strength parameters and settlement potentials at the site.

A list of the bore holes with the reduced level and standing water level are presented in a tabular form below:-

Name of the Structure	BH No.	Co-ordinate (M)			Terminating Depth (M)	SWL (M)	Top of rock below EGL(M)
		E	N	G.L.			
Chimney	01	1413	-49	219.643	25.00	1.30	5.50
	02	1402	-46	219.481	25.00	2.35	7.00
	03	1398	-33	219.174	25.00	1.20	6.00
ESP & ID Fan Area	04	1385	9	218.565	25.00	0.80	5.50
	05	1418	9	218.658	25.00	1.05	5.50
	06	1426	30	218.736	25.00	1.00	6.50
	07	1395	58	218.826	25.00	1.20	7.50
	08	1360	52	218.463	20.00	1.90	7.00
Boiler & Mill Bunker Area	09	1374	105	219.235	25.00	2.60	5.80
	10	1418	105	219.500	25.00	2.20	7.00
	11	1429	136	218.957	25.00	2.30	8.30
	12	1403	147	218.869	25.00	2.50	9.00
	13	1402	169	218.452	25.00	2.30	7.30
Power House	14	1444	206	218.569	25.00	2.40	7.50
Near Plant Compressor Room	15	1448	221	218.622	20.00	1.20	6.10
Power House	16	1422	219	218.406	25.00	2.60	7.00
Transformer Yard	17	1411	263	218.423	20.00	2.55	7.30
Switch Yard	18	1398	283	218.015	20.00	1.45	6.50
	19	1356	279	217.036	20.00	1.65	7.00
Power House	20	1370	217	218.036	25.00	2.65	7.00
Emergency DG Station	21	1340	197	216.219	15.00	0.45	4.50
CWPH	22	1292	256	215.997	20.00	0.60	5.30
Boundary Wall	23	1252	300	216.344	15.00	0.85	6.80
Cooling Tower	24	1214	261	216.532	25.00	0.60	6.00

Name of the Structure	BH No.	Co-ordinate (M)			Terminating Depth (M)	SWL (M)	Top of rock below EGL(M)
		E	N	G.L.			
Near Chlorine Dioxide Dosing System	25	1252	233	216.047	20.00	0.50	4.50
Rain Water Harvesting Pond	26	1249	174	215.959	15.00	0.45	4.75
Service Water Tank & P/H	27	1213	153	215.805	20.00	0.45	6.50
--	28	1206	225	215.693	20.00	0.55	4.75
Cooling Tower	29	1162	259	215.743	25.00	0.70	5.75
--	30	1067	300	216.407	15.00	0.30	5.80
--	31	965	257	215.838	15.00	0.80	6.85
PT Plant	32	1015	238	215.012	20.00	0.60	6.80
Clarified Water Storage Tank	33	1018	173	215.886	20.00	0.50	8.10
--	34	985	120	215.843	20.00	0.80	5.90
Boiler & Mill Bunker Area	35	1403	119	219.115	25.00	2.40	7.20
Near Construction Store	36	1045	39	216.771	20.00	0.45	5.60
New Administrative Building	37	1075	-41	217.707	20.00	1.15	4.80
O & M Store	38	1110	-38	218.143	20.00	1.25	7.60
ETP & Guard Pond	39	1235	-72	218.950	15.00	2.20	3.90
	40	1259	-92	219.092	20.00	2.80	4.25
STP	41	1249	-130	218.525	20.00	1.40	4.30
DM Storage Tank	42	1331	-90	218.694	15.00	1.10	4.40
Chimney	43	1392	-55	219.747	25.00	1.44	6.00
Cooling Tower	44	1110	-270	215.844	25.00	0.40	6.30
ESP & ID Fan Area	45	1377	41	218.523	25.00	1.25	5.50
	46	1403	71	218.952	25.00	1.35	7.20
Power House	47	1435	221	218.547	25.00	2.20	6.90

2.2. BORING:

Boring was carried out by Shell and Auger method to sink nominal 150mm diameter bore holes to depths envisaged by using a mechanical winch. Undisturbed soil samples were collected at suitable intervals or at change of strata whichever is earlier by open drive sampling method since it was intended to ascertain the sub-soil characteristics.

2.3. SAMPLING:

Nominal 100 mm diameter undisturbed samples were recovered. The sampling equipment used consists of a two-tier assembly of sample tubes 450 mm in length fitted at its lower end. The sampling assembly was driven by means of a jarring link to its full length or as far downs as was found practicable. As the soil is very stiff to hard and contains sand mixtures /

calcareous nodules, cutting shoe was used with a area ratio < 20%. After withdrawal the ends of the tubes were sealed with wax and capped before onward transmission to the laboratory. At close intervals in depth disturbed samples were collected for identification and logging purpose. These were tagged and packed in polythene packets and transported to the laboratory.

2.4. STANDARD PENETRATION TESTS:

Standard Penetration Tests were conducted in the bore holes at intervals of 1.5M to 3.0M depth or at change of strata whichever is earlier using a split spoon sampler. The split spoon sampler used is of a Standard design having an outer diameter of 50.8 mm and inner diameter of 35 mm, driven with a monkey weighing 63.5 kgs, falling freely through 75cms. A record of the number of blows required to penetrate every 15cms to a maximum depth of 45cms was made. The first 15cm of drive are considered to be seating drive and are neglected. The total blows required for second & third 15cm of penetration is counted and termed as penetration resistance "N". On completion of a test, the split spoon sampler was opened and soil specimens were preserved in polythene bags for logging purpose.

All the boreholes were sunk with winch. However, raising of hammer for SP Tests were done manually. Hence there will not be any inertia loss and the efficiency of hammer blows should be considered as 100%.

2.5. MEASUREMENT OF WATER TABLE:

Standing water level after 24 hours of removal of casing was also noted and shown in the profile.

2.6. ROTARY CORE DRILLING:

This drilling technique is regarded as the most satisfactory method of assessing the character of rock formations, which lie at depth below the ground surface. Specimens of rock in the form of cylindrical cores are recovered from the drill holes by means of a core barrel. Double barrel technique is adopted according to field condition. The core barrel is provided at its lower end with a detachable shoe or core bit, which is of diamond. All rotary core bits were of NX size.

2.7. TRIAL PITS:

5 nos. Trial Pits were excavated for physical verification of subsoil with depth. The co-ordinates of the Trial Pit locations are presented below.

Trial Pit No.	Co-ordinate (M)			Depth (M)	Standing Water Level (M)
	Easting	Northing	G.L.		
TP – 1	1441	52	218.527	4.00	3.80
TP – 2	1362	150	218.452	4.00	4.00
TP – 3	1446	300	218.173	4.00	Not Available
TP – 4	1174	300	215.891	4.00	Not Available
TP – 5	965	192	215.911	4.00	0.70

2.8. FIELD PERMEABILITY TEST:

Field Permeability Tests were conducted in five (5) locations using falling head method as per IS: 5529 (Part 1).The test locations are presented below.

Test Locations	Co-ordinates (M)			Type of Test	Depth of Test (M)
	Easting	Northing	G.L.		
BH-01	1413	-49	219.643	Falling Head	2.20 – 2.80
				Falling Head	4.00 – 4.60
BH-10	1418	105	219.500	Falling Head	1.70 – 2.40
				Falling Head	3.65 – 4.45
BH-18	1398	283	218.015	Falling Head	1.60 – 2.40
				Falling Head	3.70 – 4.40
BH-27	1213	153	215.805	Falling Head	1.70 – 2.30
				Falling Head	3.80 – 4.50
BH-29	1162	259	215.743	Falling Head	2.00 – 2.70
				Falling Head	4.00 – 4.70

2.9. FIELD CBR TEST:

The tests were carried out in accordance with IS 2720 (Part 31): 1969 (and Amendment 1).

Apparatus used: Jacks, proving ring of capacity 500kg with a dial gauge to read to an accuracy of 0.002mm, metal penetration piston, extension rods, MS truss, connector, surcharge weight etc.

Test Procedure & Loading Arrangement: A pit was excavated of a suitable size upto the desired depth. A truss, used for providing reaction for loading was suitably anchored. The loading arrangement was made with sand bags. The sand bags were loaded on the truss suitably. The equipment used to provide load reaction was located at the centre of the truss against which the loading jack worked. The proving ring was connected to the bottom end of the jack and the piston connector to the bottom of the proving ring. Then the piston was

connected using extension rods. The dial gauge was fitted suitably. It was ensured that the entire assembly was plumbed and the loading jack should be clamped in position. The surcharge weight of 10 kg was kept in position on the test surface. The penetration piston was seated with the smallest possible load. Then the load was applied on the penetration piston to penetrate approximately 1.25mm / minute. Then the load reading was recorded at penetration of 0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 7.5, 10.0 & 12.5mm. Then the set up was dismantled. In this manner the test was conducted in unsoaked & soaked condition.

Total 5nos. Field C.B.R. Tests were conducted. The co-ordinates of the test locations are presented below. The test results & curves are presented in Volume-2.

FCBR No.	Co-ordinate (M)			Depth (M)
	E	N	G.L.	
CBR - 1	1330	23	218.475	0.50
CBR - 2	1314	193	215.713	0.50
CBR - 3	1449	278	218.591	0.50
CBR - 4	1023	289	216.118	0.50
CBR - 5	1036	81	215.885	0.50

2.10. DYNAMIC CONE PENETRATION TEST:

Total 4 nos. Dynamic Cone Penetration Tests were conducted at the following locations. The co-ordinates at each DCPT locations are presented below. The DCPT values vs. depth plots are presented in Volume-2.

DCPT No.	Co-ordinate (M)			Depth (M)	
	E	N	G.L.	Starting depth	Ending Depth
1	1342	300	218.028	0.00	5.70
2	1370	262	217.913	0.00	6.00
3	1316	249	216.211	0.00	4.80
4	1354	34	218.470	0.00	5.40

2.11. STATIC CONE PENETRATION TEST:

Total 4 nos. Static Cone Penetration Tests were conducted at the following locations. The co-ordinates at each SCPT locations are presented below.

SCPT No.	Co-ordinate (M)			Depth (M)	
	E	N	G.L.	Starting depth	Ending Depth
1	1412	244	218.479	0.60	7.00
2	1418	286	217.994	0.40	7.20
3	1035	259	215.218	0.60	6.60
4	1033	150	215.657	0.40	7.80

2.12. PLATE LOAD TESTS:

Total eight (8) sets of Plate Load Tests were conducted (five no. tests are of routine type & rest three nos. are of cyclic type). For Test results of PLT & CPLT, refer Volume-III of the report.

2.13. ELECTRICAL RESISTIVITY TESTS:

Nineteen (19) nos. Electrical Resistivity Tests were carried out at the following locations. The test procedure and results are presented in Volume – 2/Part IB.

ERT	Co-ordinate (M)		G.L. in metre	ERT	Co-ordinate (M)		G.L. in metre
	E	N			E	N	
1	1384	266	217.845	11	1260	-17	218.520
2	1344	260	216.766	12	1083	-63	217.749
3	1424	249	218.562	13	1135	47	216.453
4	1398	226	218.252	14	1281	28	218.310
5	1362	161	218.572	15	1008	146	215.625
6	1372	121	219.220	16	1018	251	215.194
7	1402	50	218.657	17	1186	260	215.736
8	1361	4	218.425	18	1296	245	215.999
9	1404	-56	219.985	19	1380	205	218.058
10	1246	-86	219.188				

2.14. CROSS HOLE SHEAR TEST:

Three (3) nos. Cross Hole Shear Test were carried out to determine the dynamic properties of the layer for the construction of machine foundations at the following locations. The test procedure and results are presented and discussed in Volume – 2/Part IB.

CHT No.	Co-ordinates (M)		Ground Level (M)
	E	N	
CST -1	1402	-12	218.404
CST -2	1400	93	219.158
CST -3	1395	212	218.326

2.15. PRESSURE METER TESTS:

Total 3nos. Pressure Meter Tests were conducted at the following locations. The test procedure and results are presented in Volume – 2/Part IB.

PMT No.	Co-ordinates (M)		Ground Level (M)
	E	N	
PMT - 1	1390	-41	219.322
PMT - 2	1417	126	219.406
PMT - 3	1379	228	218.134

3. LABORATORY TESTING

For proper identification and classification of the sub-soil deposits and for deriving adequate information regarding its relevant physical and geotechnical properties at the site under investigation, the following laboratory tests were conducted on the soil / rock samples collected from the exploratory bore holes:

On Soil Samples:

1. **Grain size analysis (Sieve as well as Hydrometer).**
2. **Determination of Liquid Limit, Plastic Limit and Shrinkage Limit.**
3. **Determination of Natural Moisture Content.**
4. **Determination of Specific Gravity.**
5. **Determination of Bulk & Dry Unit Weight.**
6. **Strength determination by Triaxial Unconsolidated Undrained Test (UU).**
7. **Strength Determination of Unconfined Compression Test on "UDS" (UNCONFD).**
8. **Strength Determination of Unconfined Compression Test on REMOULDED samples.**
9. **Strength determination by Direct Shear Test.**
10. **One-dimensional Consolidation Test for determining settlement potentiality.**
11. **Determination of Free Swelling Index & Swelling Pressure.**
12. **Conducting Standard Proctor Compaction Test to determine Optimum Moisture Content (OMC) and Maximum Dry Density (MDD).**
13. **Conducting CBR test (unsoaked & soaked) on sample prepared at OMC / MDD.**
14. **Chemical tests on soil and water samples to determine pH value, Sulphate, Chloride content etc.**

On Rock Samples:

1. **Determination of Bulk Density, Water Content, Specific Gravity & Porosity of Rock.**
2. **Determination of Unconfined Compressive Strength of Rock samples (Saturated & In-situ State)**
3. **Determination of Point Load Strength Index.**
4. **Determination of Slake Durability Index of Rock.**
5. **Determination of Hardness, Soundness, Deformability both saturated and in-situ water content.**

Laboratory test results are presented in a tabular form in Volume - 2. The results are self explanatory excepting that of consolidation tests. The compressibility for a pressure range has been separated into 2 components through the compression ratio. As a first step dial gauge reading is plotted against square root of time and by extrapolation dial reading at zero time, is obtained. The compression ratio is given as

$r = (d_i - d_s)/(d_i - d_f)$, where

d_i = Initial reading of dial before load application

d_s = Dial reading corresponding to theoretical zero time

d_f = Final dial reading after 24 hrs.

Now we write $m_{vc} = (1- r) \times m_v$

All the tests were conducted as per relevant Indian Standard Specifications.

4. SUBSOIL CONDITION, STRATIFICATION AND PROPERTIES

4.1. SUB-SOIL CONDITIONS:

The boring records showing the various soils met with are enclosed in Volume-2. These are prepared from field logs after proper modifications in the light of the laboratory test results and observation of disturbed and penetrometer soil samples. The results of the Standard Penetration Tests are given as 'N' values in these boring records. The sub-soil profiles (as obtained from field and Laboratory test results) across the bore holes are shown under Figs. 2.01 to 2.15 giving description, consistency and colour of each strata. The "N" values are shown in the profiles as well as presented in the borelogs in Volume-2. The laboratory test results and the back up sheets are also presented there.

4.2. SUB-SOIL STRATIFICATIONS:

The subsoils is characterised by a filled up soil followed by stiff silty clay / clayey silt layer. Below this very stiff to hard silty clay / clayey silt layer was observed. After that weathered rock layer was struck and that continues upto the terminating depth of all the boreholes. However around some borehole locations, soft to medium silty clay and very dense silty sand layer was observed.The description of each layer is presented below.

4.2.1. FILL:

Filled up soil consists of fly ash, brick bats, kankar, stone, gravel, boulder etc**.** The average properties of this layer shows the following properties, however these properties does not truly represents the properties of the whole stratum,

Bulk Density, gms/cc	2.06	Specific gravity	2.69
Dry Density, gms/cc	1.75	Liquid limit %	40
Natural Water Content %	18	Plastic Limit %	17

4.2.2. STRATUM - IA:

The soil in this layer consists of stiff, grayish yellow / dark grey to brownish grey, silty clay with sand mixture. Kankar, steel grey spots & reddish spots have been observed in this layer. The average properties of this layer are presented below.

Bulk Density, gms/cc	2.05	Void Ratio	0.589
Dry Density, gms/cc	1.71	Liquid limit %	43
Natural Water Content %	20	Plastic Limit %	20
Specific gravity	2.69	Shrinkage Limit %	16

TRSH-UU:			
Cohesion kg/sqcm	0.54	**GRAIN SIZE**	
Friction angle °	5°	Gravel %	01
Unconfined cohesion, kg/sqcm	**0.60**	Sand %	24
Remoulded cohesion, kg/sqcm	**0.45**	Silt %	58
SENSITIVITY, S_t	**1.33**	Clay %	17

4.2.3. STRATUM - IB:

The soil in this layer consists of soft to medium, grayish yellow to brownish grey / yellowish brown, silty clay with traces of kankar, sand mixture, steel grey spots, kankar & reddish spots. The average properties of this layer are presented below.

Bulk Density, gms/cc	2.03	Specific gravity	2.67
Dry Density, gms/cc	1.69	Void Ratio	0.546
Natural Water Content %	20	Liquid limit %	40
TRSH-UU:		Plastic Limit %	19
Cohesion kg/sqcm	0.35	Shrinkage Limit %	19
Friction angle °	0°	**GRAIN SIZE**	
Unconfined cohesion, kg/sqcm	**0.41**	Sand %	22
Remoulded cohesion, kg/sqcm	**0.32**	Silt %	58
SENSITIVITY, S_t	**1.30**	Clay %	20

4.2.4. STRATUM - I:

The soil in this layer consists of very stiff to hard, yellowish grey / brownish grey / light grey, silty clay with sand mixture & decomposed rock fragments. Kankar, reddish & black spots have also been observed in this layer. The average properties of this layer are presented below.

Bulk Density, gms/cc	2.06	Specific gravity	2.70
Dry Density, gms/cc	1.73	Void Ratio	0.529
Natural Water Content %	19	Liquid limit %	40
		Plastic Limit %	21
TRSH-UU:		Shrinkage Limit %	16
Cohesion kg/sqcm	1.11	**GRAIN SIZE**	
Friction angle °	5°	Gravel %	01
Unconfined cohesion, kg/sqcm	**0.97**	Sand %	22
Remoulded cohesion, kg/sqcm	**0.77**	Silt %	62
SENSITIVITY, S_t	**1.26**	Clay %	15

4.2.5. STRATUM - II:

Underlying the above, we have a layer of very dense, light yellowish brown silty fine sand / sandy silt with mica, decomposed rock fragments. The average properties of this layer are presented below.

Specific gravity	2.67
GRAIN SIZE	
Gravel %	02
Sand %	54
(Silt+Clay) %	44

4.2.6. STRATUM - IIA:

Underlying the above, we have a layer of medium dense, light yellowish brown silty fine sand / sandy silt with mica, decomposed rock fragments and present only around BH-23, 31, 33, 40 & 43 locations. The average properties of this layer are presented below.

Liquid limit %	32
Plastic Limit %	25
GRAIN SIZE	
Gravel %	03
Sand %	54
(Silt+Clay) %	43

4.2.7. STRATUM - III:

This is a rock layer and this layer consists of completely to highly weathered, brownish grey to dark grey / yellowish grey, fine to medium grained, highly fractured rock.

The following tests were carried out on the rock samples viz.

1. Unconfined Compressive Strength determination of the rock samples after 24 hours full submergence and thereafter air drying before testing (i.e. saturated condition).
2. Determination of Point Load Strength Index.

The average properties of this layer as revealed from the routine laboratory test are as follows.

Bulk Density, gms/cc	2.541
Dry Density, gms/cc	2.509
Water Content %	1.275
Specific Gravity	2.624
Porosity %	3.284
UCS (saturated), kg/sqcm	22
Point Load Strength Index, kg/sqcm	1.04

4.2.8. STRATUM - IV:

This is also a rock layer, consists of highly to moderately weathered, yellowish grey to light grey / dark grey, medium to fine grained, highly to moderately / slightly fractured rock with rusty / brown spots.

The average properties of this layer as revealed from the routine laboratory test are as follows.

Bulk Density, gms/cc	2.636	UCS (insitu), kg/sqcm	188
Dry Density, gms/cc	2.610	UCS (saturated), kg/sqcm	120
Water Content %	0.996	Co-efficient of Softening	0.64
Specific Gravity	2.652		
Porosity %	2.640	Point Load Strength Index, kg/sqcm	1.67

4.2.9. STRATUM - V:

This is also a rock layer and continues upto the terminating depth of boreholes, consists of moderately to slightly weathered, yellowish grey to light grey / dark grey, fine grained, moderately to slightly fractured rock with rusty / brown spots. The average properties of this layer as revealed from the routine laboratory test are as follows.

Bulk Density, gms/cc	2.748	UCS (insitu), kg/sqcm	350
Dry Density, gms/cc	2.739	UCS (saturated), kg/sqcm	217
Water Content %	0.329	Co-efficient of Softening	0.62
Specific Gravity	2.757		
Porosity %	0.880	Point Load Strength Index, kg/sqcm	11.61

4.3. GRAPHICAL PRESENTATION:

The detailed Laboratory Test Results in tabular form are given in Volume-2. The back up sheets are also presented there as given in below:

1. ***Strength envelopes from Triaxial Tests.***
2. ***Standard Proctor Compaction Curves.***
3. ***CBR Curves.***
4. ***e-log p curves from consolidation tests.***
5. ***Grain size distribution curves for sieve and hydrometer tests.***

The consolidation test results are analysed by numerical methods and only the final output in a tabular form is given. The m_{vc} indicates the time dependent component of m_v and c_v is the co-efficient of consolidation.

Project :	Geotechnical Investigation Work at 1x250 MW NSPCL Rourkela TPP-III, Odisha.		CETEST
Job No : 3766	Created by : SKD	Created on : 05 / 09 / 2016	Sheet No:

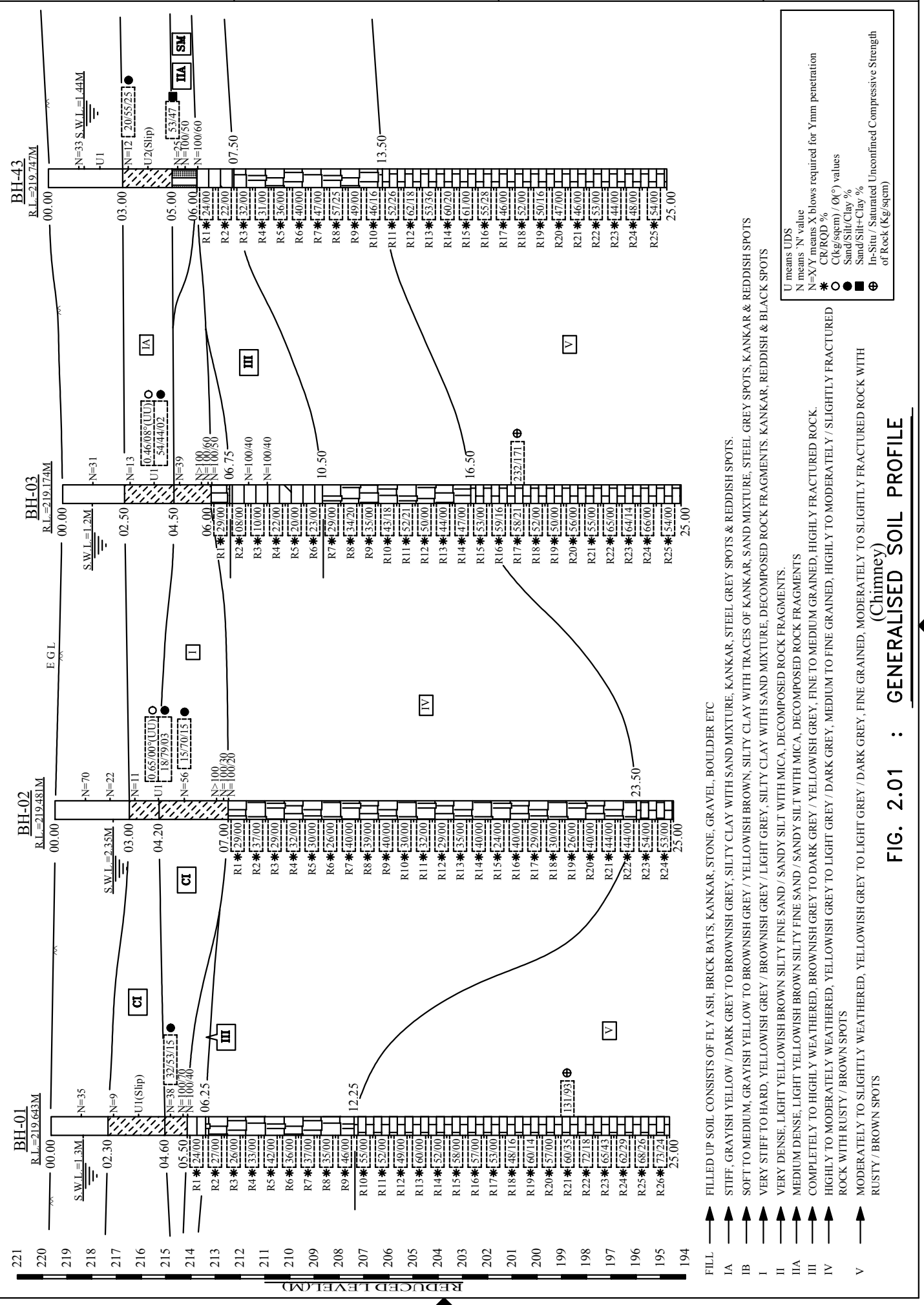
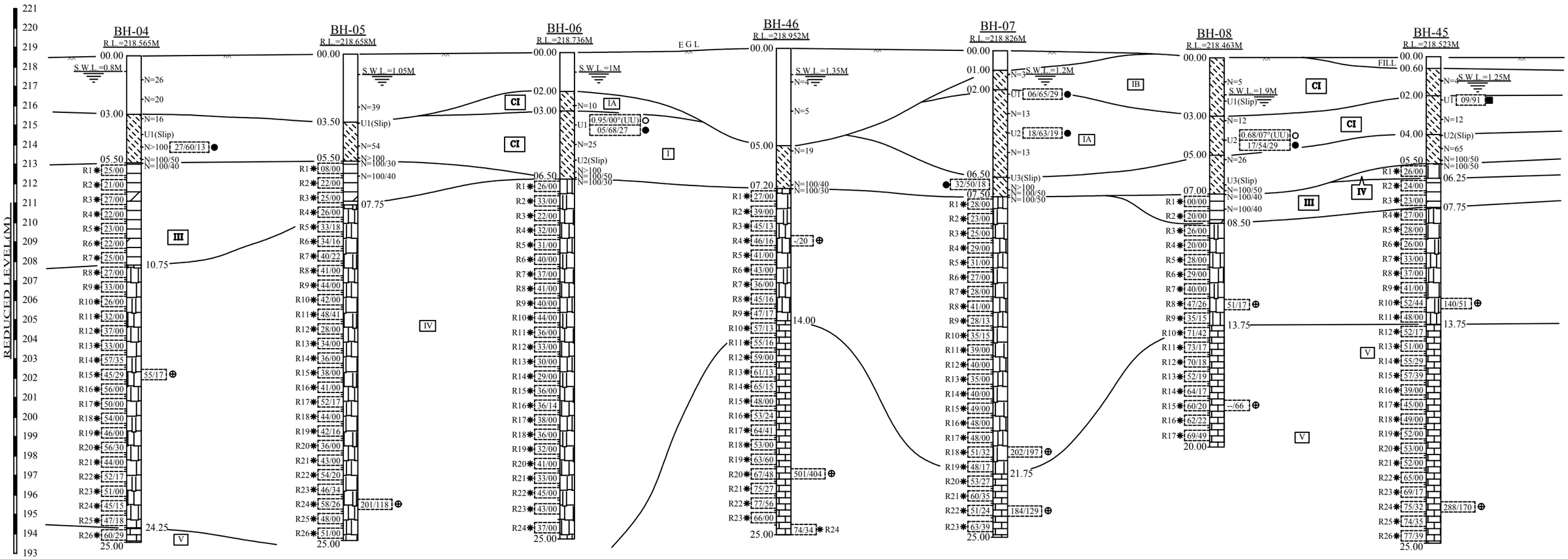


FIG. 2.01 : GENERALISED SOIL PROFILE (Chimney)

Project :	Geotechnical Investigation Work at 1x250 MW NSPCL Rourkela TPP-III, Odisha.		CETEST
Job No : 3766	Created by : SKD	Created on : 06 / 09 / 2016	Sheet No:



FILL → FILLED UP SOIL CONSISTS OF FLY ASH, BRICK BATS, KANKAR, STONE, GRAVEL, BOULDER ETC

IA → STIFF, GRAYISH YELLOW / DARK GREY TO BROWNISH GREY, SILTY CLAY WITH SAND MIXTURE, KANKAR, STEEL GREY SPOTS & REDDISH SPOTS.

IB → SOFT TO MEDIUM, GRAYISH YELLOW TO BROWNISH GREY / YELLOWISH BROWN, SILTY CLAY WITH TRACES OF KANKAR, SAND MIXTURE, STEEL GREY SPOTS, KANKAR & REDDISH SPOTS

I → VERY STIFF TO HARD, YELLOWISH GREY / BROWNISH GREY / LIGHT GREY, SILTY CLAY WITH SAND MIXTURE, DECOMPOSED ROCK FRAGMENTS. KANKAR, REDDISH & BLACK SPOTS

II → VERY DENSE, LIGHT YELLOWISH BROWN SILTY FINE SAND / SANDY SILT WITH MICA, DECOMPOSED ROCK FRAGMENTS.

IIA → MEDIUM DENSE, LIGHT YELLOWISH BROWN SILTY FINE SAND / SANDY SILT WITH MICA, DECOMPOSED ROCK FRAGMENTS

III → COMPLETELY TO HIGHLY WEATHERED, BROWNISH GREY TO DARK GREY / YELLOWISH GREY, FINE TO MEDIUM GRAINED, HIGHLY FRACTURED ROCK.

IV → HIGHLY TO MODERATELY WEATHERED, YELLOWISH GREY TO LIGHT GREY / DARK GREY, MEDIUM TO FINE GRAINED, HIGHLY TO MODERATELY / SLIGHTLY FRACTURED ROCK WITH RUSTY / BROWN SPOTS

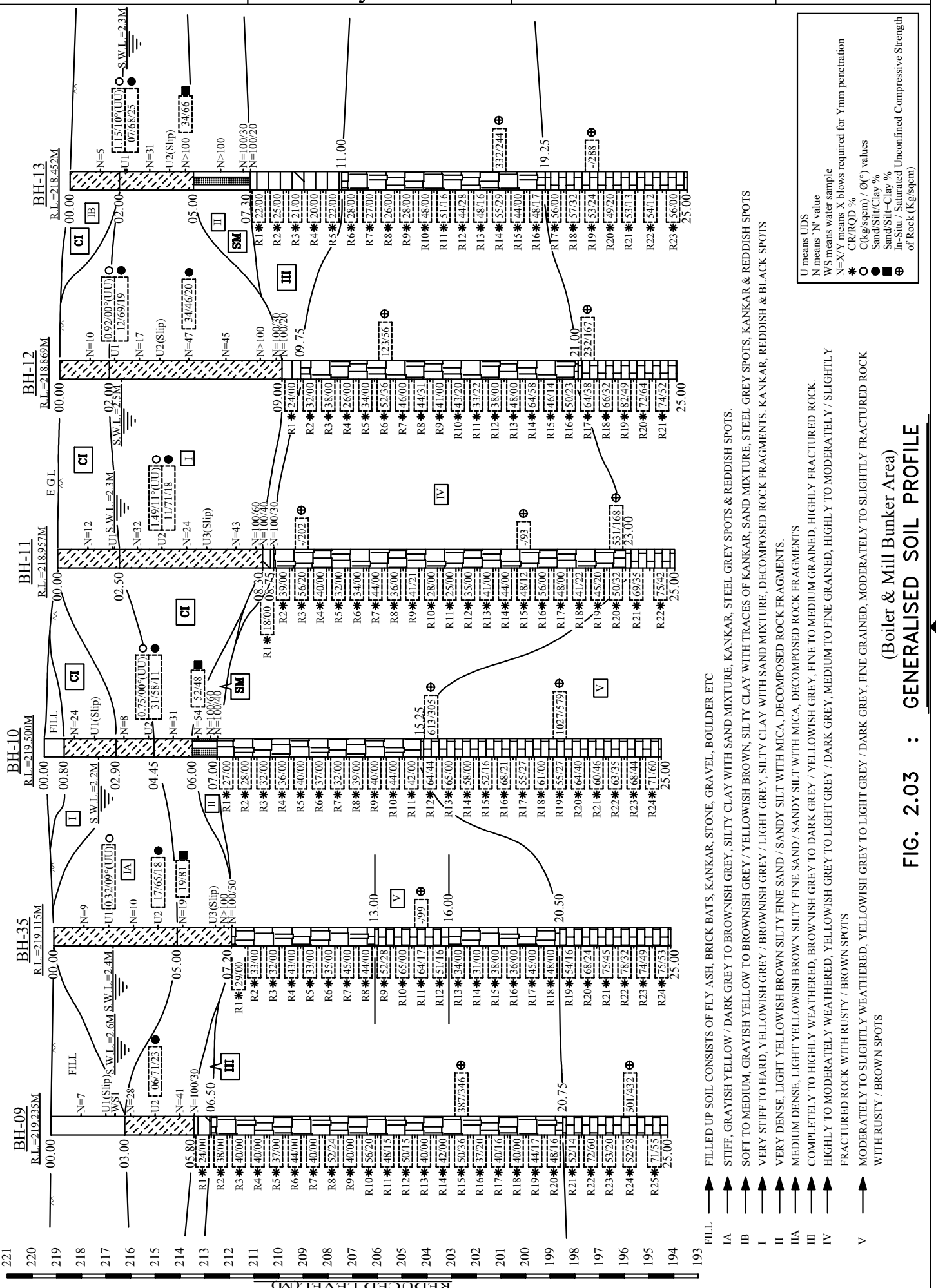
V → MODERATELY TO SLIGHTLY WEATHERED, YELLOWISH GREY TO LIGHT GREY / DARK GREY, FINE GRAINED, MODERATELY TO SLIGHTLY FRACTURED ROCK WITH RUSTY / BROWN SPOTS

U means UDS
N means `N' value
N=X/Y means X blows required for Ymm penetration
✱ CR/RQD %
○ C(kg/sqcm) / Ø(°) values
● Sand/Silt/Clay %
■ Sand/Silt+Clay %
⊕ In-Situ / Saturated Unconfined Compressive Strength of Rock (Kg/sqcm)

(ESP & ID Fan Area)

FIG. 2.02 : GENERALISED SOIL PROFILE

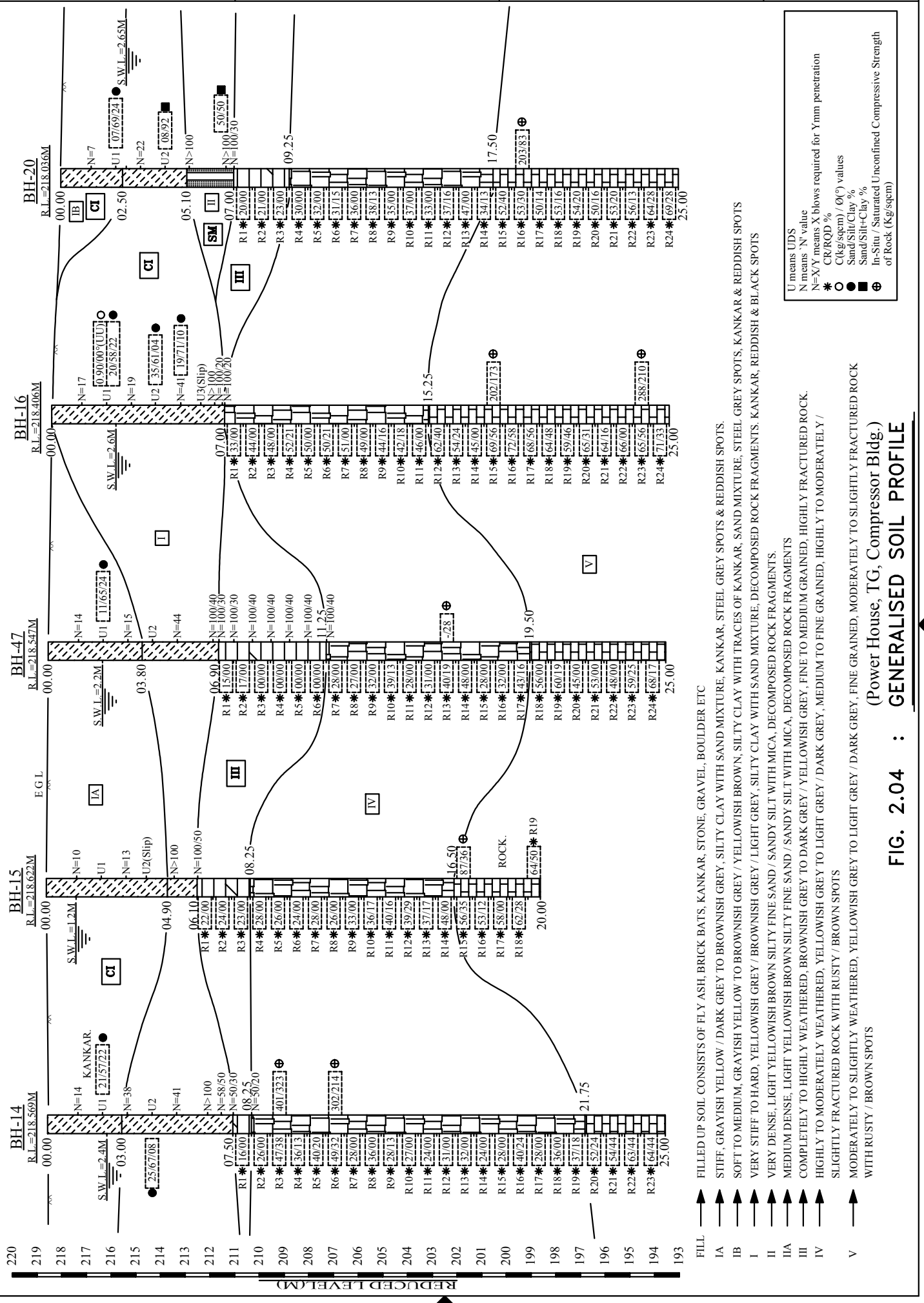
Project :	Geotechnical Investigation Work at 1x250 MW NSPCL Rourkela TPP-III, Odisha.		CETEST
Job No : 3766	Created by : SKD	Created on : 05 / 09 / 2016	Sheet No:



(Boiler & Mill Bunker Area)

FIG. 2.03 : GENERALISED SOIL PROFILE

Project :	Geotechnical Investigation Work at 1x250 MW NSPCL Rourkela TPP-III, Odisha.		CETEST
Job No : 3766	Created by : SKD	Created on : 05 / 09 / 2016	Sheet No:



FILLED UP SOIL CONSISTS OF FLY ASH, BRICK BATS, KANKAR, STONE, GRAVEL, BOULDER ETC

STIFF, GRAYISH YELLOW / DARK GREY TO BROWNISH GREY, SILTY CLAY WITH SAND MIXTURE, KANKAR, STEEL GREY SPOTS & REDDISH SPOTS.

SOFT TO MEDIUM, GRAYISH YELLOW TO BROWNISH GREY / YELLOWISH BROWN, SILTY CLAY WITH TRACES OF KANKAR, SAND MIXTURE, STEEL GREY SPOTS, KANKAR & REDDISH SPOTS

VERY STIFF TO HARD, YELLOWISH GREY / BROWNISH GREY / LIGHT GREY, SILTY CLAY WITH SAND MIXTURE, DECOMPOSED ROCK FRAGMENTS. KANKAR, REDDISH & BLACK SPOTS

VERY DENSE, LIGHT YELLOWISH BROWN SILTY FINE SAND / SANDY SILT WITH MICA, DECOMPOSED ROCK FRAGMENTS.

MEDIUM DENSE, LIGHT YELLOWISH BROWN SILTY FINE SAND / SANDY SILT WITH MICA, DECOMPOSED ROCK FRAGMENTS

COMPLETELY TO HIGHLY WEATHERED, BROWNISH GREY TO DARK GREY / YELLOWISH GREY, FINE TO MEDIUM GRAINED, HIGHLY FRACTURED ROCK.

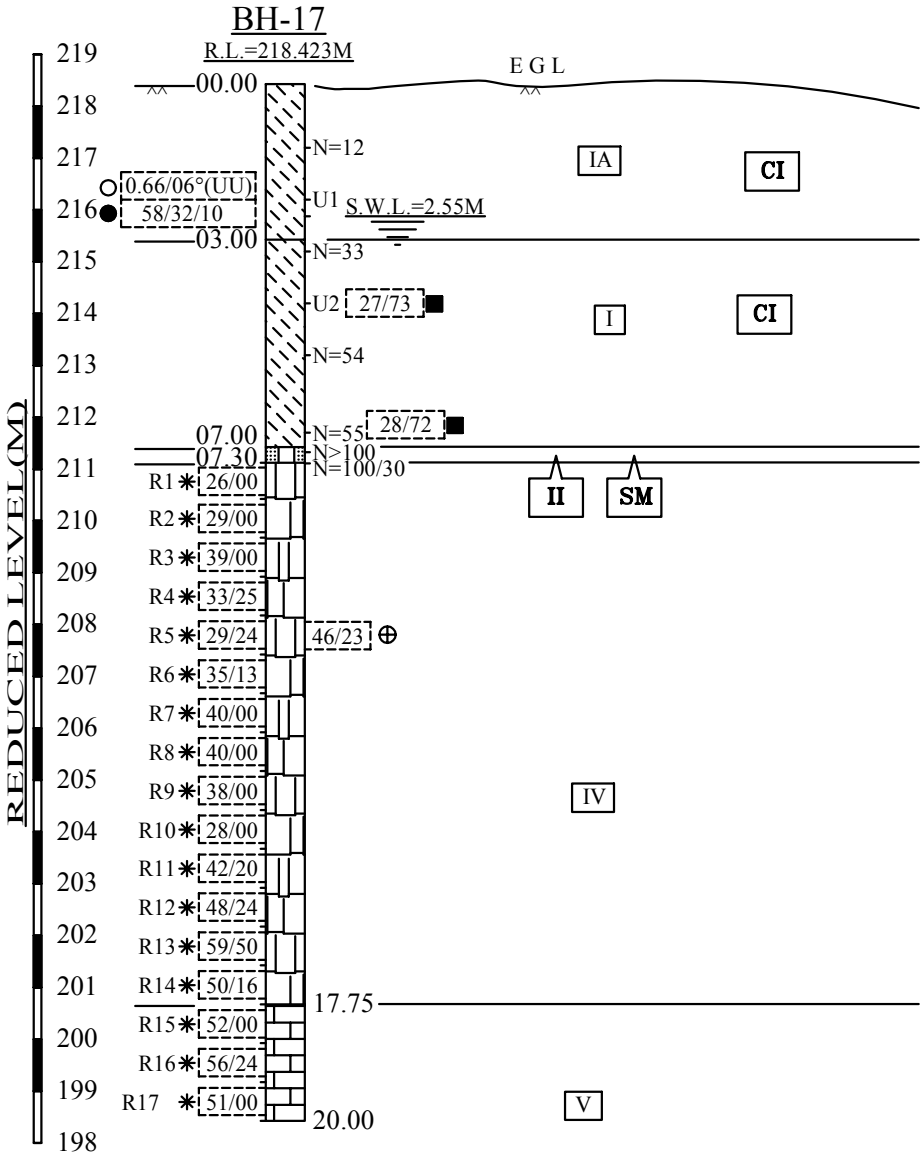
HIGHLY TO MODERATELY WEATHERED, YELLOWISH GREY TO LIGHT GREY / DARK GREY, MEDIUM TO FINE GRAINED, HIGHLY TO MODERATELY / SLIGHTLY FRACTURED ROCK WITH RUSTY / BROWN SPOTS

MODERATELY TO SLIGHTLY WEATHERED, YELLOWISH GREY TO LIGHT GREY / DARK GREY, FINE GRAINED, MODERATELY TO SLIGHTLY FRACTURED ROCK WITH RUSTY / BROWN SPOTS

(Power House, TG, Compressor Bldg.)

FIG. 2.04 : GENERALISED SOIL PROFILE

Project :	Geotechnical Investigation Work at 1x250 MW NSPCL Rourkela TPP-III, Odisha.		CETEST
Job No : 3766	Created by : SKD	Created on : 05 / 09 / 2016	Sheet No:

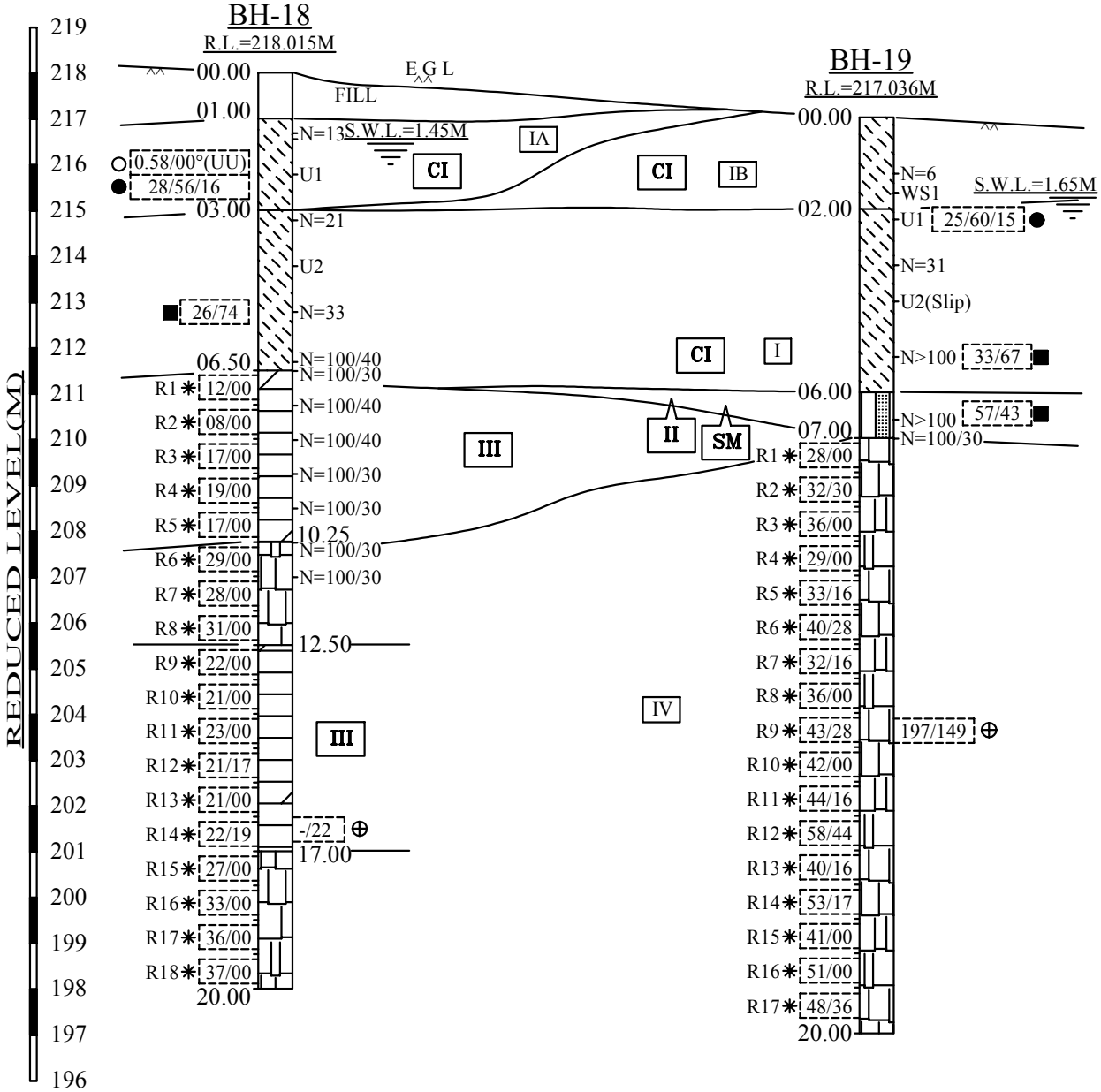


FILL	→	FILLED UP SOIL CONSISTS OF FLY ASH, BRICK BATS, KANKAR, STONE, GRAVEL, BOULDER ETC
IA	→	STIFF, GRAYISH YELLOW / DARK GREY TO BROWNISH GREY, SILTY CLAY WITH SAND MIXTURE, KANKAR, STEEL GREY SPOTS & REDDISH SPOTS.
IB	→	SOFT TO MEDIUM, GRAYISH YELLOW TO BROWNISH GREY / YELLOWISH BROWN, SILTY CLAY WITH TRACES OF KANKAR, SAND MIXTURE, STEEL GREY SPOTS, KANKAR & REDDISH SPOTS
I	→	VERY STIFF TO HARD, YELLOWISH GREY / BROWNISH GREY / LIGHT GREY, SILTY CLAY WITH SAND MIXTURE, DECOMPOSED ROCK FRAGMENTS, KANKAR, REDDISH & BLACK SPOTS
II	→	VERY DENSE, LIGHT YELLOWISH BROWN SILTY FINE SAND / SANDY SILT WITH MICA, DECOMPOSED ROCK FRAGMENTS.
IIA	→	MEDIUM DENSE, LIGHT YELLOWISH BROWN SILTY FINE SAND / SANDY SILT WITH MICA, DECOMPOSED ROCK FRAGMENTS
III	→	COMPLETELY TO HIGHLY WEATHERED, BROWNISH GREY TO DARK GREY / YELLOWISH GREY, FINE TO MEDIUM GRAINED, HIGHLY FRACTURED ROCK.
IV	→	HIGHLY TO MODERATELY WEATHERED, YELLOWISH GREY TO LIGHT GREY / DARK GREY, MEDIUM TO FINE GRAINED, HIGHLY TO MODERATELY / SLIGHTLY FRACTURED ROCK WITH RUSTY / BROWN SPOTS
V	→	MODERATELY TO SLIGHTLY WEATHERED, YELLOWISH GREY TO LIGHT GREY / DARK GREY, FINE GRAINED, MODERATELY TO SLIGHTLY FRACTURED ROCK WITH RUSTY / BROWN SPOTS

U means UDS
N means `N' value
N=X/Y means X blows required for Ymm penetration
✳ CR/RQD %
○ C(kg/sqcm) / Ø(°) values
● Sand/Silt/Clay %
■ Sand/Silt+Clay %
⊕ In-Situ / Saturated Unconfined Compressive Strength of Rock (Kg/sqcm)

(Transformer Yard)

FIG. 2.05 : SUB-SOIL PROFILE



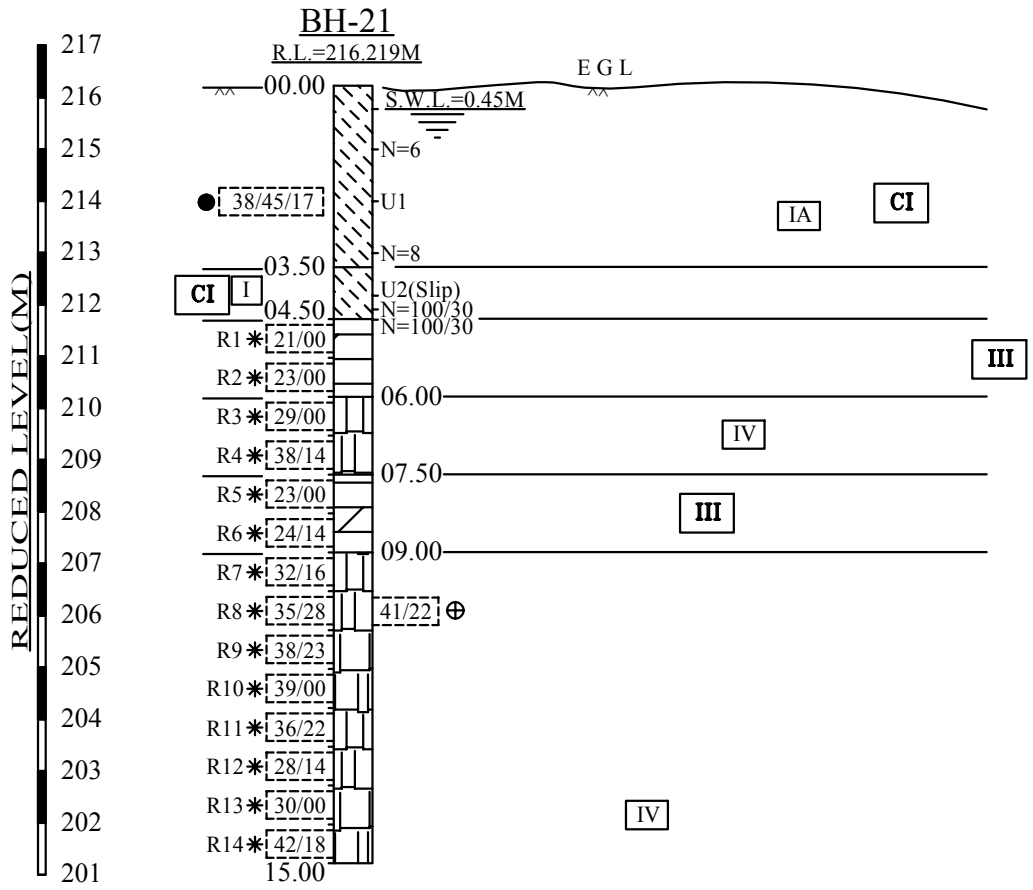
FILL	→	FILLED UP SOIL CONSISTS OF FLY ASH, BRICK BATS, KANKAR, STONE, GRAVEL, BOULDER ETC
IA	→	STIFF, GRAYISH YELLOW / DARK GREY TO BROWNISH GREY, SILTY CLAY WITH SAND MIXTURE, KANKAR, STEEL GREY SPOTS & REDDISH SPOTS.
IB	→	SOFT TO MEDIUM, GRAYISH YELLOW TO BROWNISH GREY / YELLOWISH BROWN, SILTY CLAY WITH TRACES OF KANKAR, SAND MIXTURE, STEEL GREY SPOTS, KANKAR & REDDISH SPOTS
I	→	VERY STIFF TO HARD, YELLOWISH GREY / BROWNISH GREY / LIGHT GREY, SILTY CLAY WITH SAND MIXTURE, DECOMPOSED ROCK FRAGMENTS, KANKAR, REDDISH & BLACK SPOTS
II	→	VERY DENSE, LIGHT YELLOWISH BROWN SILTY FINE SAND / SANDY SILT WITH MICA, DECOMPOSED ROCK FRAGMENTS.
IIA	→	MEDIUM DENSE, LIGHT YELLOWISH BROWN SILTY FINE SAND / SANDY SILT WITH MICA, DECOMPOSED ROCK FRAGMENTS
III	→	COMPLETELY TO HIGHLY WEATHERED, BROWNISH GREY TO DARK GREY / YELLOWISH GREY, FINE TO MEDIUM GRAINED, HIGHLY FRACTURED ROCK.
IV	→	HIGHLY TO MODERATELY WEATHERED, YELLOWISH GREY TO LIGHT GREY / DARK GREY, MEDIUM TO FINE GRAINED, HIGHLY TO MODERATELY / SLIGHTLY FRACTURED ROCK WITH RUSTY / BROWN SPOTS
V	→	MODERATELY TO SLIGHTLY WEATHERED, YELLOWISH GREY TO LIGHT GREY / DARK GREY, FINE GRAINED, MODERATELY TO SLIGHTLY FRACTURED ROCK WITH RUSTY / BROWN SPOTS

U means UDS
N means `N' value
WS means water sample
N=X/Y means X blows required for Ymm penetration
✱ CR/RQD %
○ C(kg/sqcm) / Ø(°) values
● Sand/Silt/Clay %
■ Sand/Silt+Clay %
⊕ In-Situ / Saturated Unconfined Compressive Strength of Rock (Kg/sqcm)

(Switch Yard)

FIG. 2.06 : GENERALISED SOIL PROFILE

Project :	Geotechnical Investigation Work at 1x250 MW NSPCL Rourkela TPP-III, Odisha.		CETEST
Job No : 3766	Created by : SKD	Created on : 05 / 09 / 2016	Sheet No:



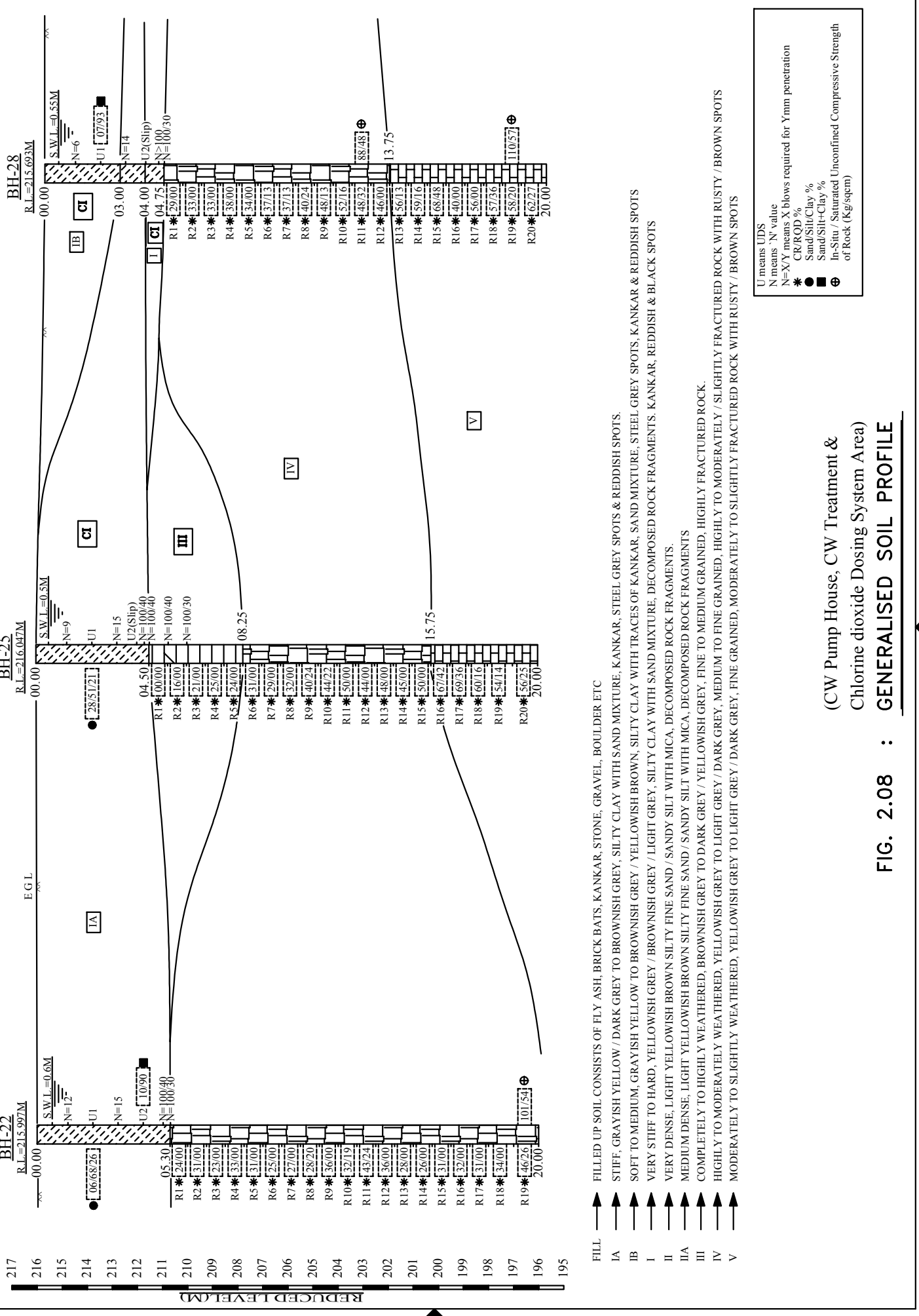
FILL	→	FILLED UP SOIL CONSISTS OF FLY ASH, BRICK BATS, KANKAR, STONE, GRAVEL, BOULDER ETC
IA	→	STIFF, GRAYISH YELLOW / DARK GREY TO BROWNISH GREY, SILTY CLAY WITH SAND MIXTURE, KANKAR, STEEL GREY SPOTS & REDDISH SPOTS.
IB	→	SOFT TO MEDIUM, GRAYISH YELLOW TO BROWNISH GREY / YELLOWISH BROWN, SILTY CLAY WITH TRACES OF KANKAR, SAND MIXTURE, STEEL GREY SPOTS, KANKAR & REDDISH SPOTS
I	→	VERY STIFF TO HARD, YELLOWISH GREY / BROWNISH GREY / LIGHT GREY, SILTY CLAY WITH SAND MIXTURE, DECOMPOSED ROCK FRAGMENTS, KANKAR, REDDISH & BLACK SPOTS
II	→	VERY DENSE, LIGHT YELLOWISH BROWN SILTY FINE SAND / SANDY SILT WITH MICA, DECOMPOSED ROCK FRAGMENTS.
IIA	→	MEDIUM DENSE, LIGHT YELLOWISH BROWN SILTY FINE SAND / SANDY SILT WITH MICA, DECOMPOSED ROCK FRAGMENTS
III	→	COMPLETELY TO HIGHLY WEATHERED, BROWNISH GREY TO DARK GREY / YELLOWISH GREY, FINE TO MEDIUM GRAINED, HIGHLY FRACTURED ROCK.
IV	→	HIGHLY TO MODERATELY WEATHERED, YELLOWISH GREY TO LIGHT GREY / DARK GREY, MEDIUM TO FINE GRAINED, HIGHLY TO MODERATELY / SLIGHTLY FRACTURED ROCK WITH RUSTY / BROWN SPOTS
V	→	MODERATELY TO SLIGHTLY WEATHERED, YELLOWISH GREY TO LIGHT GREY / DARK GREY, FINE GRAINED, MODERATELY TO SLIGHTLY FRACTURED ROCK WITH RUSTY / BROWN SPOTS

U means UDS
N means `N' value
N=X/Y means X blows required for Ymm penetration
✳ CR/RQD %
● Sand/Silt/Clay %
⊕ In-Situ / Saturated Unconfined Compressive Strength of Rock (Kg/sqcm)

(Emergency DG Station)

FIG. 2.07 : SUB-SOIL PROFILE

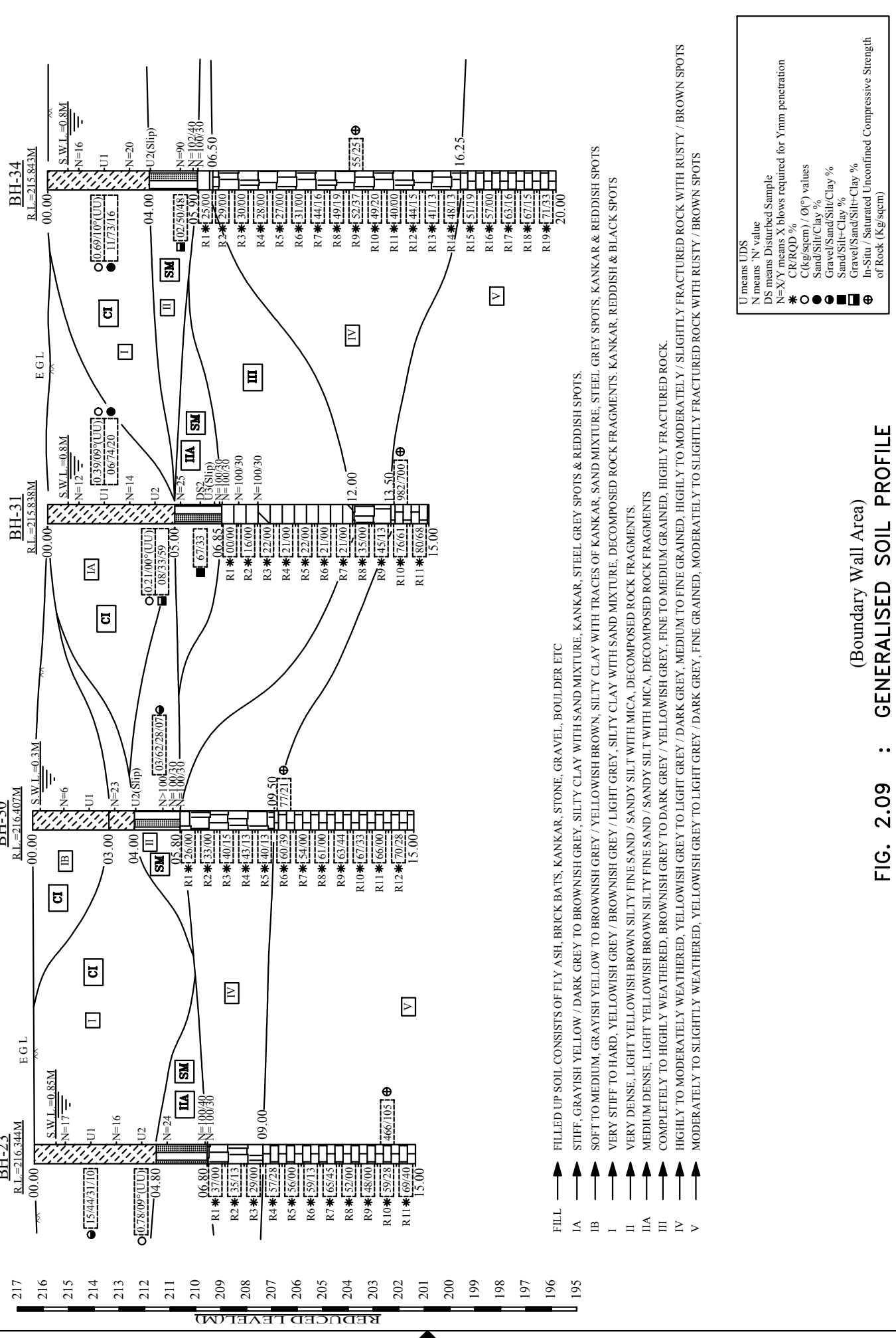
Project :	Geotechnical Investigation Work at 1x250 MW NSPCL Rourkela TPP-III, Odisha.		CETEST
Job No : 3766	Created by : SKD	Created on : 22 / 09 / 2016	Sheet No:



(CW Pump House, CW Treatment & Chlorine dioxide Dosing System Area)

FIG. 2.08 : GENERALISED SOIL PROFILE

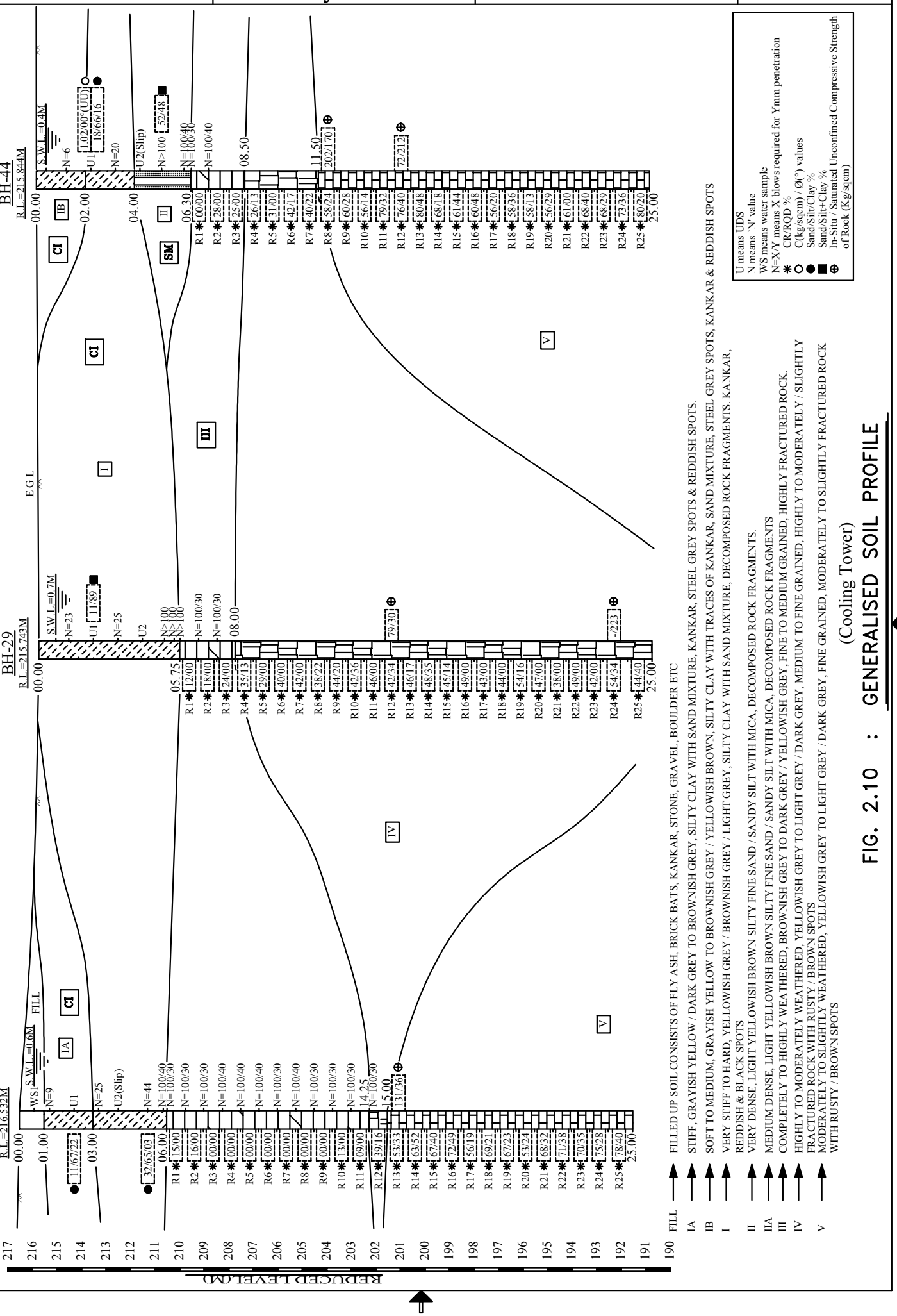
Project :	Geotechnical Investigation Work at 1x250 MW NSPCL Rourkela TPP-III, Odisha.		CETEST
Job No : 3766	Created by : SKD	Created on : 22 / 09 / 2016	Sheet No:



(Boundary Wall Area)

FIG. 2.09 : GENERALISED SOIL PROFILE

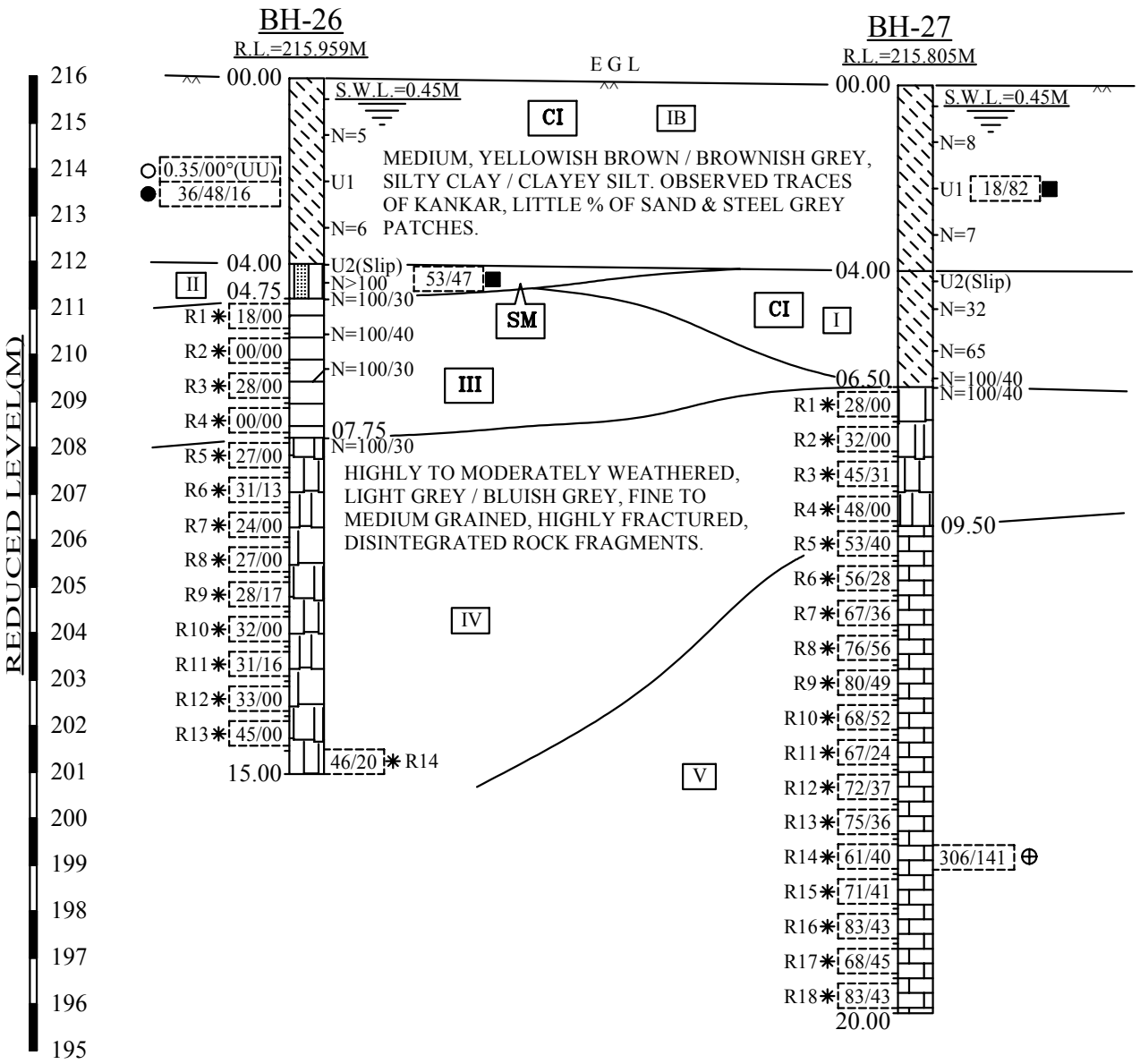
Project :	Geotechnical Investigation Work at 1x250 MW NSPCL Rourkela TPP-III, Odisha.		CETEST
Job No : 3766	Created by : SKD	Created on : 05 / 09 / 2016	Sheet No:



(Cooling Tower)

FIG. 2.10 : GENERALISED SOIL PROFILE

Project :	Geotechnical Investigation Work at 1x250 MW NSPCL Rourkela TPP-III, Odisha.		CETEST
Job No : 3766	Created by : SKD	Created on : 05 / 09 / 2016	Sheet No:

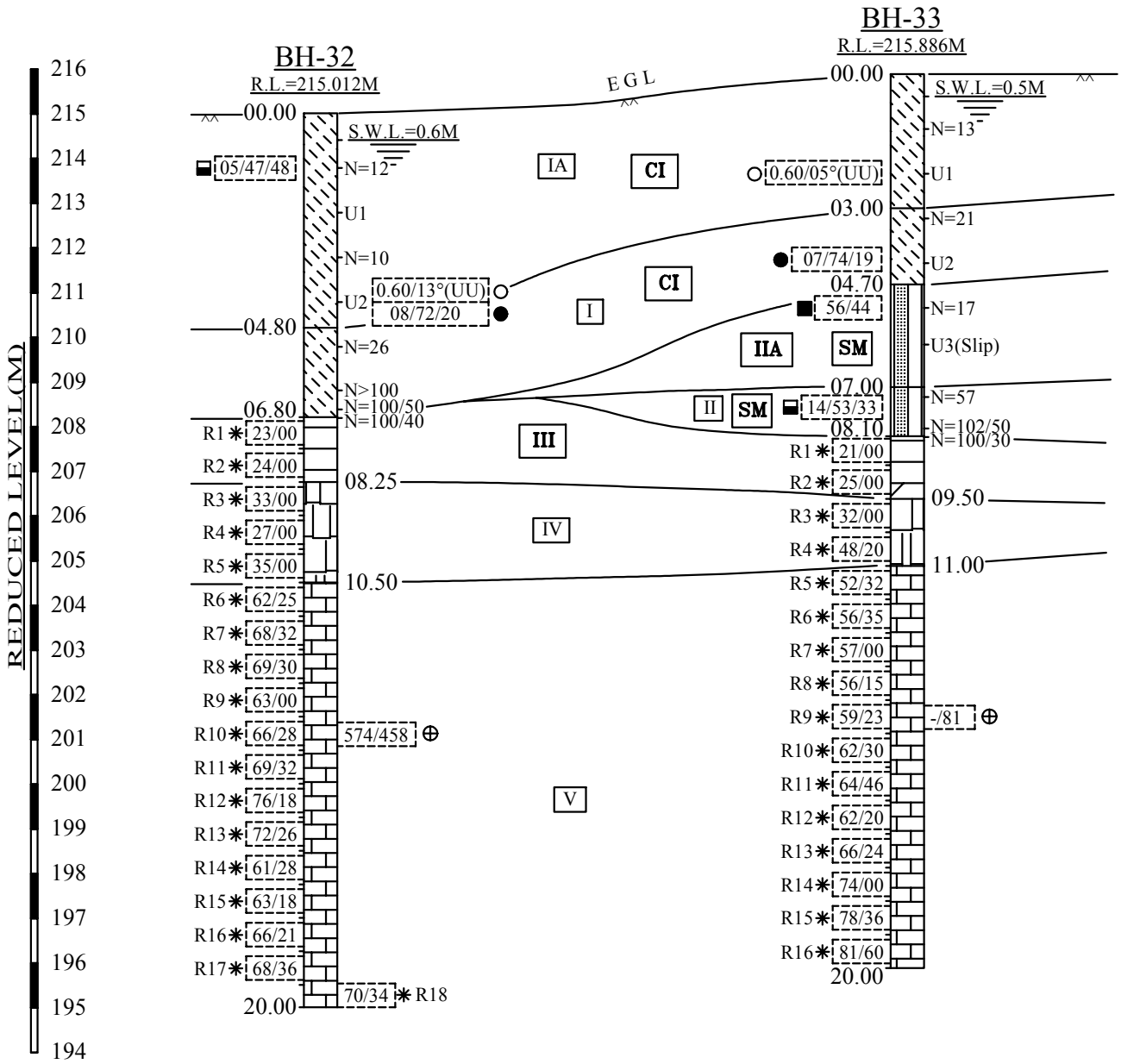


FILL	→	FILLED UP SOIL CONSISTS OF FLY ASH, BRICK BATS, KANKAR, STONE, GRAVEL, BOULDER ETC
IA	→	STIFF, GRAYISH YELLOW / DARK GREY TO BROWNISH GREY, SILTY CLAY WITH SAND MIXTURE, KANKAR, STEEL GREY SPOTS & REDDISH SPOTS.
IB	→	SOFT TO MEDIUM, GRAYISH YELLOW TO BROWNISH GREY / YELLOWISH BROWN, SILTY CLAY WITH TRACES OF KANKAR, SAND MIXTURE, STEEL GREY SPOTS, KANKAR & REDDISH SPOTS
I	→	VERY STIFF TO HARD, YELLOWISH GREY / BROWNISH GREY / LIGHT GREY, SILTY CLAY WITH SAND MIXTURE, DECOMPOSED ROCK FRAGMENTS, KANKAR, REDDISH & BLACK SPOTS
II	→	VERY DENSE, LIGHT YELLOWISH BROWN SILTY FINE SAND / SANDY SILT WITH MICA, DECOMPOSED ROCK FRAGMENTS.
IIA	→	MEDIUM DENSE, LIGHT YELLOWISH BROWN SILTY FINE SAND / SANDY SILT WITH MICA, DECOMPOSED ROCK FRAGMENTS
III	→	COMPLETELY TO HIGHLY WEATHERED, BROWNISH GREY TO DARK GREY / YELLOWISH GREY, FINE TO MEDIUM GRAINED, HIGHLY FRACTURED ROCK.
IV	→	HIGHLY TO MODERATELY WEATHERED, YELLOWISH GREY TO LIGHT GREY / DARK GREY, MEDIUM TO FINE GRAINED, HIGHLY TO MODERATELY / SLIGHTLY FRACTURED ROCK WITH RUSTY / BROWN SPOTS
V	→	MODERATELY TO SLIGHTLY WEATHERED, YELLOWISH GREY TO LIGHT GREY / DARK GREY, FINE GRAINED, MODERATELY TO SLIGHTLY FRACTURED ROCK WITH RUSTY / BROWN SPOTS

U means UDS
N means `N' value
N=X/Y means X blows required for Ymm penetration
✱ CR/RQD %
○ C(kg/sqcm) / Ø(°) values
● Sand/Silt/Clay %
■ Sand/Silt+Clay %
⊕ In-Situ / Saturated Unconfined Compressive Strength of Rock (Kg/sqcm)

(Service Water Tank & Pump House Area)

FIG. 2.11 : GENERALISED SOIL PROFILE

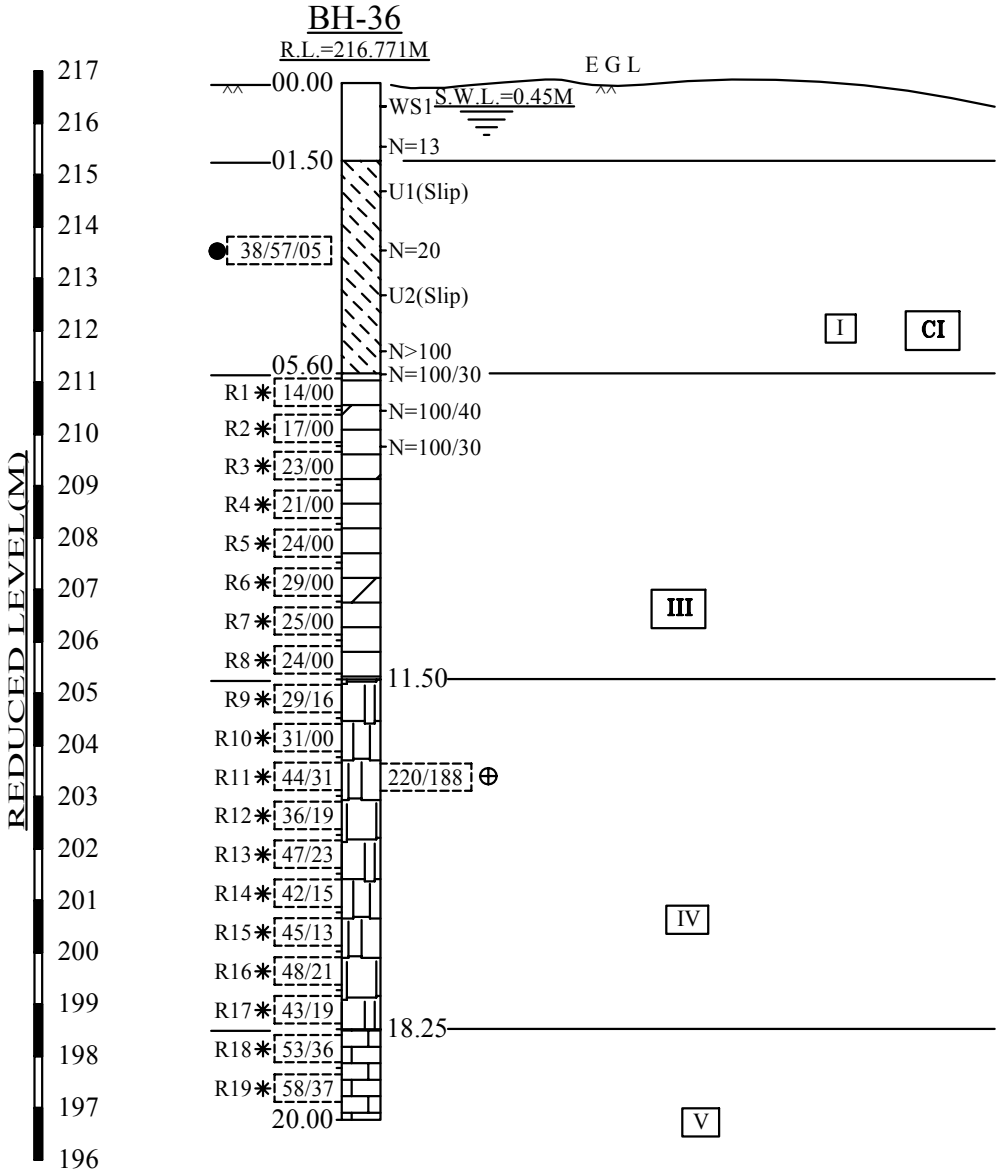


FILL	→	FILLED UP SOIL CONSISTS OF FLY ASH, BRICK BATS, KANKAR, STONE, GRAVEL, BOULDER ETC
IA	→	STIFF, GRAYISH YELLOW / DARK GREY TO BROWNISH GREY, SILTY CLAY WITH SAND MIXTURE, KANKAR, STEEL GREY SPOTS & REDDISH SPOTS.
IB	→	SOFT TO MEDIUM, GRAYISH YELLOW TO BROWNISH GREY / YELLOWISH BROWN, SILTY CLAY WITH TRACES OF KANKAR, SAND MIXTURE, STEEL GREY SPOTS, KANKAR & REDDISH SPOTS
I	→	VERY STIFF TO HARD, YELLOWISH GREY / BROWNISH GREY / LIGHT GREY, SILTY CLAY WITH SAND MIXTURE, DECOMPOSED ROCK FRAGMENTS, KANKAR, REDDISH & BLACK SPOTS
II	→	VERY DENSE, LIGHT YELLOWISH BROWN SILTY FINE SAND / SANDY SILT WITH MICA, DECOMPOSED ROCK FRAGMENTS.
IIA	→	MEDIUM DENSE, LIGHT YELLOWISH BROWN SILTY FINE SAND / SANDY SILT WITH MICA, DECOMPOSED ROCK FRAGMENTS
III	→	COMPLETELY TO HIGHLY WEATHERED, BROWNISH GREY TO DARK GREY / YELLOWISH GREY, FINE TO MEDIUM GRAINED, HIGHLY FRACTURED ROCK.
IV	→	HIGHLY TO MODERATELY WEATHERED, YELLOWISH GREY TO LIGHT GREY / DARK GREY, MEDIUM TO FINE GRAINED, HIGHLY TO MODERATELY / SLIGHTLY FRACTURED ROCK WITH RUSTY / BROWN SPOTS
V	→	MODERATELY TO SLIGHTLY WEATHERED, YELLOWISH GREY TO LIGHT GREY / DARK GREY, FINE GRAINED, MODERATELY TO SLIGHTLY FRACTURED ROCK WITH RUSTY / BROWN SPOTS

U means UDS
N means `N' value
N=X/Y means X blows required for Ymm penetration
✱ CR/RQD %
○ C(kg/sqcm) / Ø(°) values
● Sand/Silt/Clay %
■ Sand/Silt+Clay %
⬓ Gravel/Sand/Silt+Clay %
⊕ In-Situ / Saturated Unconfined Compressive Strength of Rock (Kg/sqcm)

(Clarified Water Storage Tank, Fire Water & Make up water Pump House and PT Plant Area)

FIG. 2.12 : GENERALISED SOIL PROFILE

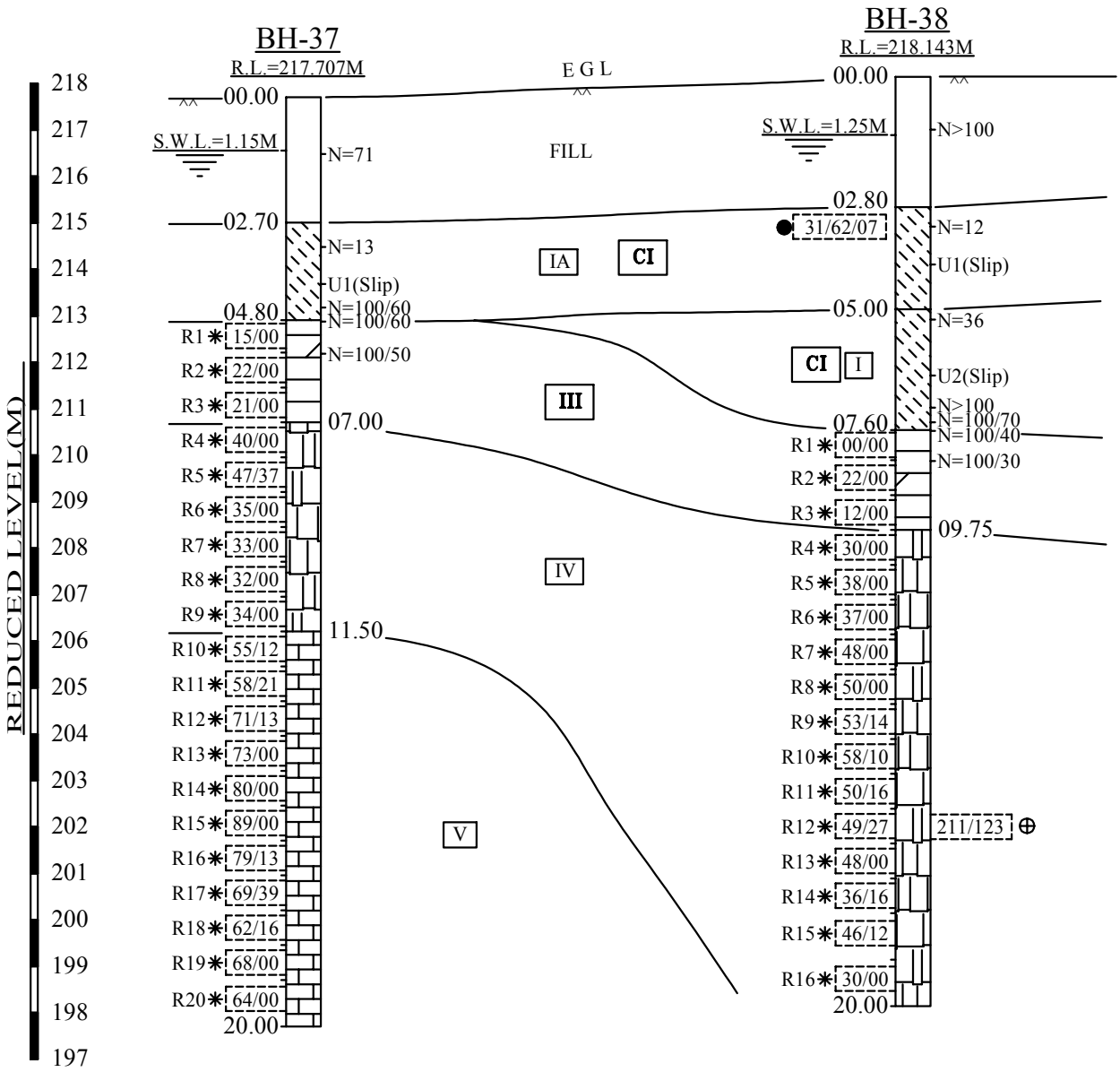


FILL	→	FILLED UP SOIL CONSISTS OF FLY ASH, BRICK BATS, KANKAR, STONE, GRAVEL, BOULDER ETC
IA	→	STIFF, GRAYISH YELLOW / DARK GREY TO BROWNISH GREY, SILTY CLAY WITH SAND MIXTURE, KANKAR, STEEL GREY SPOTS & REDDISH SPOTS.
IB	→	SOFT TO MEDIUM, GRAYISH YELLOW TO BROWNISH GREY / YELLOWISH BROWN, SILTY CLAY WITH TRACES OF KANKAR, SAND MIXTURE, STEEL GREY SPOTS, KANKAR & REDDISH SPOTS
I	→	VERY STIFF TO HARD, YELLOWISH GREY / BROWNISH GREY / LIGHT GREY, SILTY CLAY WITH SAND MIXTURE, DECOMPOSED ROCK FRAGMENTS, KANKAR, REDDISH & BLACK SPOTS
II	→	VERY DENSE, LIGHT YELLOWISH BROWN SILTY FINE SAND / SANDY SILT WITH MICA, DECOMPOSED ROCK FRAGMENTS.
IIA	→	MEDIUM DENSE, LIGHT YELLOWISH BROWN SILTY FINE SAND / SANDY SILT WITH MICA, DECOMPOSED ROCK FRAGMENTS
III	→	COMPLETELY TO HIGHLY WEATHERED, BROWNISH GREY TO DARK GREY / YELLOWISH GREY, FINE TO MEDIUM GRAINED, HIGHLY FRACTURED ROCK.
IV	→	HIGHLY TO MODERATELY WEATHERED, YELLOWISH GREY TO LIGHT GREY / DARK GREY, MEDIUM TO FINE GRAINED, HIGHLY TO MODERATELY / SLIGHTLY FRACTURED ROCK WITH RUSTY / BROWN SPOTS
V	→	MODERATELY TO SLIGHTLY WEATHERED, YELLOWISH GREY TO LIGHT GREY / DARK GREY, FINE GRAINED, MODERATELY TO SLIGHTLY FRACTURED ROCK WITH RUSTY / BROWN SPOTS

U means UDS
N means `N' value
WS means water sample
N=X/Y means X blows required for Ymm penetration
✳ CR/RQD %
● Sand/Silt/Clay %
⊕ In-Situ / Saturated Unconfined Compressive Strength of Rock (Kg/sqcm)

(Construction Store)

FIG. 2.13 : SUB-SOIL PROFILE



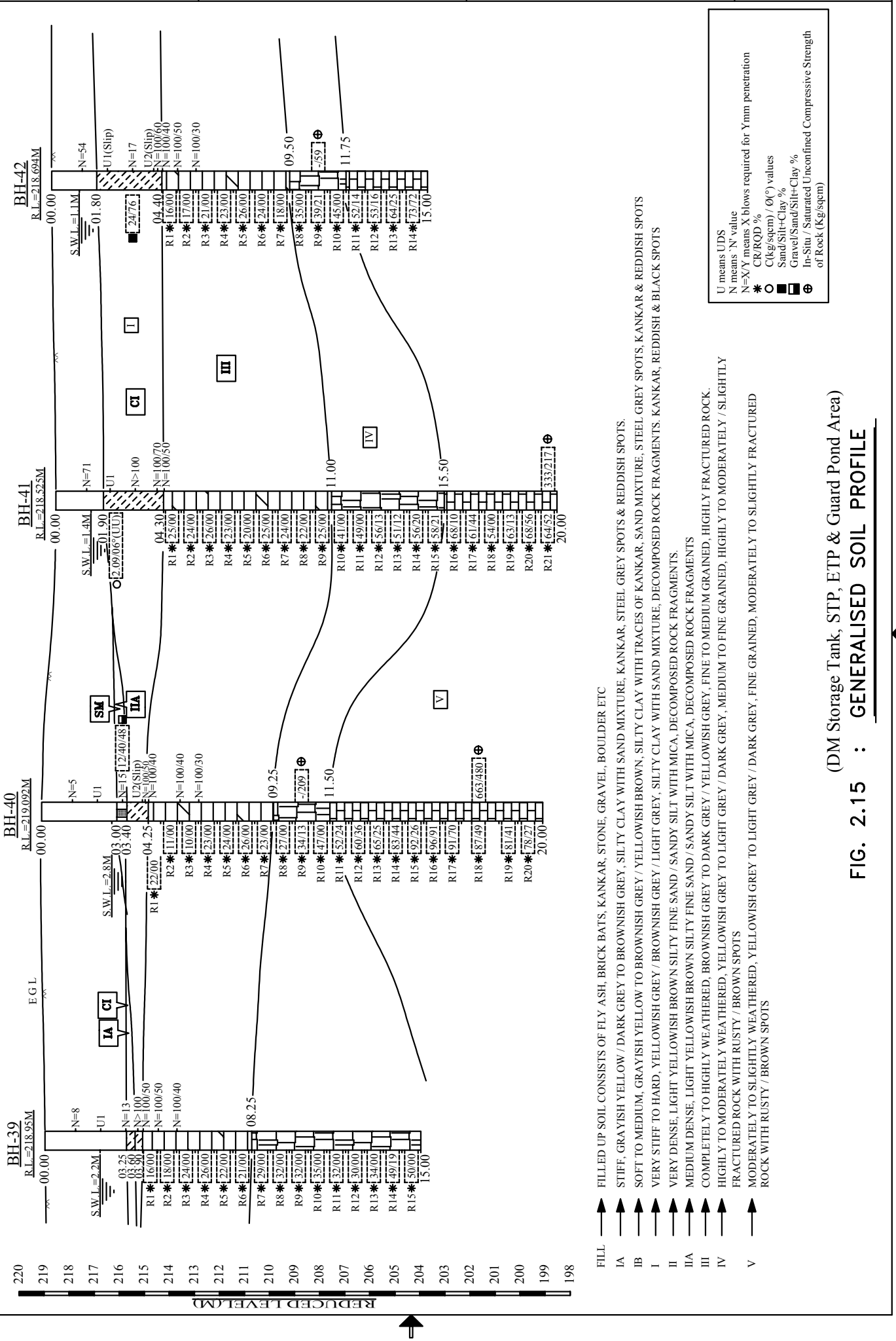
FILL	→	FILLED UP SOIL CONSISTS OF FLY ASH, BRICK BATS, KANKAR, STONE, GRAVEL, BOULDER ETC
IA	→	STIFF, GRAYISH YELLOW / DARK GREY TO BROWNISH GREY, SILTY CLAY WITH SAND MIXTURE, KANKAR, STEEL GREY SPOTS & REDDISH SPOTS.
IB	→	SOFT TO MEDIUM, GRAYISH YELLOW TO BROWNISH GREY / YELLOWISH BROWN, SILTY CLAY WITH TRACES OF KANKAR, SAND MIXTURE, STEEL GREY SPOTS, KANKAR & REDDISH SPOTS
I	→	VERY STIFF TO HARD, YELLOWISH GREY / BROWNISH GREY / LIGHT GREY, SILTY CLAY WITH SAND MIXTURE, DECOMPOSED ROCK FRAGMENTS, KANKAR, REDDISH & BLACK SPOTS
II	→	VERY DENSE, LIGHT YELLOWISH BROWN SILTY FINE SAND / SANDY SILT WITH MICA, DECOMPOSED ROCK FRAGMENTS.
IIA	→	MEDIUM DENSE, LIGHT YELLOWISH BROWN SILTY FINE SAND / SANDY SILT WITH MICA, DECOMPOSED ROCK FRAGMENTS
III	→	COMPLETELY TO HIGHLY WEATHERED, BROWNISH GREY TO DARK GREY / YELLOWISH GREY, FINE TO MEDIUM GRAINED, HIGHLY FRACTURED ROCK.
IV	→	HIGHLY TO MODERATELY WEATHERED, YELLOWISH GREY TO LIGHT GREY / DARK GREY, MEDIUM TO FINE GRAINED, HIGHLY TO MODERATELY / SLIGHTLY FRACTURED ROCK WITH RUSTY / BROWN SPOTS
V	→	MODERATELY TO SLIGHTLY WEATHERED, YELLOWISH GREY TO LIGHT GREY / DARK GREY, FINE GRAINED, MODERATELY TO SLIGHTLY FRACTURED ROCK WITH RUSTY / BROWN SPOTS

U means UDS
N means `N' value
N=X/Y means X blows required for Ymm penetration
✳ CR/RQD %
● Sand/Silt/Clay %
⊕ In-Situ / Saturated Unconfined Compressive Strength of Rock (Kg/sqcm)

(Administrative Building and O&M Store)

FIG. 2.14 : GENERALISED SOIL PROFILE

Project : Geotechnical Investigation Work at 1x250 MW NSPCL Rourkela TPP-III, Odisha.			CETEST
Job No : 3766	Created by : SKD	Created on : 22 / 09 / 2016	Sheet No:



(DM Storage Tank, STP, ETP & Guard Pond Area)

FIG. 2.15 : GENERALISED SOIL PROFILE

5. DISCUSSION

5.1. DETAILS OF STRUCTURES:

The subsoil quality, thickness of each layer varies widely within the zone of investigation. Again, the type of structures to be constructed is different with different requirement. Considering all these aspect, the entire area is subdivided in to the following.

Sl. No.	Structure Name	Bore Hole Points	Reference Figure No.
1	Chimney	BH-01, 02, 03 & 43	2.01
2	ESP & ID Fan Area	BH-04 to 08, 45 & 46	2.02
3	Boiler & Mill Bunker Area	BH-09 to 13 & 35	2.03
4	Power House, TG, Compressor Building	BH-14, 15, 16, 20 & 47	2.04
5	Transformer Yard	BH-17	2.05
6	Switch Yard	BH-18 & 19	2.06
7	Emergency DG Station	BH-21	2.07
8	CWPH, CW Treatment & Chlorine Dioxide Dosing System Area	BH-22, 25 & 28	2.08
9	Boundary Wall	BH-23, 30, 31& 34	2.09
10	Cooling Tower	BH-24, 29 & 44	2.10
11	Service Water Tank & Pump House Area	BH-26 & 27	2.11
12	Clarified Water Storage Tank, Fire Water & Make up Water Pump House & PT Plant Area	BH-32 & 33	2.12
13	Near Construction Store	BH-36	2.13
14	Administrative Building and O & M Store	BH-37 & 38	2.14
15	DM Storage Tank, STP, ETP & Guard Pond Area	BH-39 to 42	2.15

5.2. CHOICE OF FOUNDATION AND FOUNDING LEVEL:

Considering the nature of the subsoil and the type of structures to be constructed at the present site, it is suggested to go for open foundation. Such foundation may be placed at a depth of 1.50m or more below FGL. The determination of bearing capacity is presented below.

5.3. DETERMINATION OF BEARING CAPACITY AROUND ESP & ID FAN AREA (REFER FIG. 2.02):

Let us consider BH-07 as this is worst case.

Place the foundation at 6.00m below FGL. (FGL = 218.500M)

Founding level falls inside stratum - I.

The field N value at or around the founding level is greater than 100. however considering this as a transition zone (from soil to rock) with rock fragments present in the subsoil, let us restrict the design C value of this layer to 2.00 kg/sqcm & $\Phi = 0°$ for the present case.

[Refer IS :2911 (Part I / Sec II) 2010 Annex C Table 4]

EVALUATION OF STRENGTH AND DEFORMATION PARAMETERS:

For Stratum I

Total soil modulus, $E_s = 4.4 \times N = 440$ kg/sqcm

[Ref. to "History of Soil penetration testing" by B. B. Broms & N. Flodin in "Penetration Testing 1988", ISPOT-1: vol.1, p – 185]

Undrained Young's modulus, $E_u = K \times C = 500 \times 2.00 = 1000$ kg/sqcm

Again, $1/E_s = 1/E_u + 1/E_d$ giving drained young's modulus, $E_d = 785.71$ kg/sqcm

Now, we have, $E_d = E_u/3 = 333.33$ kg/sqcm

[Refer to "Cone Penetration Testing" by A.C.Meigh, pp. No. – 53]

Considering the above, let us use $E_d = 555$ kg/sqcm

From E_d, $m_{vc} = 1/G.E_d = 0.0036$ sqcm/kg [Geological Factor, G = 0.50 & μ = 0.35]

Again from SPT "N", $m_{vc} = 1/5N = 0.0020$ sqcm/kg

[Refer to "Standard Penetration Test, State-of-the-art-Report" by Ivan K. Nixon in "Penetration testing 1" Edited by A.Verrujt, F.L.beringen & E.H.De Leeuw, pp. No. 11]

Thus average $m_{vc} = [1 \times 0.0036 + 0.0020]/2 = 0.0028$ sqcm/kg

For Rock layer (Layer IV)

Approach-1:

The 'E' value for fissured and jointed rock varies from a minimum of 1500 kg/sqcm to a

maximum of 30000 kg/sqcm whereas for sound rock the same is 30000 kg/sqcm or more.

[Refer to "Soil Mechanics and Foundation Engineering" 4th Edition by Prof. V. N. S. Murthy, pp – 271]

Approach-2:

Again, from Pressuremeter test results average Menard's modulus of deformation, E_m of layer III, IV & V are 868.69 kg/sqcm, 1459.13 kg/sqcm & 2880.62 kg/sqcm respectively. Hence corresponding Young's modulus, $E = E_m/0.67$ = 1296.54 kg/sqcm, 2177.81 kg/sqcm & 4299.43 kg/sqcm respectively.

Based on the above two approaches, following design deformation parameters are used for further calculation.

For layer-III, Young's modulus = 1000 kg/sqcm

For layer-IV, Young's modulus = 2000 kg/sqcm

For layer- V, Young's modulus = 4000 kg/sqcm

CALCULATION OF SAFE BEARING CAPACITY:

Use depth of foundation = 5.00M below FGL

The Net Ultimate Bearing Capacity is given as:

$$q_{nu} = C.N_c.S_c.D_c + q.N_q.S_q.D_q + 0.5\gamma.B.N_\gamma.S_\gamma.D_\gamma - q$$

Where,

N_c, N_q and N_γ are bearing capacity factors,
S_c, S_q and S_γ are shape factors,
D_c, D_q and D_γ are depth factors,

And

C = Cohesion
q = Overburden pressure,
B = Width of foundation,
γ = Effective density below foundation.

For 5m x 5m Isolated footing

Cohesion, C = 20.00 t/sqm

Using ϕ = 0 degree, the bearing capacity factors are:

N_c = 5.14; N_q = 1.00 & N_γ = 0.00

Use,

Depth of Foundation = D_f = 6 M below FGL
Size of Foundation = B = 5 M Square

Overburden Pressure = q =6.000 (Depth) x 0.90 (Submerged density) = 5.40 t/sqm (assuming water level flushing with the ground)

The Shape factors are [IS:6403 - 1981]

S_c = 1.30 S_q = 1.20 S_γ = 0.80

The Depth factors are [IS:6403 - 1981]

D_c = 1.24 D_q = 1.00 D_γ = 1.00

Computed Net Ultimate Bearing Capacity = 166.93 t/sqm

Using a factor of safety of 2.5, Net Safe Bearing Capacity = 66.77 t/sqm

The above bearing capacity should be checked against settlement criteria.

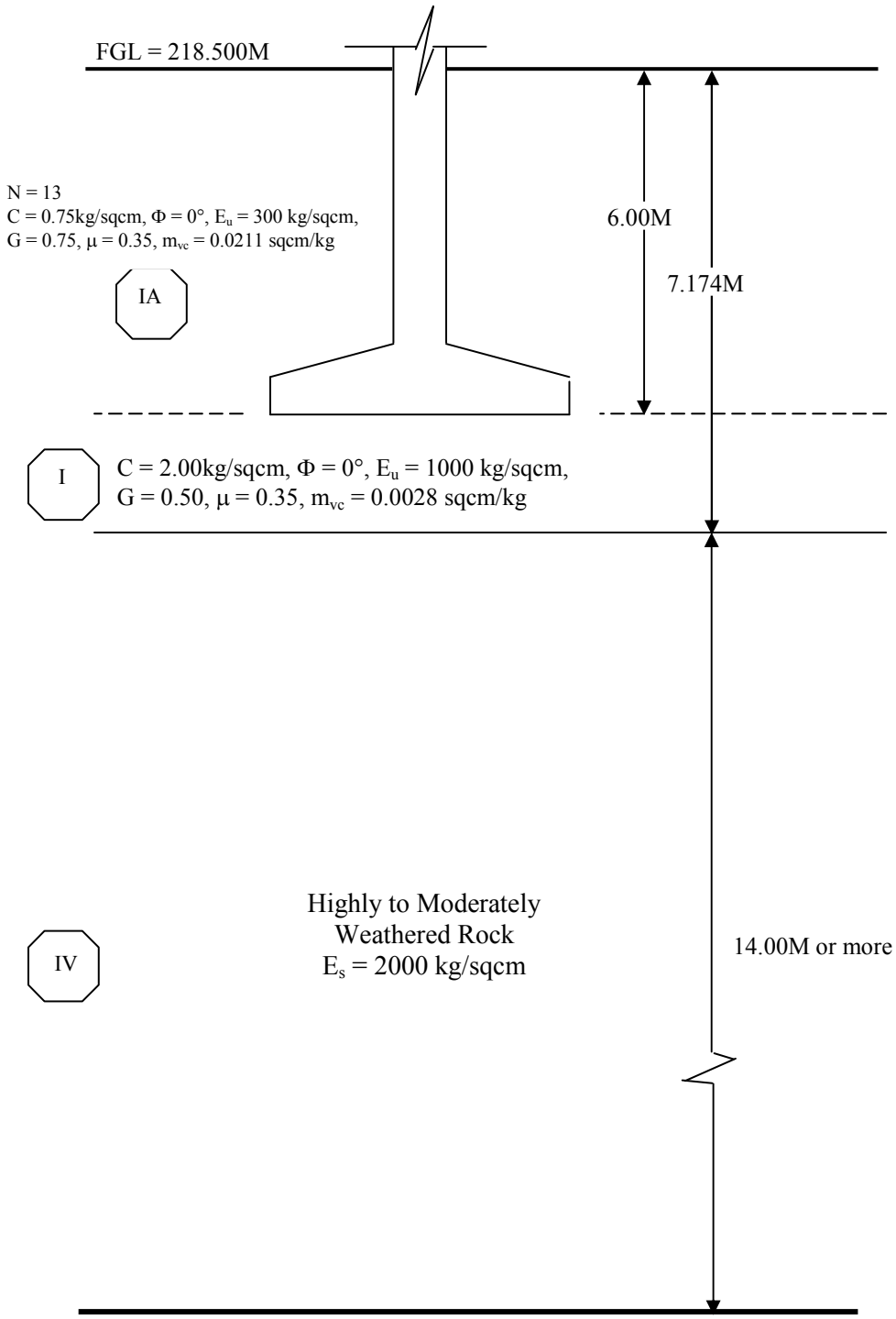


FIG. 3.01. SHALLOW FOUNDATION DESIGN MODEL
Around ESP & ID Fan Area
(Not to Scale)

SETTLEMENT CALCULATION:

With reference to the above, the settlement is calculated and is presented below.

Settlement Analysis

A) General Data:

Width of foundation =	5.0	m
Length of foundation =	5.0	m
Depth of foundation =	6.0	m
Net Base Pressure =	6.6	kg/sqcm

B) Subsoil Properties:

Layer - I			**Layer - IV**		
Young's Modulus =	1000	kg/sqcm	Young's Modulus =	2000	kg/sqcm
Poisson Ratio, μ =	0.35		Poisson Ratio, μ =	0.25	
Top of Stratum =	6.00	m	Top of Stratum =	7.17	m
End of Stratum =	7.17	m	End of Stratum =	16.00	m
Geological factor, G =	0.50		Geological factor, G =	1.00	
m_{vc} =	0.0028	sqcm/kg	m_{vc} =	0.0000	sqcm/kg

C) Calculation of Immediate Settlement:

Settlement at center			*Settlement at center*		
M = L' / B' =	1.000		M = L' / B' =	1.000	
N = H / B' =	0.470		N = H / B' =	2.859	
I_1 =	0.044		I_1 =	0.355	
I_2 =	0.072		I_2 =	0.050	
$I_s = I_1 + \{(1-2\mu) / (1-\mu)\} I_2$ =		0.077	$I_s = I_1 + \{(1-2\mu) / (1-\mu)\} I_2$ =		0.388
Immediate settlement S_i =		0.445 cm	Immediate settlement S_i =		0.971 cm
$[q_o \times B' \times (1-\mu^2) \times m \times I_s] / E_s$			$[q_o \times B' \times (1-\mu^2) \times m \times I_s] / E_s$		

Settlement at corner			*Settlement at corner*		
M = L' / B' =	1.00		M = L' / B' =	1.00	
N = H / B' =	0.235		N = H / B' =	1.430	
I_1 =	0.011997		I_1 =	0.214	
I_2 =	0.046566		I_2 =	0.076	
$I_s = I_1 + \{(1-2\mu) / (1-\mu)\} I_2$ =		0.033	$I_s = I_1 + \{(1-2\mu) / (1-\mu)\} I_2$ =		0.264
Immediate settlement S_i =		0.097 cm	Immediate settlement S_i =		0.331 cm

Average S_i for Stratum I=	2.71 mm	Average S_i for Stratum IV=	6.51 mm
Total immediate settlement =	9.22 mm	(for both the layer)	

D) Calculation of Consolidation Settlement:

Strata	From (M)	To (M)	Thickness (M)	Mid depth (M)	Δ P (kg/sqcm)	m_{vc}, sqcm/kg	G	S_c (cm)
Layer - I	6.00	6.59	0.59	0.29	5.89	0.0028	0.50	0.48
	6.59	7.17	0.59	0.88	4.77	0.0028	0.50	0.39
Hence, Total Consolidation Settlement =								8.76 mm

So, Total Settlement =	17.98 mm	
Foxe's Depth correction Factor =	0.69	
Corrected total settlement =	**12.48 mm**	

However, let us restrict the bearing capacity to 35t/sqm.

Sample bearing capacity calculations for other important structures are presented from page no. 98 to 113.

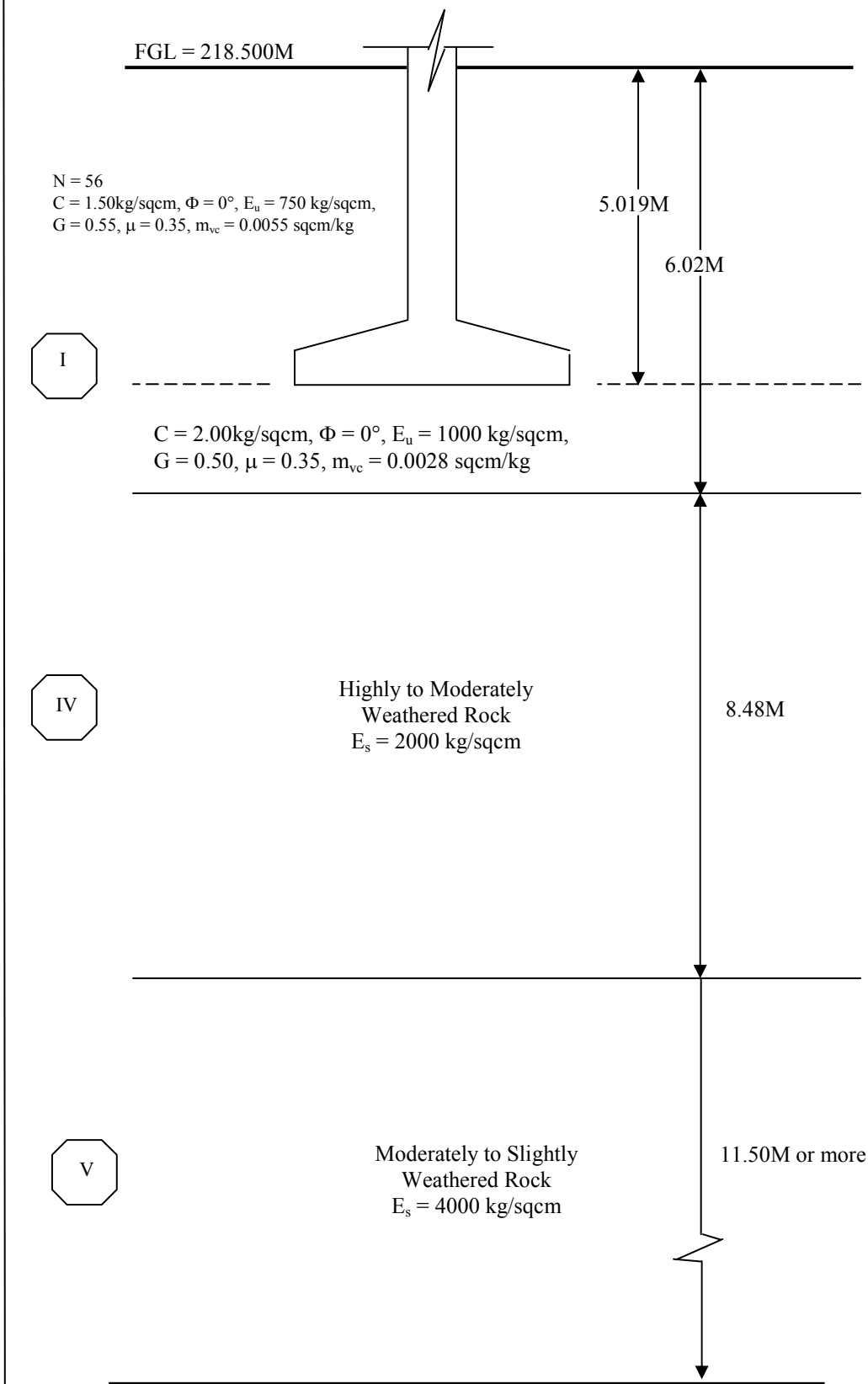


FIG. 3.02. SHALLOW FOUNDATION DESIGN MODEL
Around Chimney Area
(Not to Scale)

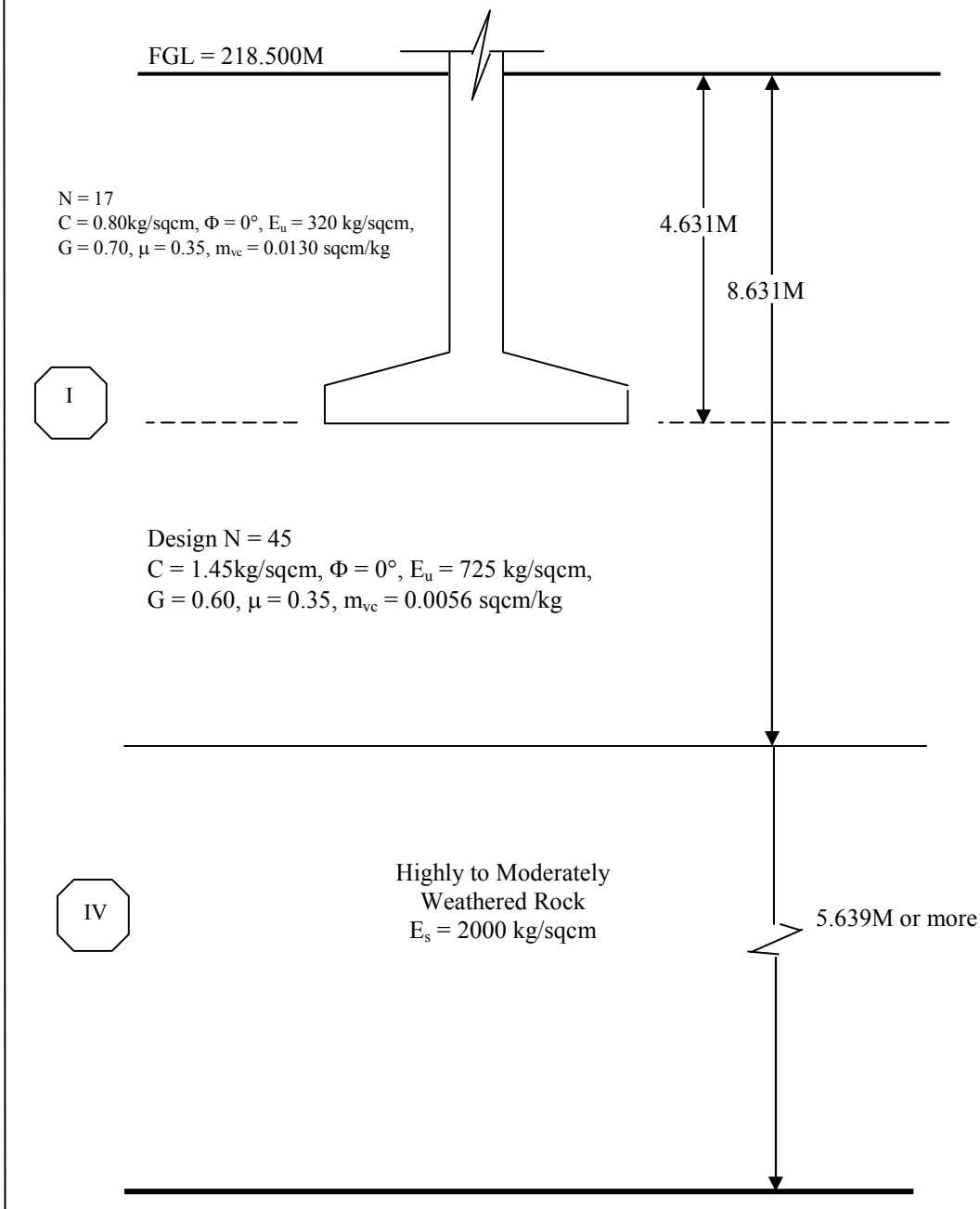


FIG. 3.03. SHALLOW FOUNDATION DESIGN MODEL
Around Boiler & Mill Bunker Area
(Not to Scale)

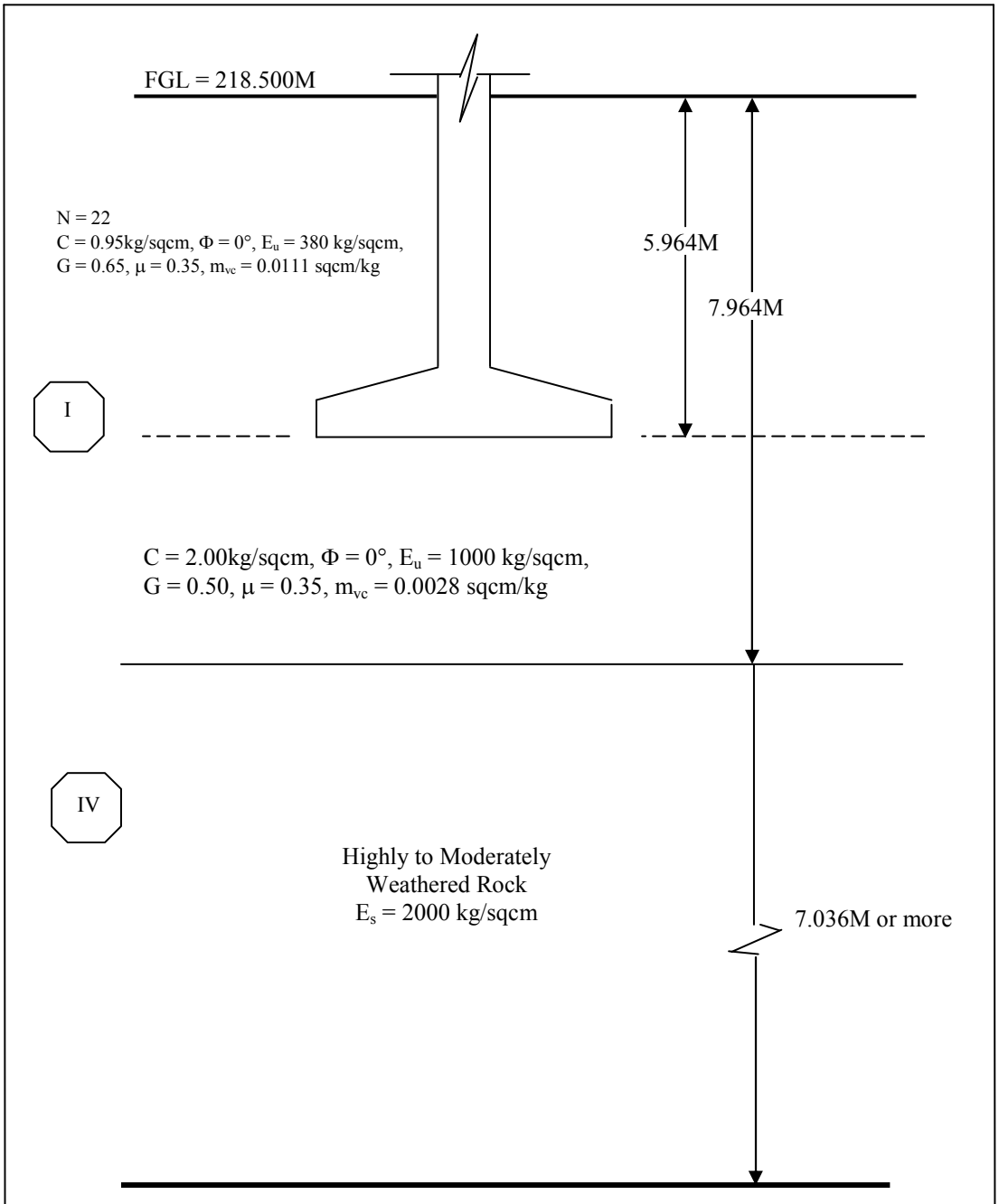


FIG. 3.04. SHALLOW FOUNDATION DESIGN MODEL
Around Power House, TG, Compressor Building Area
(Not to Scale)

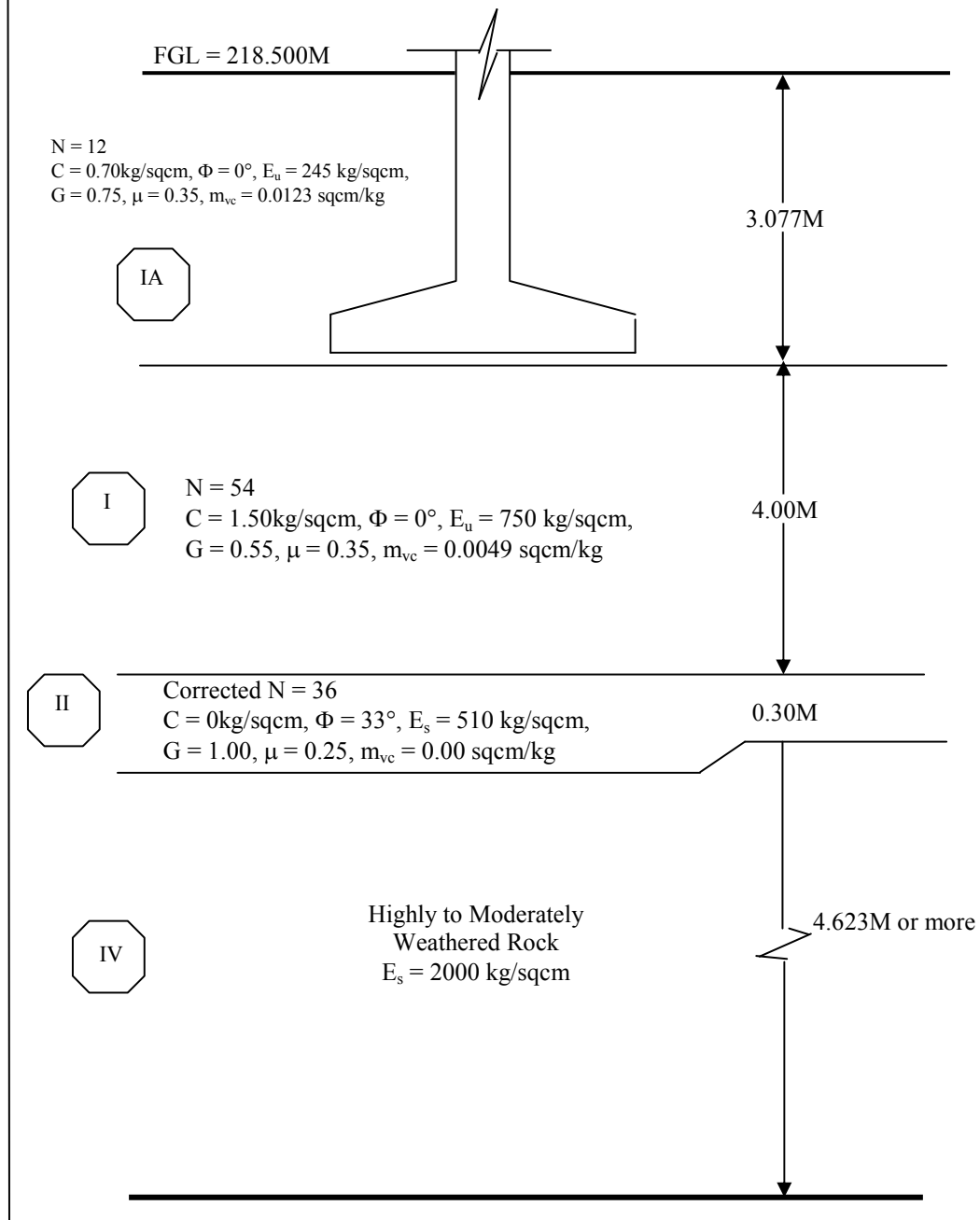


FIG. 3.05. SHALLOW FOUNDATION DESIGN MODEL
Around Transformer Yard Area
(Not to Scale)

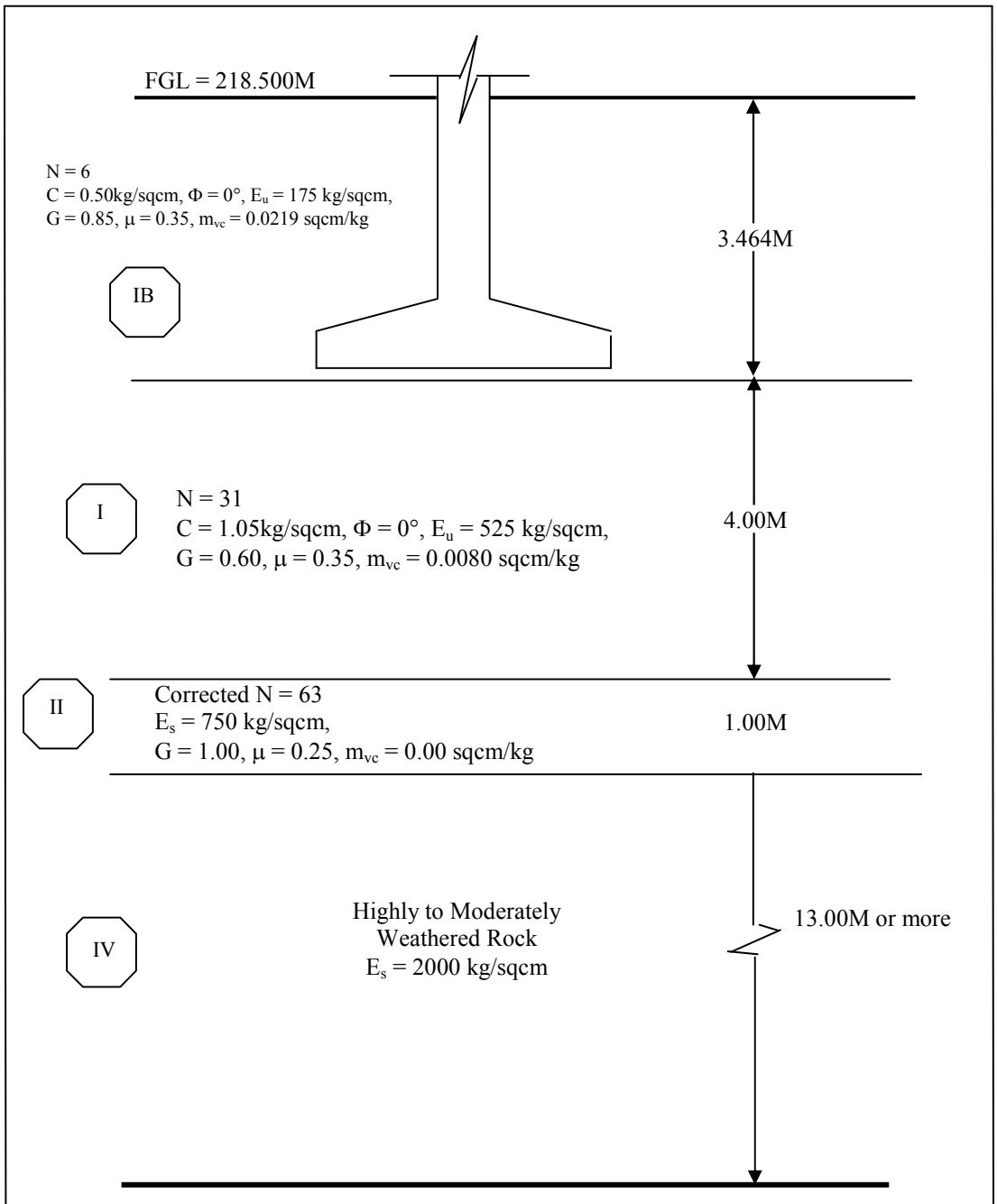


FIG. 3.06. SHALLOW FOUNDATION DESIGN MODEL
Around Switch Yard Area
(Not to Scale)

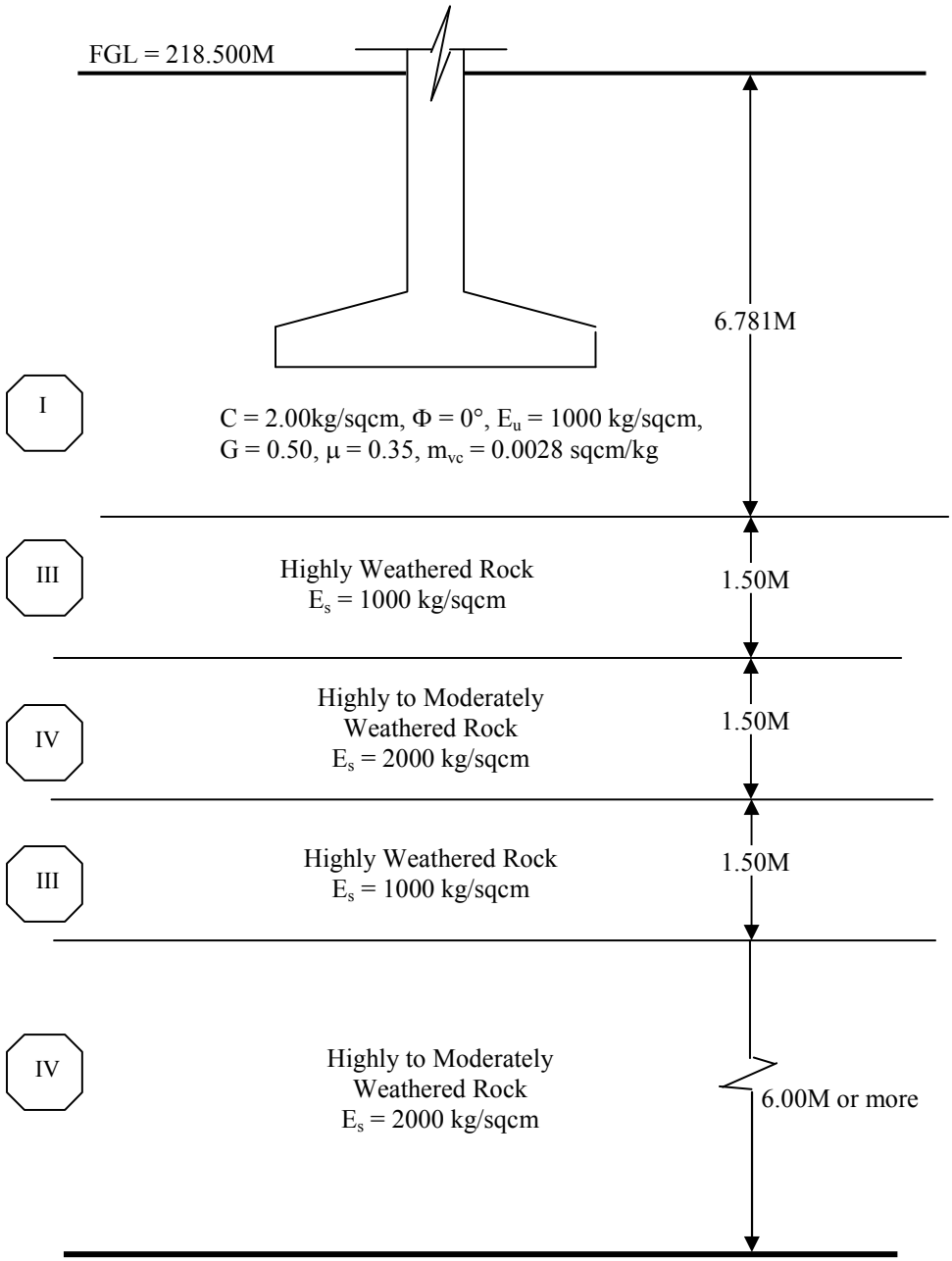


FIG. 3.07. SHALLOW FOUNDATION DESIGN MODEL
Around Emergency DG Station Area
(Not to Scale)

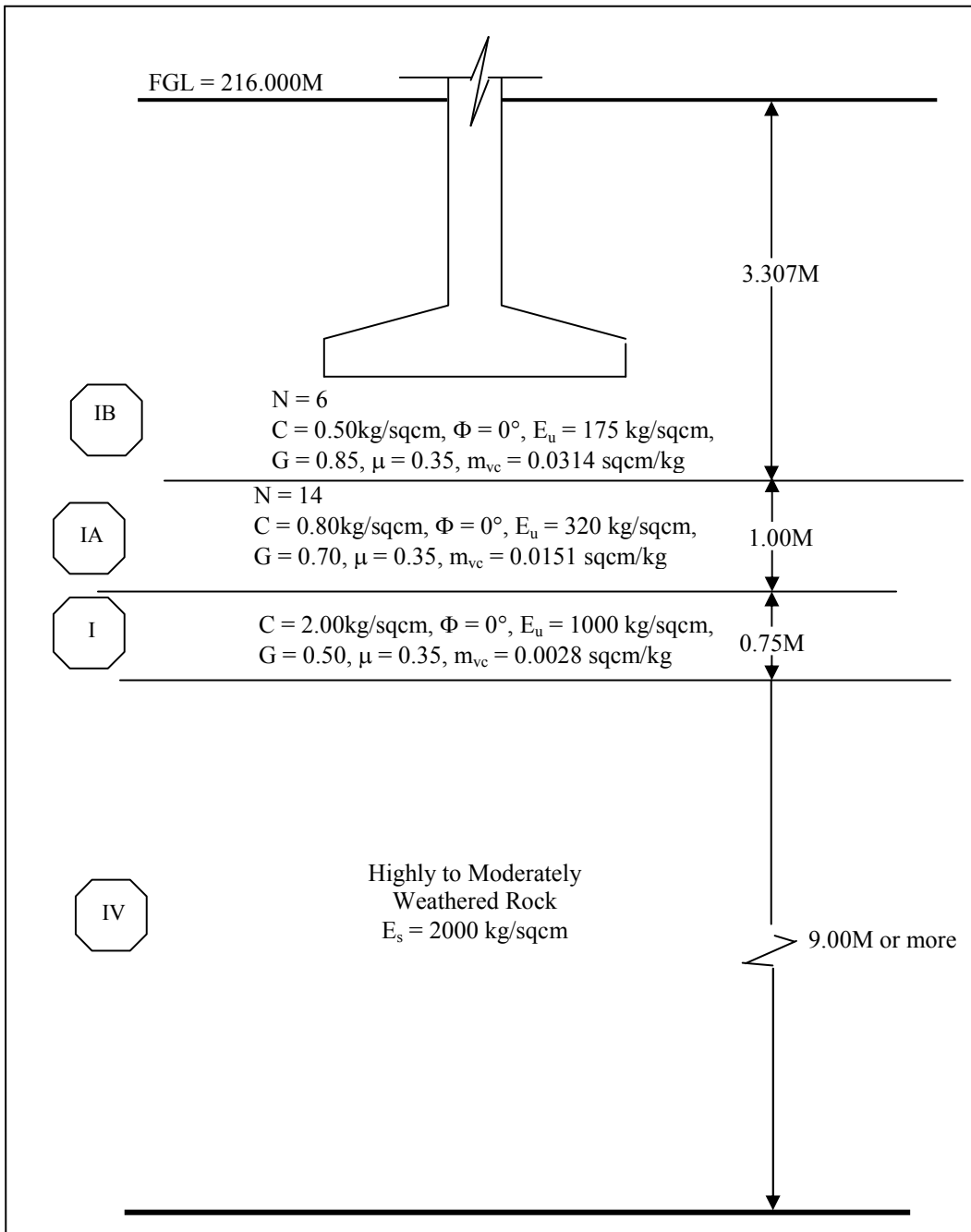


FIG. 3.08. SHALLOW FOUNDATION DESIGN MODEL

Around CWPH, CW Treatment & Chlorine Dioxide Dosing System Area

(Not to Scale)

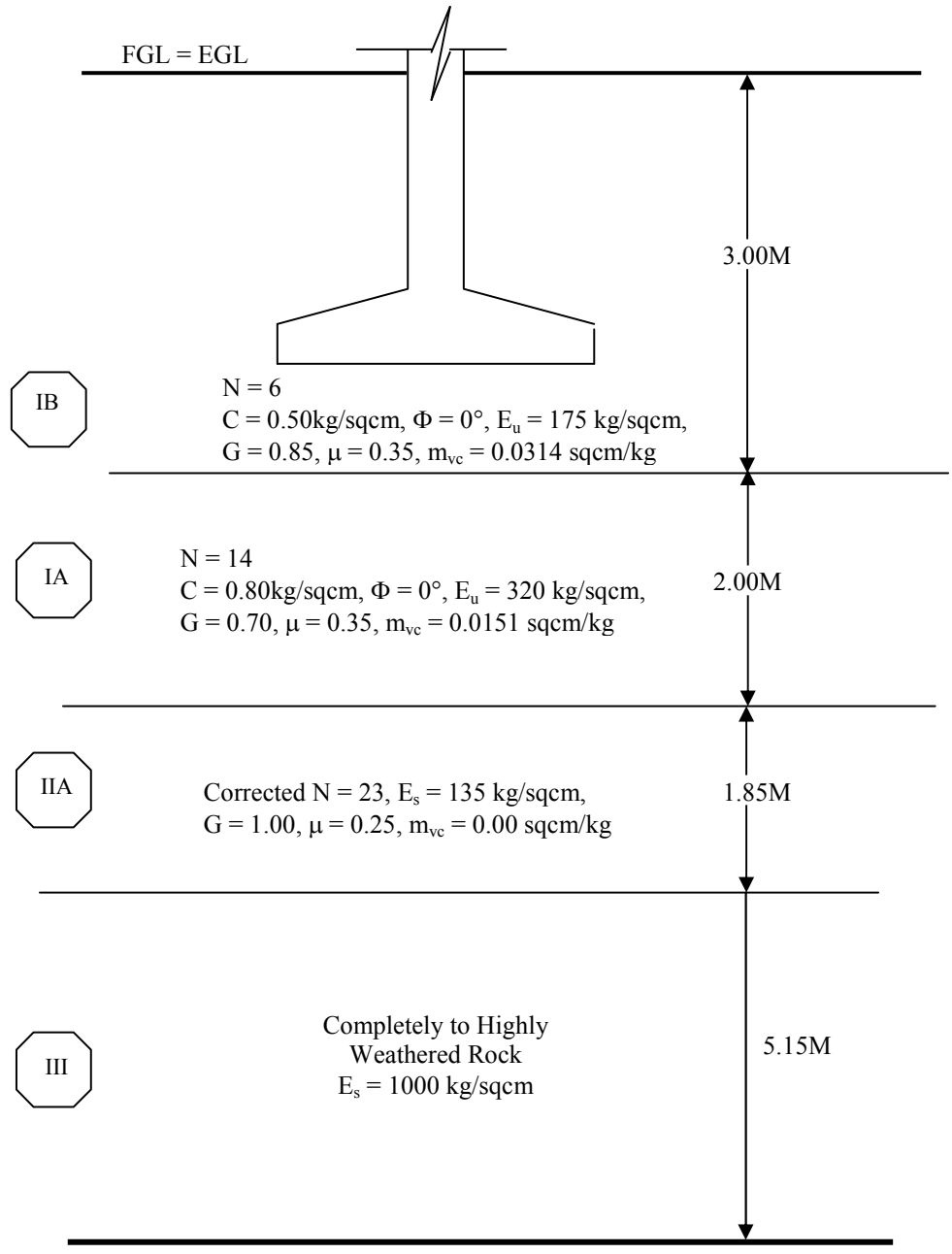


FIG. 3.09A. SHALLOW FOUNDATION DESIGN MODEL

Around Boundary Wall Area (For BH-30 & 31)

(Not to Scale)

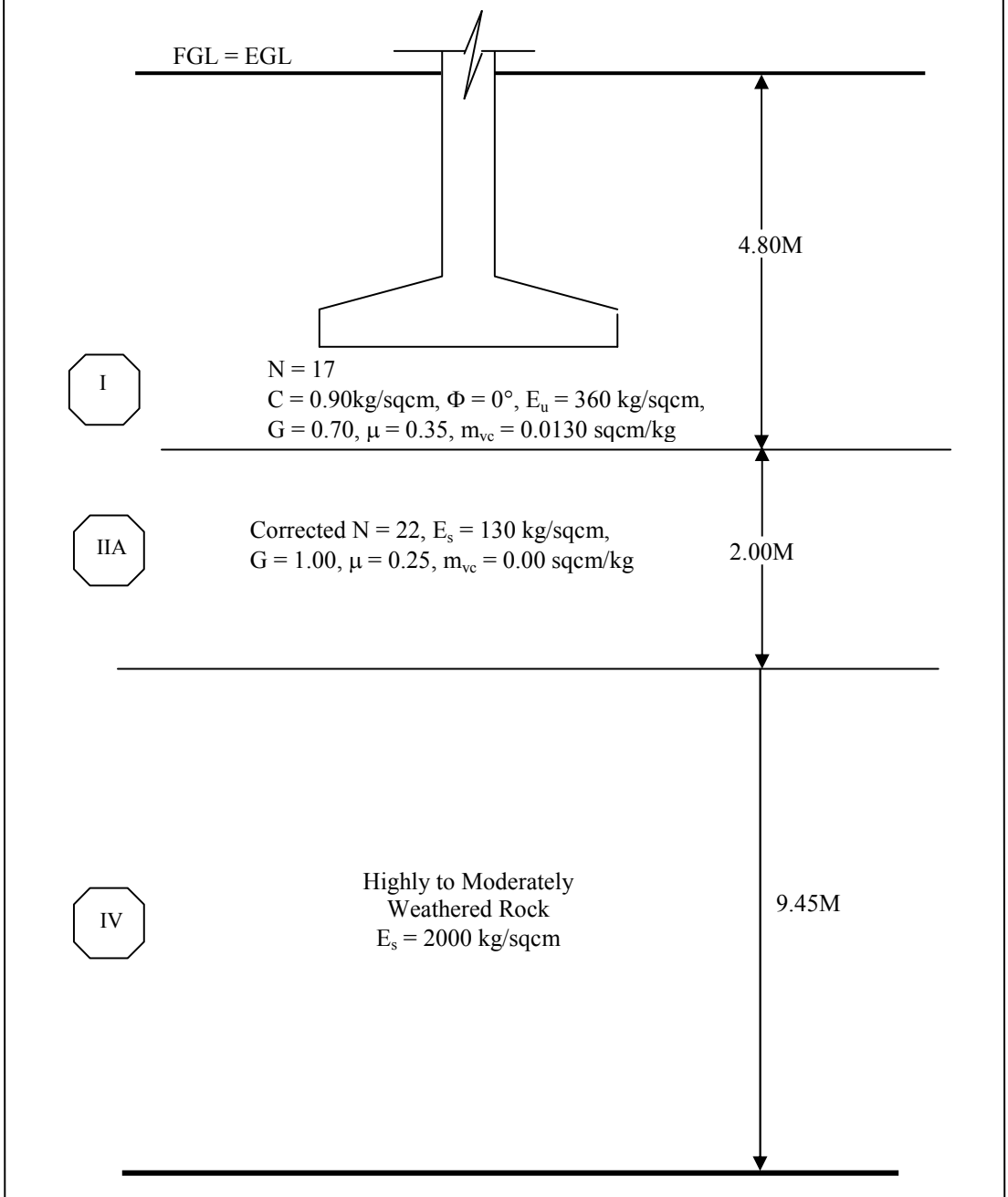


FIG. 3.09B. SHALLOW FOUNDATION DESIGN MODEL

Around Boundary Wall Area (For BH-23 & 34)

(Not to Scale)

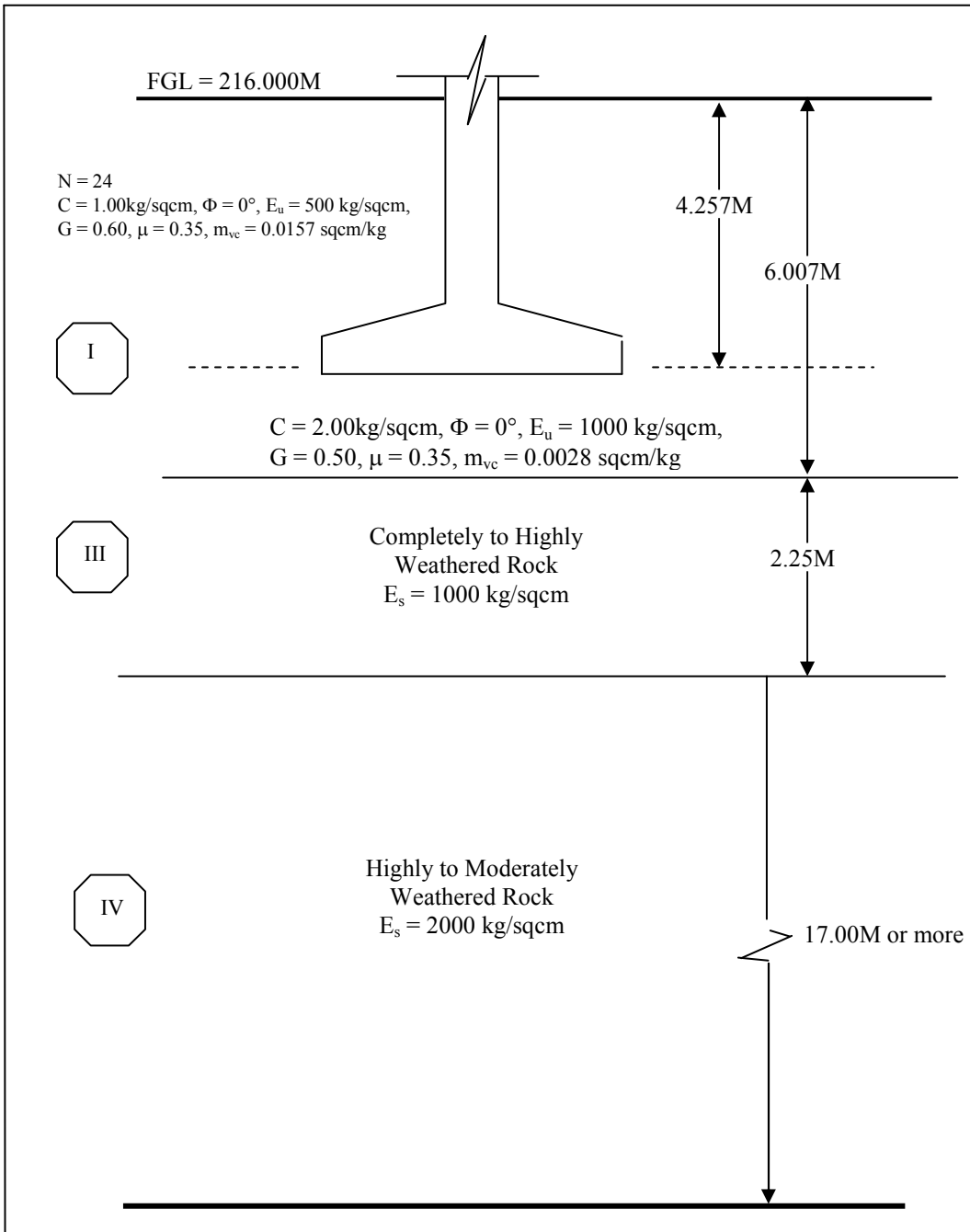


FIG. 3.10. SHALLOW FOUNDATION DESIGN MODEL

Around Cooling Tower Area

(Not to Scale)

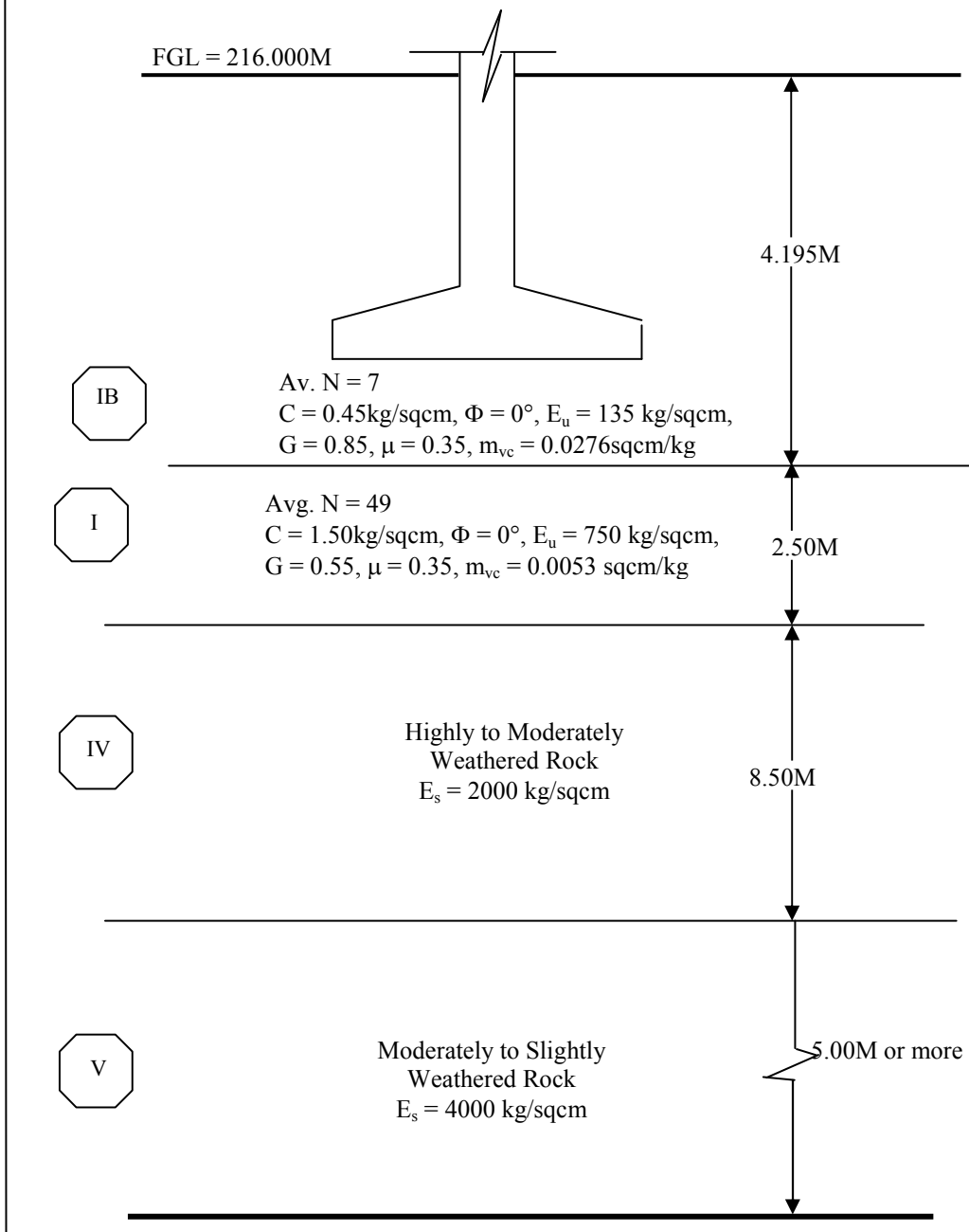


FIG. 3.11. SHALLOW FOUNDATION DESIGN MODEL

Around Service Water Tank & Pump House Area

(Not to Scale)

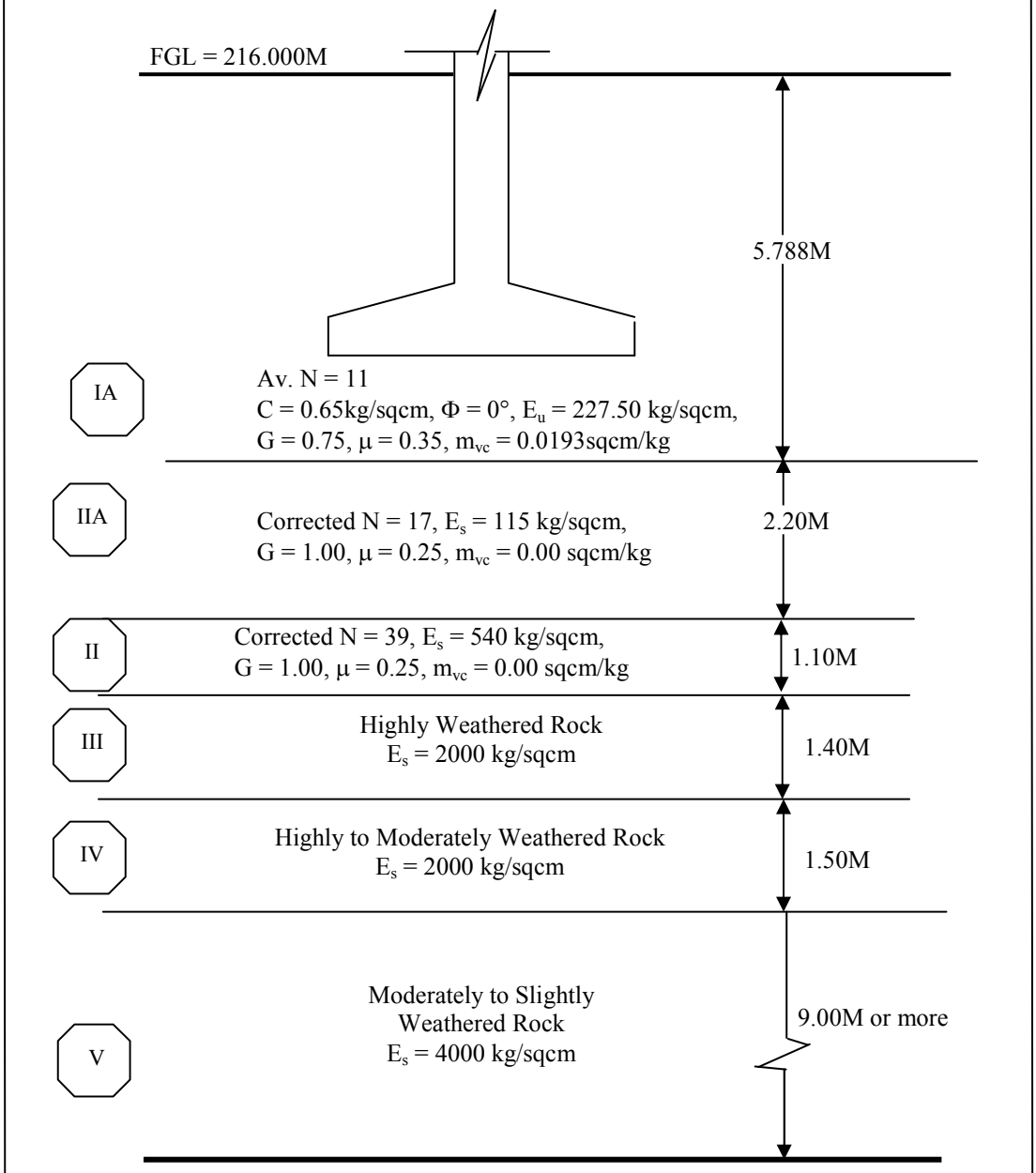


FIG. 3.12. SHALLOW FOUNDATION DESIGN MODEL

Around Clarified Water Storage Tank, Fire Water & Make up Water Pump House & PT Plant Area

(Not to Scale)

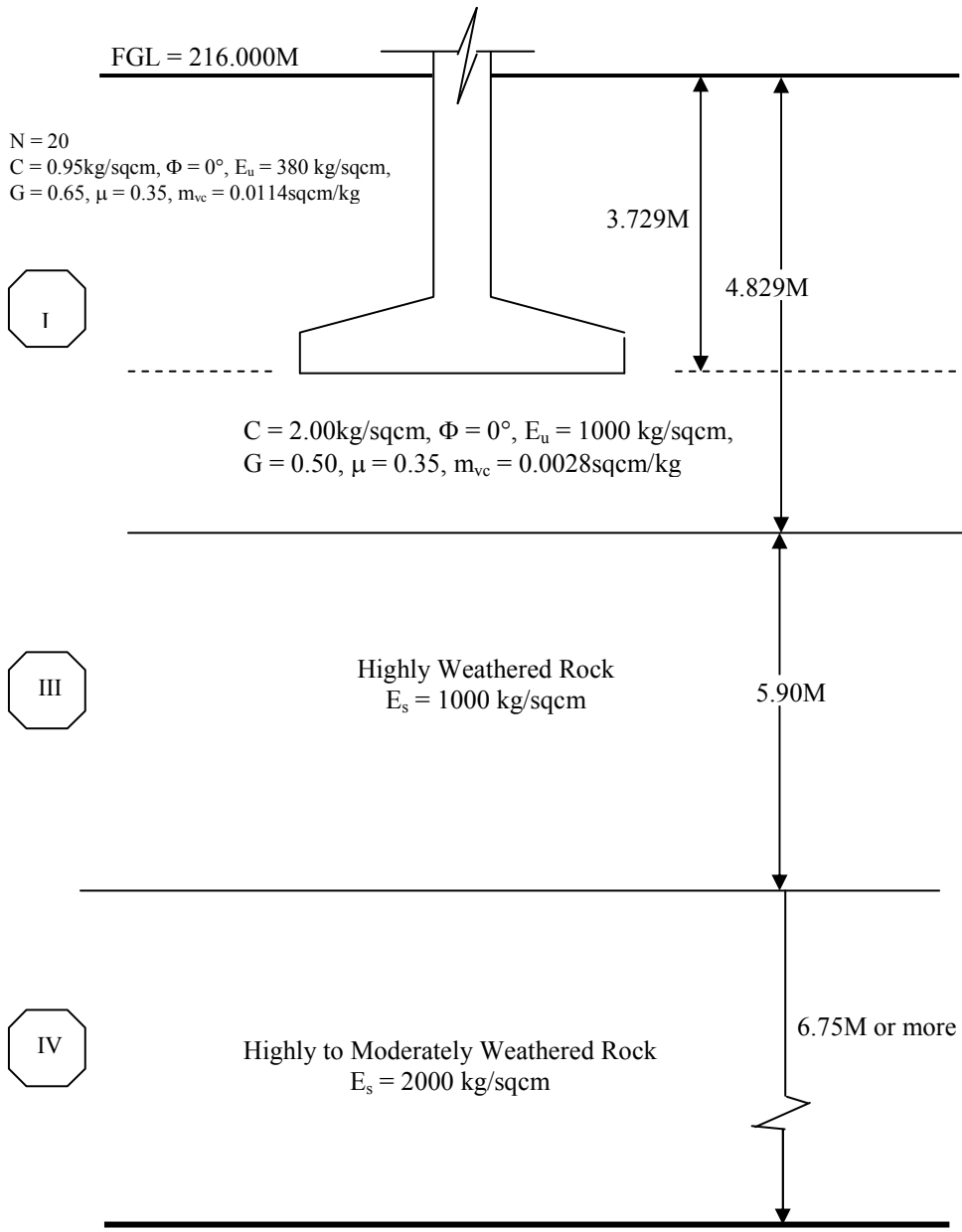


FIG. 3.13. SHALLOW FOUNDATION DESIGN MODEL
Around Near Construction Store Area
(Not to Scale)

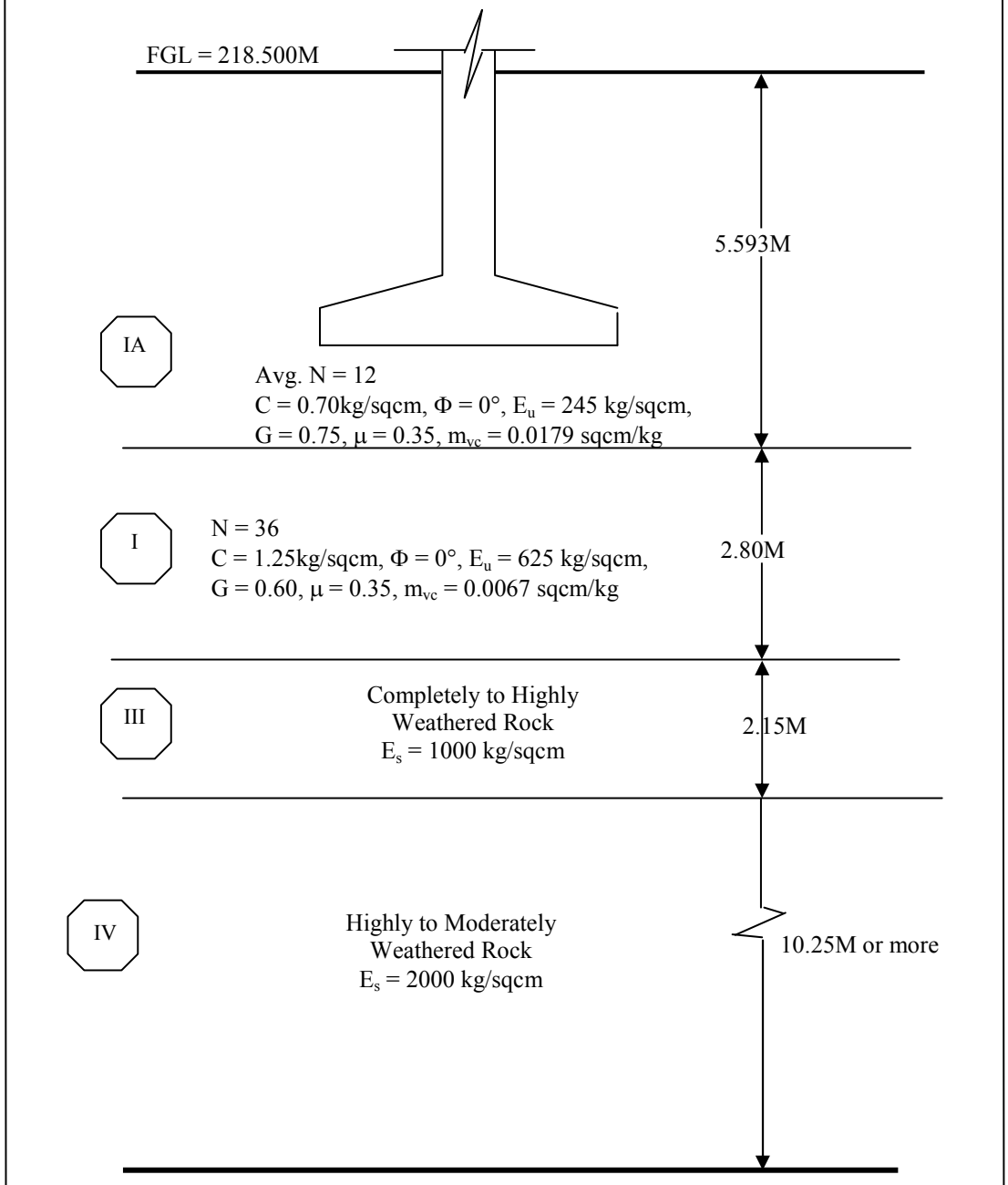


FIG. 3.14. SHALLOW FOUNDATION DESIGN MODEL
Around Administrative Building and O & M Store Area
(Not to Scale)

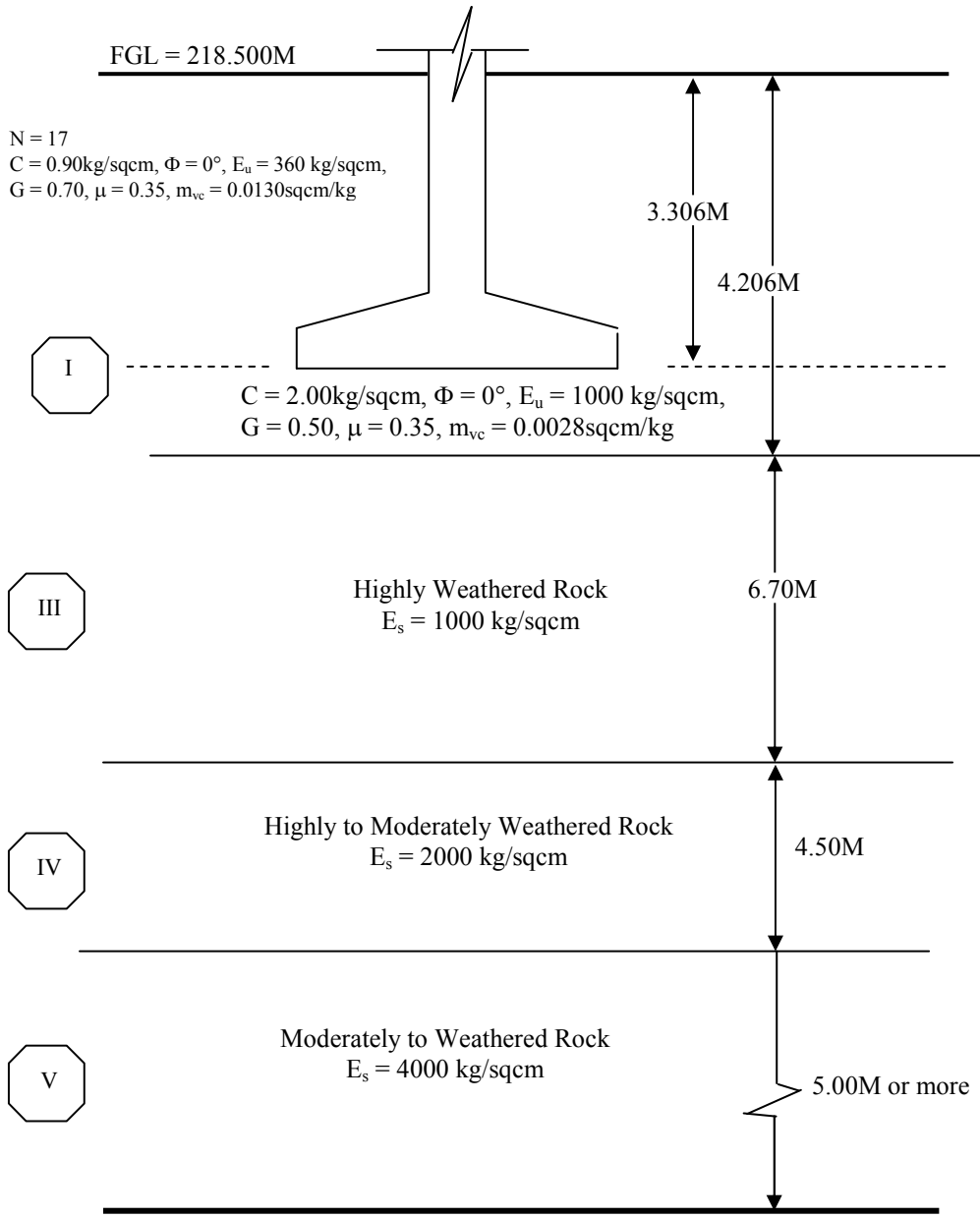


FIG. 3.15. SHALLOW FOUNDATION DESIGN MODEL

Around DM Storage Tank, STP, ETP & Guard Pond Area

(Not to Scale)

With reference to the above and considering the subsoil condition around each bore hole, the following bearing capacity values are recommended.

Foundation Location	D_f below FGL (M)	Width of Foundation (m)	L/B Ratio	Computed NSBC (t/sqm)	Recommended NABC (t/sqm)			Remarks
					S = 25mm	S = 40mm	S = 75mm	
Chimney (BH-01, 02, 03 & 43)	1.00 – 3.00	--	--	--	*			FGL considered RL(+) 218.500M
	4.00	20m dia	--	42.02	30	40	40	
	6.00	20m dia	--	57.14	40	40	40	
	6.60	20m dia	--	180.98	45#			
	4.00	25m dia	--	41.70	30	40	40	
	6.00	25m dia	--	56.50	40	40	40	
	6.60	25m dia	--	202.11	45#			
	4.00	30m dia	--	41.48	30	40	40	
	6.00	30m dia	--	56.07	40	40	40	
	6.60	30m dia	--	223.59	45#			
	4.00	35m dia	--	41.33	30	40	40	
	6.00	35m dia	--	55.77	40	40	40	
	6.60	35m dia	--	245.27	45#			
ESP & ID Fan Area (BH-04 to 08, 45 & 46)	1.00 – 3.00	--	--	--	*			FGL considered RL(+) 218.500M
	4.00	Upto 5	1.0	23.56	12	18	--	
			2.0 – 5.0	18.68	9	14	--	
			Strip (L/B=10)	18.29	8	13	--	
		≥ 6	Raft	23.03	10	18	22	
	5.00	Upto 5	1.0	24.44	18	24	--	
			2.0 – 5.0	19.33	14	18	--	
			Strip (L/B=10)	18.93	13	18	--	
		≥ 6	Raft	23.77	13	22	22	
	6.00	Upto 5	1.0	66.67	35	40	--	
			2.0 – 5.0	53.16	35	40	--	
			Strip (L/B=10)	52.10	35	40	--	
		≥ 6	Raft	64.63	35	40	40	
	7.70	Upto 5	1.0	161.65	45#			
			2.0 – 5.0	150.53	45#			
			Strip (L/B=10)	150.33	45#			
		≥ 6	Raft	162.83	45#			
Boiler & Mill Bunker Area (BH-09 to 13 & 35)	1.00 – 3.00	--	--	--	*			FGL considered RL(+) 218.500M
	4.00	Upto 5	1.0	25.11	24	25	--	
			2.0 – 5.0	19.92	16	18	--	
			Strip (L/B=10)	19.51	15	18	--	
		≥ 6	Raft	24.54	15	24	24	
	5.00	Upto 5	1.0	46.91	35	40	--	
			2.0 – 5.0	37.31	30	36	--	
			Strip (L/B=10)	36.56	28	36	--	
		≥ 6	Raft	45.61	28	40	40	
	6.00	Upto 5	1.0	48.53	40	40	--	
			2.0	40.91	40	40	--	
			5.0	38.56	38	38	--	
			Strip (L/B=10)	37.78	36	36	--	
		≥ 6	Raft	46.98	38	40	40	
	9.20	Upto 5	1.0	193.98	45#			
			2.0 – 5.0	178.95	45#			
			Strip (L/B=10)	178.32	45#			
		≥ 6	Raft	193.15	45#			

Foundation Location	D_f below FGL (M)	Width of Foundation (m)	L/B Ratio	Computed NSBC (t/sqm)	Recommended NABC (t/sqm)			Remarks
					S = 25mm	S = 40mm	S = 75mm	
Power House, TG, Compressor Building (BH-14, 15, 16, 20 & 47)	1.00 – 3.00	--	--	--	*			FGL considered RL(+) 218.500M
	4.00	Upto 5	1.0	29.77	22	28	--	
			2.0 – 5.0	23.64	18	22	--	
			Strip (L/B=10)	23.16	17	22	--	
		≥ 6	Raft	29.09	18	28	28	
	5.00	Upto 5	1.0	30.86	30	30	--	
			2.0 – 5.0	24.47	24	24	--	
			Strip (L/B=10)	23.96	22	22	--	
		≥ 6	Raft	30.01	24	30	30	
	6.00	Upto 5	1.0	66.77	40	40	--	
			2.0 – 5.0	53.16	40	40	--	
			Strip (L/B=10)	52.10	40	40	--	
		≥ 6	Raft	64.63	38	40	40	
	8.00	Upto 5	1.0	167.94	45#			
			2.0 – 5.0	156.06	45#			
			Strip (L/B=10)	155.78	45#			
		≥ 6	Raft	168.75	45#			
Transformer Yard (BH-17)	2.00 – 3.00	Upto 5	1.0	20.37	18	20	--	FGL considered RL(+) 218.500M
			2.0 – 5.0	16.21	10	16	--	
			Strip (L/B=10)	15.88	9	15	--	
		≥ 6	Raft	20.12	10	20	20	
	4.00 – 6.00	Upto 5	1.0	46.83	40	40	--	
			2.0 – 5.0	37.29	36	36	--	
			Strip (L/B=10)	36.55	35	35	--	
		≥ 6	Raft	45.76	36	40	40	
	7.90	Upto 5	1.0	165.84	45#			
			2.0 – 5.0	154.21	45#			
			Strip (L/B=10)	153.96	45#			
		≥ 6	Raft	166.77	45#			
Switch Yard (BH-18 & 19)	2.00	Upto 3	1.0	15.30	10	15	--	FGL considered RL(+) 218.500M
			2.0 – 5.0	12.16	8	12	--	
			Strip (L/B=10)	11.91	7	11	--	
		3 - 5	1.0	14.59	9	14	--	
			2.0 – 5.0	11.59	6	10	--	
			Strip (L/B=10)	11.35	5	10	--	
		≥ 6	Raft	14.41	8	14	14	
	3.00	Upto 3	1.0	16.27	16	16	--	
			2.0 – 5.0	12.88	12	12	--	
			Strip (L/B=10)	12.62	11	11	--	
		3 - 5	1.0	15.20	15	15	--	
			2.0 – 5.0	12.03	12	12	--	
			Strip (L/B=10)	11.78	11	11	--	
		≥ 6	Raft	14.93	10	14	14	
	5.00	Upto 3	1.0	37.81	36	36	--	
			2.0 – 5.0	30.03	30	30	--	
			Strip (L/B=10)	29.42	28	28	--	
		3 - 5	1.0	34.07	34	34	--	
			2.0 – 5.0	27.04	26	26	--	
			Strip (L/B=10)	26.48	25	25	--	
		≥ 6	Raft	33.13	25	32	32	
	6.00	Upto 3	1.0	39.76	38	38	--	
			2.0 – 5.0	31.55	30	30	--	
			Strip (L/B=10)	30.90	30	30	--	

Foundation Location	D_f below FGL (M)	Width of Foundation (m)	L/B Ratio	Computed NSBC (t/sqm)	Recommended NABC (t/sqm)			Remarks
					S = 25mm	S = 40mm	S = 75mm	
Switch Yard (BH-18 & 19)	6.00	3 - 5	1.0	35.26	35	35	--	FGL considered RL(+) 218.500M
			2.0 – 5.0	27.95	26	26	--	
			Strip (L/B=10)	27.37	25	25	--	
		≥ 6	Raft	34.14	26	34	34	
	9.00	Upto 5	1.0	189.55	45#			
			2.0 – 5.0	175.05	45#			
			Strip (L/B=10)	174.48	45#			
		≥ 6	Raft	189.00	45#			
Emergency DG Station (BH-21)	1.00 – 5.00	--	--	--	*			FGL considered RL(+) 218.500M
	6.50	Upto 5	1.0	67.88	40	40	--	
			2.0 – 5.0	54.02	40	40	--	
			Strip (L/B=10)	52.94	40	40	--	
		≥ 6	Raft	65.56	--	40	40	
CWPH, CW Treatment & Chlorine di oxide Dosing System Area (BH-22, 25 & 28)	2.00	Upto 3	1.0	15.30	9	15	--	FGL considered RL(+) 216.000M
			2.0 – 5.0	12.16	7	12	--	
			Strip (L/B=10)	11.91	6	10	--	
		3 - 5	1.0	14.59	7	12	--	
			2.0 – 5.0	11.59	6	10	--	
			Strip (L/B=10)	11.35	5	9	--	
		≥ 6	Raft	14.41	--	12	14	
	3.00	Upto 3	1.0	16.27	16	16	--	
			2.0 – 5.0	12.88	12	12	--	
			Strip (L/B=10)	12.62	10	10	--	
		3 - 5	1.0	15.20	15	15	--	
			2.0 – 5.0	12.03	12	12	--	
			Strip (L/B=10)	11.78	11	11	--	
		≥ 6	Raft	14.93	--	14	14	
	4.00	Upto 3	1.0	27.40	26	26	--	
			2.0 – 5.0	21.74	20	20	--	
			Strip (L/B=10)	21.30	18	18	--	
		3 - 5	1.0	25.11	25	25	--	
			2.0 – 5.0	19.92	18	18	--	
			Strip (L/B=10)	19.51	17	17	--	
		≥ 6	Raft	24.54	--	24	24	
	5.00	Upto 5	1.0	64.56	40	40	--	
			2.0 – 5.0	51.43	40	40	--	
			Strip (L/B=10)	50.41	40	40	--	
		≥ 6	Raft	62.78	--	40	40	
Boundary Wall (BH-30 & 31)	1.50	Upto 2	1.0	15.49	8	12	15	FGL considered at EGL
			2.0 – 5.0	12.33	--	5	7	
			Strip (L/B=10)	12.08	--	4	11	
		2 – 3	1.0	14.82	6	10	14	
			2.0 – 5.0	11.79	--	5	10	
			Strip (L/B=10)	11.55	--	4	9	
		3 - 5	1.0	14.29	--	8	12	
			2.0 – 5.0	11.36	--	5	7	
			Strip (L/B=10)	11.14	--	4	6	
	2.00	Upto 2	1.0	16.19	10	16	16	
			2.0 – 5.0	12.87	7	12	12	
			Strip (L/B=10)	12.61	6	11	11	
		2 – 3	1.0	15.30	9	15	15	
			2.0 – 5.0	12.16	7	12	12	
			Strip (L/B=10)	11.91	6	11	11	

Foundation Location	D_f below FGL (M)	Width of Foundation (m)	L/B Ratio	Computed NSBC (t/sqm)	Recommended NABC (t/sqm)			Remarks
					S = 25mm	S = 40mm	S = 75mm	
Boundary Wall (BH-30 & 31)	2.00	3 - 5	1.0	14.59	7	10	14	FGL considered at EGL
			2.0 – 5.0	11.59	--	5	7	
			Strip (L/B=10)	11.35	--	4	6	
	3.00	Upto 2	1.0	17.60	16	16	16	
			2.0 – 5.0	13.95	12	12	12	
			Strip (L/B=10)	13.66	11	11	11	
		2 – 3	1.0	16.27	16	16	16	
			2.0 – 5.0	12.88	12	12	12	
			Strip (L/B=10)	12.62	11	11	11	
		3 - 5	1.0	15.20	15	15	15	
			2.0 – 5.0	12.03	12	12	12	
			Strip (L/B=10)	11.78	11	11	11	
	4.00	Upto 2	1.0	30.25	30	30	30	
			2.0 – 5.0	24.03	24	24	24	
			Strip (L/B=10)	23.54	22	22	22	
		2 – 3	1.0	27.40	26	26	26	
			2.0 – 5.0	21.74	20	20	20	
			Strip (L/B=10)	21.30	19	19	19	
		3 - 5	1.0	25.11	20	25	25	
			2.0 – 5.0	19.92	11	18	18	
			Strip (L/B=10)	19.51	10	16	18	
Boundary Wall (BH-23 & 34)	1.50	Upto 2	1.0	27.79	20	26	26	FGL considered at EGL
			2.0 – 5.0	22.17	12	20	22	
			Strip (L/B=10)	21.73	11	20	20	
		2 – 3	1.0	26.59	14	22	26	
			2.0 – 5.0	21.21	10	18	20	
			Strip (L/B=10)	20.79	9	14	20	
		3 - 5	1.0	25.63	10	16	24	
			2.0 – 5.0	20.44	6	10	15	
			Strip (L/B=10)	20.03	5	8	12	
	2.00	Upto 2	1.0	29.03	26	28	28	
			2.0 – 5.0	23.14	13	22	22	
			Strip (L/B=10)	22.68	12	18	22	
		2 – 3	1.0	27.43	18	26	26	
			2.0 – 5.0	21.86	12	20	20	
			Strip (L/B=10)	21.42	11	16	20	
		3 - 5	1.0	26.14	12	20	26	
			2.0 – 5.0	20.83	10	16	20	
			Strip (L/B=10)	20.42	9	14	20	
	3.00	Upto 2	1.0	31.51	30	30	30	
			2.0 – 5.0	25.08	25	25	25	
			Strip (L/B=10)	24.58	24	24	24	
		2 – 3	1.0	29.11	22	28	28	
			2.0 – 5.0	23.16	13	22	22	
			Strip (L/B=10)	22.69	12	18	22	
		3 - 5	1.0	27.18	16	26	26	
			2.0 – 5.0	21.61	12	20	20	
			Strip (L/B=10)	21.18	11	16	20	
Cooling Tower (BH-24, 29 & 44)	1.00 – 3.00	--	--	--	*			FGL considered RL(+) 216.000M

Foundation Location	D_f below FGL (M)	Width of Foundation (m)	L/B Ratio	Computed NSBC (t/sqm)	Recommended NABC (t/sqm)			Remarks
					S = 25mm	S = 40mm	S = 75mm	
Cooling Tower (BH-24, 29 & 44)	4.00	Upto 5	1.0	31.32	30	30	--	FGL considered RL(+) 216.000M
			2.0 – 5.0	24.88	24	24	--	
			Strip (L/B=10)	24.38	22	22	--	
		≥ 6	Raft	30.61	--	30	30	
	5.00 – 6.00	Upto 5	1.0	64.56	40	40	--	
			2.0 – 5.0	51.43	40	40	--	
			Strip (L/B=10)	50.41	40	40	--	
		≥ 6	Raft	62.78	--	40	40	
Service Water Tank & Pump House Area (BH-26 & 27)	2.00	Upto 3	1.0	13.79	8	12	--	FGL considered RL(+) 216.000M
			2.0 – 5.0	10.94	6	10	--	
			Strip (L/B=10)	10.72	5	8	--	
		3 - 5	1.0	13.15	6	10	--	
			2.0 – 5.0	10.43	5	8	--	
			Strip (L/B=10)	10.22	4	6	--	
		≥ 6	Raft	12.98	--	10	12	
	3.00	Upto 3	1.00	14.66	12	14	--	FGL considered RL(+) 216.000M
			2.0 – 5.0	11.60	6	10	--	
			Strip (L/B=10)	11.36	5	8	--	
		3 - 5	1.0	13.70	10	12	--	
			2.0 – 5.0	10.83	6	10	--	
			Strip (L/B=10)	10.60	5	8	--	
		≥ 6	Raft	13.46	--	12	12	
	4.00	Upto 3	1.0	15.54	15	15	--	
			2.0 – 5.0	12.26	12	12	--	
			Strip (L/B=10)	11.99	10	10	--	
		3 - 5	1.0	14.25	14	14	--	
			2.0 – 5.0	11.23	10	10	--	
			Strip (L/B=10)	10.99	9	9	--	
		≥ 6	Raft	13.93	--	12	12	
	5.00	Upto 5	1.0	48.51	40	40	--	
			2.0 – 5.0	38.59	38	38	--	
			Strip (L/B=10)	37.82	36	36	--	
		≥ 6	Raft	47.17	--	40	40	
Clarified Water Storage Tank, Fire Water & Make up Water Pump House & PT Plant Area (BH-32 & 33)	2.00	Upto 3	1.0	19.85	10	16	--	FGL considered RL(+) 216.000M
			2.0 – 5.0	15.79	7	12	--	
			Strip (L/B=10)	15.48	6	10	--	
		3 - 5	1.0	18.92	7	11	--	
			2.0 – 5.0	15.05	5	8	--	
			Strip (L/B=10)	14.75	4	6	--	
		≥ 6	Raft	18.69	--	11	16	
	3.00	Upto 3	1.0	21.08	12	20	--	
			2.0 – 5.0	16.74	10	16	--	
			Strip (L/B=10)	16.39	9	14	--	
		3 - 5	1.0	19.69	9	14	--	
			2.0 – 5.0	15.62	6	10	--	
			Strip (L/B=10)	15.30	5	8	--	
		≥ 6	Raft	19.34	--	14	18	
	4.00	Upto 3	1.0	22.31	15	22	--	
			2.0 – 5.0	17.68	10	16	--	
			Strip (L/B=10)	17.31	9	14	--	
		3 - 5	1.0	20.46	12	18	--	
			2.0 – 5.0	16.19	8	14	--	
			Strip (L/B=10)	15.86	7	11	--	

Foundation Location	D_f below FGL (M)	Width of Foundation (m)	L/B Ratio	Computed NSBC (t/sqm)	Recommended NABC (t/sqm)			Remarks
					S = 25mm	S = 40mm	S = 75mm	
Clarified Water Storage Tank, Fire Water & Make up Water Pump House & PT Plant Area (BH-32 & 33)	4.00	≥ 6	Raft	20.00	--	18	20	FGL considered RL(+) 216.000M
Near Construction Store (BH-36)	2.00	Upto 3	1.0	28.94	28	28	--	FGL considered RL(+) 216.000M
			2.0 – 5.0	23.07	22	22	--	
			Strip (L/B=10)	22.61	21	21	--	
		3 - 5	1.0	27.59	22	26	--	
			2.0 – 5.0	21.99	12	20	--	
			Strip (L/B=10)	21.55	10	16	--	
		≥ 6	Raft	27.25	--	26	26	
	3.00	Upto 3	1.0	30.71	30	30	--	
			2.0 – 5.0	24.44	24	24	--	
			Strip (L/B=10)	23.95	22	22	--	
		3 - 5	1.0	28.68	28	28	--	
			2.0 – 5.0	22.81	22	22	--	
			Strip (L/B=10)	22.35	21	21	--	
		≥ 6	Raft	28.17	--	28	28	
	4.00	Upto 5	1.0	62.35	40	40	--	
			2.0 – 5.0	49.71	40	40	--	
			Strip (L/B=10)	48.72	40	40	--	
		≥ 6	Raft	60.92	--	40	40	
Administrative Building and O & M Store (BH-37 & 38)	1.00 – 3.00	--	--	--	*			FGL considered RL(+) 218.500M
	4.00	Upto 3	1.0	24.01	16	24	--	
			2.0 – 5.0	19.03	11	18	--	
			Strip (L/B=10)	18.64	10	16	--	
		3 - 5	1.0	22.01	12	20	--	
			2.0 – 5.0	17.44	10	16	--	
			Strip (L/B=10)	17.07	9	14	--	
		≥ 6	Raft	21.51	--	20	20	
	5.00	Upto 3	1.0	25.33	25	25	--	
			2.0 – 5.0	20.05	20	20	--	
			Strip (L/B=10)	19.63	18	18	--	
		3 - 5	1.0	22.83	22	22	--	
			2.0 – 5.0	18.05	18	18	--	
			Strip (L/B=10)	17.67	16	16	--	
		≥ 6	Raft	22.21	--	22	22	
	6.00	Upto 3	1.0	47.25	40	40	--	
			2.0 – 5.0	37.54	36	36	--	
			Strip (L/B=10)	36.77	35	35	--	
		3 - 5	1.0	41.90	40	40	--	
			2.0 – 5.0	33.26	32	32	--	
			Strip (L/B=10)	32.58	30	30	--	
		≥ 6	Raft	40.56	--	40	40	
DM Storage Tank, STP, ETP & Guard Pond Area (BH-39 to 42)	2.00	--	--	--	*			FGL considered RL(+) 218.500M
	3.00	Upto 3	1.0	29.11	22	28	--	
			2.0 – 5.0	23.16	13	22	--	
			Strip (L/B=10)	22.69	12	18	--	

Foundation Location	D_f below FGL (M)	Width of Foundation (m)	L/B Ratio	Computed NSBC (t/sqm)	Recommended NABC (t/sqm)			Remarks
					S = 25mm	S = 40mm	S = 75mm	
DM Storage Tank, STP, ETP & Guard Pond Area (BH-39 to 42)	3.00	3 - 5	1.0	27.18	24	26	--	FGL considered RL(+) 218.500M
			2.0 – 5.0	21.61	12	20	--	
			Strip (L/B=10)	21.18	10	16	--	
		≥ 6	Raft	26.70	--	26	26	
	4.00	Upto 5	1.0	62.35	40	40	--	
			2.0 – 5.0	49.71	40	40	--	
			Strip (L/B=10)	48.72	40	40	--	
		≥ 6	Raft	60.92	--	40	40	

Note:

1. NSBC = Computed Net Safe Bearing Capacity, NABC = Recommended Net Allowable Bearing Capacity, FGL = Finished Ground Level
2. S = Limiting Settlement.
3. In case of any loose soil is observed at the founding level the same shall be removed and filled up by PCC upto the required founding level.
4. * - The minimum depth of open foundation shall be 1.50m below FGL subject to at least 1.0m below bottom of fill layer. However ground floor slabs, trenches, pipe pedestals, channels / drains etc. with maximum net allowable bearing capacity of 5 t/sqm shall be supported on open / shallow foundations resting on virgin soil / controlled compacted filled up soil. No major foundation shall be placed on soft / loose soil, ash, brick bats, boulders, kankar, industrial solid waste or any other heterogeneous material. In such case, minimum depth of open foundation shall be 1m below bottom of such fill.
5. # - For foundation placed inside rock, the permissible settlement is considered as 12mm irrespective of foundation types.

5.4. SWELLING CHARACTERISTICS:

The swelling pressure and Free Swell Index tests were performed on a few samples and the test results are presented at the end of Volume-2. The average swelling pressure and Free Swell Index as found from the tests are 0.34kg/sqcm and 14.68% respectively. It is seen that the soil has low to medium swelling characteristics. So, no problem with respect to the swelling of the subsoil is anticipated in general.

5.5. FIELD PERMEABILITY TEST RESULTS:

Field permeability test was conducted at two different depths in nine bore holes by falling head method and the test results are presented below. A sample calculation is also enclosed at the end of Volume-2.

Test Locations	Type of Test	Depth of Test (M)	Permeability (cm/sec)
BH-01	Falling Head	2.20 – 2.80	2.919×10^{-5}
	Falling Head	4.00 – 4.60	5.884×10^{-5}
BH-10	Falling Head	1.70 – 2.40	2.710×10^{-6}
	Falling Head	3.65 – 4.45	2.190×10^{-6}
BH-18	Falling Head	1.60 – 2.40	3.370×10^{-6}
	Falling Head	3.70 – 4.40	1.822×10^{-6}
BH-27	Falling Head	1.70 – 2.30	1.048×10^{-5}
	Falling Head	3.80 – 4.50	9.641×10^{-5}
BH-29	Falling Head	2.00 – 2.70	9.976×10^{-6}
	Falling Head	4.00 – 4.70	8.084×10^{-6}

5.6. FIELD CBR TEST RESULTS:

Both soaked & unsoaked field CBR test were conducted at site and the test results are presented below. The graphs are presented in Volume-2.

Sl No.	Test Location	Depth of Test (m)	Soaked			Un Soaked		
			2.50mm Penetration	5.00mm Penetration	Average	2.50mm Penetration	5.00mm Penetration	Average
1	FCBR-01	0.50	2.15 1.99 2.28	1.70 1.75 1.84	2.14	1.83 2.32 2.64	1.68 2.05 2.61	2.26
2	FCBR-02	0.50	2.46 2.23 2.15	2.19 2.11 1.81	2.28	3.63 4.03 3.30	3.11 3.30 2.70	3.65
3	FCBR-03	0.50	2.01 2.34 2.32	1.81 2.17 1.99	2.22	Unsoaked Test not possible due to seepage water.		
4	FCBR-04	0.50	2.15 2.32 2.75	1.89 1.99 2.36	2.41	Unsoaked Test not possible due to seepage water.		
5	FCBR-05	0.50	1.96 2.15 2.45	1.72 1.82 2.07	2.19	Unsoaked Test not possible due to seepage water.		

5.7. CHEMICAL TESTS:

Chemical tests were performed on few soil and water samples for determining the pH value, Sulphate, Chloride content etc. The results are given in a tabular form below:

CHEMICAL TEST RESULTS ON SOIL SAMPLES:-

BH/Sample No.	Depth (m)	pH value	Sulphate as SO_3 (%)	Chloride as Cl (%)	Carbonate as Co_3 (%)	Organic Matter (%)
03/ UDS-01	3.50	7.32	0.050	0.018	1.329	0.167
07 / UDS-02	4.00	7.50	BDL	0.015	1.947	0.118
11 / UDS-01	2.00	6.87	0.050	0.015	1.947	0.339
20 / UDS-02	4.00	6.35	0.050	0.018	1.020	0.311
34 / UDS-01	2.00	6.06	0.050	0.034	0.711	0.156

CHEMICAL TEST RESULTS ON WATER SAMPLES: -

BH/Sample No.	Depth (M)	pH value	Sulphate as (mg/litre)	Chloride as (mg/litre)	Nitrate as (mg/litre)	Organic Matter (mg/litre)
02	2.35	6.53	60	18	0.06	8.29
09	2.60	7.00	60	27	0.10	11.05
19	1.65	7.22	60	22	0.12	55.26
24	0.60	7.12	60	24	0.10	13.25
36	0.45	7.22	60	26	0.12	10.05

It is seen that the values are on a safe side and so no special cement will be required for foundation concrete. **Either Ordinary Portland cement or Portland slag cement or Portland Pozzolana cement can be used for the purpose.**

5.8. POSSIBILITY OF SUBSOIL LIQUEFACTION DUE TO EARTHQUAKE:

As per H. B. Seed and I.M. Idriss (1982) a soil is said to be non-liquefiable if any one of the following three criteria is satisfied.

a) the soil contains fine grained soils with clay contents greater than 15%,
b) liquid limit greater than 35% or
c) moisture contents less than 90% of the liquid limit.

Based on the above parameters, it is seen that the soil (layer-I, IA & IB) at the present site is non-liquefiable as clay content is 15%, 17% & 20%, LL is 40%, 43% & 40% and moisture content (19%, 20% & 20%) is less than 90% of the liquid limit. The soil of layer –II & IIA is clayey silty sand having high N values. Hence, liquefaction of this layer is also not anticipated.

Based on the above discussion, it can be conclude that the subsoil at the present site is non liquefiable.

5.9. SUITABILITY OF EXISTING SOIL FOR FILLING AND BACK-FILLING:

The subsoil at the site consists of silty clay with fine sand mixtures having low swelling properties. So, the soil can be used for filling and backfilling purposes with necessary compaction as required.

5.10. SUITABILITY OF SOIL FOR CONSTRUCTION OF ROADS:

The subsoils at the site consist of silty clay / clayey silt with sand mixture having low swelling properties. So, the soil can be used for the construction of roads and pavement as a fill material with necessary compaction as required.

5.11. EXCAVATION:

For excavation in virgin soil (stratum-I & II), a slope of 1(H):2(V) may be used. For excavation in stratum-III, IV & V (i.e. rock layer), vertical or almost vertical slope may be used. However, to be in the safer side, a nominal side slope of 0.5(H):1(V) for stratum-III & IV and 0.25(H):1(V) for stratum-V should be provided.

It is also suggested to provide a Berm of at least 1m wide after each 3m to 4m of excavation. Excavation in stratum-I & II can be made with shovels and pick-axe. At lower reaches, pneumatic / jack hammer will be more efficient. Alternatively controlled blasting may be required.

5.12. EARTH PRESSURE CO-EFFICIENT:

The co-efficient of earth pressure at rest is calculated based on the following formula and using the Cross Hole Test results. Co-efficient of Earth Pressure at Rest, $K_0 = \mu / (1-\mu)$

For design purpose, the following average values can be used.

Depth (M)	Design Average K_0 value
0.00 – 5.00	0.51
5.00 – 10.00	0.36
10.00 – 15.00	0.34
Below 15m	0.29

The Co-efficient of earth pressure at Active and Passive State are given below in a tabular form.

Layer	K_a	K_p
Layer – IA	0.36	2.77
Layer – IB	0.38	2.66
Layer – I	0.35	2.88
Layer – II	0.28	3.54
Layer – IIA	0.33	3.00
Layer – III	0.27	3.69
Layer - IV	0.25	4.02
Layer - V	0.22	4.60

6. SUMMARY & CONCLUSIONS

Based on the field tests and the foregoing discussion the following are summarised.

1. The subsoils is characterised by a filled up soil followed by stiff silty clay / clayey silt layer. Below this very stiff to hard silty clay / clayey silt layer was observed. After that weathered rock layer was struck and that continues upto the terminating depth of all the boreholes. However around some borehole locations, soft to medium silty clay and very dense silty sand layer was observed.
2. The standing water level was struck at an average depth of about 1.40m below existing ground level. Hence, ordinary surface operated pump will be able to tackle the situation for dewatering, if required.
3. Considering the subsoil condition and the proposed structure to be constructed at the present site, it is suggested to go for open foundation.
4. The recommended bearing capacity values with various depth of foundation are presented in the previous section. However, for routine design this is further listed below.

Foundation Location	D_f below FGL (M)	Width of Foundation (m)	L/B Ratio	Computed NSBC (t/sqm)	Recommended NABC (t/sqm)			Remarks
					S = 25mm	S = 40mm	S = 75mm	
Chimney (BH-01, 02, 03 & 43)	1.00 – 3.00	--	--	--	*			FGL considered RL(+) 218.500M
	4.00	20m dia	--	42.02	30	40	40	
	6.00	20m dia	--	57.14	40	40	40	
	6.60	20m dia	--	180.98	45#			
	4.00	25m dia	--	41.70	30	40	40	
	6.00	25m dia	--	56.50	40	40	40	
	6.60	25m dia	--	202.11	45#			
	4.00	30m dia	--	41.48	30	40	40	
	6.00	30m dia	--	56.07	40	40	40	
	6.60	30m dia	--	223.59	45#			
	4.00	35m dia	--	41.33	30	40	40	
	6.00	35m dia	--	55.77	40	40	40	
	6.60	35m dia	--	245.27	45#			
ESP & ID Fan Area (BH-04 to 08, 45 & 46)	1.00 – 3.00	--	--	--	*			FGL considered RL(+) 218.500M
	4.00	Upto 5	1.0	23.56	12	18	--	
			2.0 – 5.0	18.68	9	14	--	
			Strip (L/B=10)	18.29	8	13	--	
		≥ 6	Raft	23.03	10	18	22	
	5.00	Upto 5	1.0	24.44	18	24	--	
			2.0 – 5.0	19.33	14	18	--	
			Strip (L/B=10)	18.93	13	18	--	
		≥ 6	Raft	23.77	13	22	22	
	6.00	Upto 5	1.0	66.67	35	40	--	
			2.0 – 5.0	53.16	35	40	--	
			Strip (L/B=10)	52.10	35	40	--	
		≥ 6	Raft	64.63	35	40	40	

Foundation Location	D_f below FGL (M)	Width of Foundation (m)	L/B Ratio	Computed NSBC (t/sqm)	Recommended NABC (t/sqm)			Remarks
					S = 25mm	S = 40mm	S = 75mm	
ESP & ID Fan Area (BH-04 to 08, 45 & 46)	7.70	Upto 5	1.0	161.65	45#			FGL considered RL(+) 218.500M
			2.0 – 5.0	150.53	45#			
			Strip (L/B=10)	150.33	45#			
		≥ 6	Raft	162.83	45#			
Boiler & Mill Bunker Area (BH-09 to 13 & 35)	1.00 – 3.00	--	--	--	*			FGL considered RL(+) 218.500M
	4.00	Upto 5	1.0	25.11	24	25	--	
			2.0 – 5.0	19.92	16	18	--	
			Strip (L/B=10)	19.51	15	18	--	
		≥ 6	Raft	24.54	15	24	24	
	5.00	Upto 5	1.0	46.91	35	40	--	
			2.0 – 5.0	37.31	30	36	--	
			Strip (L/B=10)	36.56	28	36	--	
		≥ 6	Raft	45.61	28	40	40	
	6.00	Upto 5	1.0	48.53	40	40	--	
			2.0	40.91	40	40	--	
			5.0	38.56	38	38	--	
			Strip (L/B=10)	37.78	36	36	--	
		≥ 6	Raft	46.98	38	40	40	
	9.20	Upto 5	1.0	193.98	45#			
			2.0 – 5.0	178.95	45#			
			Strip (L/B=10)	178.32	45#			
		≥ 6	Raft	193.15	45#			
Power House, TG, Compressor Building (BH-14, 15, 16, 20 & 47)	1.00 – 3.00	--	--	--	*			FGL considered RL(+) 218.500M
	4.00	Upto 5	1.0	29.77	22	28	--	
			2.0 – 5.0	23.64	18	22	--	
			Strip (L/B=10)	23.16	17	22	--	
		≥ 6	Raft	29.09	18	28	28	
	5.00	Upto 5	1.0	30.86	30	30	--	
			2.0 – 5.0	24.47	24	24	--	
			Strip (L/B=10)	23.96	22	22	--	
		≥ 6	Raft	30.01	24	30	30	
	6.00	Upto 5	1.0	66.77	40	40	--	
			2.0 – 5.0	53.16	40	40	--	
			Strip (L/B=10)	52.10	40	40	--	
		≥ 6	Raft	64.63	38	40	40	
	8.00	Upto 5	1.0	167.94	45#			
			2.0 – 5.0	156.06	45#			
			Strip (L/B=10)	155.78	45#			
		≥ 6	Raft	168.75	45#			
Transformer Yard (BH-17)	2.00 – 3.00	Upto 5	1.0	20.37	18	20	--	FGL considered RL(+) 218.500M
			2.0 – 5.0	16.21	10	16	--	
			Strip (L/B=10)	15.88	9	15	--	
		≥ 6	Raft	20.12	10	20	20	
	4.00 – 6.00	Upto 5	1.0	46.83	40	40	--	
			2.0 – 5.0	37.29	36	36	--	
			Strip (L/B=10)	36.55	35	35	--	
		≥ 6	Raft	45.76	36	40	40	
	7.90	Upto 5	1.0	165.84	45#			
			2.0 – 5.0	154.21	45#			
			Strip (L/B=10)	153.96	45#			
		≥ 6	Raft	166.77	45#			

Foundation Location	D_f below FGL (M)	Width of Foundation (m)	L/B Ratio	Computed NSBC (t/sqm)	Recommended NABC (t/sqm)			Remarks
					S = 25mm	S = 40mm	S = 75mm	
Switch Yard (BH-18 & 19)	2.00	Upto 3	1.0	15.30	10	15	--	FGL considered RL(+) 218.500M
			2.0 – 5.0	12.16	8	12	--	
			Strip (L/B=10)	11.91	7	11	--	
		3 - 5	1.0	14.59	9	14	--	
			2.0 – 5.0	11.59	6	10	--	
			Strip (L/B=10)	11.35	5	10	--	
		≥ 6	Raft	14.41	8	14	14	
	3.00	Upto 3	1.0	16.27	16	16	--	
			2.0 – 5.0	12.88	12	12	--	
			Strip (L/B=10)	12.62	11	11	--	
		3 - 5	1.0	15.20	15	15	--	
			2.0 – 5.0	12.03	12	12	--	
			Strip (L/B=10)	11.78	11	11	--	
		≥ 6	Raft	14.93	10	14	14	
	5.00	Upto 3	1.0	37.81	36	36	--	
			2.0 – 5.0	30.03	30	30	--	
			Strip (L/B=10)	29.42	28	28	--	
		3 - 5	1.0	34.07	34	34	--	
			2.0 – 5.0	27.04	26	26	--	
			Strip (L/B=10)	26.48	25	25	--	
		≥ 6	Raft	33.13	25	32	32	
	6.00	Upto 3	1.0	39.76	38	38	--	
			2.0 – 5.0	31.55	30	30	--	
			Strip (L/B=10)	30.90	30	30	--	
		3 - 5	1.0	35.26	35	35	--	
			2.0 – 5.0	27.95	26	26	--	
			Strip (L/B=10)	27.37	25	25	--	
		≥ 6	Raft	34.14	26	34	34	
	9.00	Upto 5	1.0	189.55	45#			
			2.0 – 5.0	175.05	45#			
			Strip (L/B=10)	174.48	45#			
		≥ 6	Raft	189.00	45#			
Emergency DG Station (BH-21)	1.00 – 5.00	--	--	--	*			FGL considered RL(+) 218.500M
	6.50	Upto 5	1.0	67.88	40	40	--	
			2.0 – 5.0	54.02	40	40	--	
			Strip (L/B=10)	52.94	40	40	--	
		≥ 6	Raft	65.56	--	40	40	
CWPH, CW Treatment & Chlorine di oxide Dosing System Area (BH-22, 25 & 28)	2.00	Upto 3	1.0	15.30	9	15	--	FGL considered RL(+) 216.000M
			2.0 – 5.0	12.16	7	12	--	
			Strip (L/B=10)	11.91	6	10	--	
		3 - 5	1.0	14.59	7	12	--	
			2.0 – 5.0	11.59	6	10	--	
			Strip (L/B=10)	11.35	5	9	--	
		≥ 6	Raft	14.41	--	12	14	
	3.00	Upto 3	1.0	16.27	16	16	--	
			2.0 – 5.0	12.88	12	12	--	
			Strip (L/B=10)	12.62	10	10	--	
		3 - 5	1.0	15.20	15	15	--	
			2.0 – 5.0	12.03	12	12	--	
			Strip (L/B=10)	11.78	11	11	--	
		≥ 6	Raft	14.93	--	14	14	
	4.00	Upto 3	1.0	27.40	26	26	--	
			2.0 – 5.0	21.74	20	20	--	

Foundation Location	D_f below FGL (M)	Width of Foundation (m)	L/B Ratio	Computed NSBC (t/sqm)	Recommended NABC (t/sqm)			Remarks
					S = 25mm	S = 40mm	S = 75mm	
CWPH, CW Treatment & Chlorine di oxide Dosing System Area (BH-22, 25 & 28)	4.00	Upto 3	Strip (L/B=10)	21.30	18	18	--	FGL considered RL(+) 216.000M
		3 - 5	1.0	25.11	25	25	--	
			2.0 – 5.0	19.92	18	18	--	
			Strip (L/B=10)	19.51	17	17	--	
		≥ 6	Raft	24.54	--	24	24	
	5.00	Upto 5	1.0	64.56	40	40	--	
			2.0 – 5.0	51.43	40	40	--	
			Strip (L/B=10)	50.41	40	40	--	
		≥ 6	Raft	62.78	--	40	40	
Boundary Wall (BH-30 & 31)	1.50	Upto 2	1.0	15.49	8	12	15	FGL considered at EGL
			2.0 – 5.0	12.33	--	5	7	
			Strip (L/B=10)	12.08	--	4	11	
		2 – 3	1.0	14.82	6	10	14	
			2.0 – 5.0	11.79	--	5	10	
			Strip (L/B=10)	11.55	--	4	9	
		3 - 5	1.0	14.29	--	8	12	
			2.0 – 5.0	11.36	--	5	7	
			Strip (L/B=10)	11.14	--	4	6	
	2.00	Upto 2	1.0	16.19	10	16	16	
			2.0 – 5.0	12.87	7	12	12	
			Strip (L/B=10)	12.61	6	11	11	
		2 – 3	1.0	15.30	9	15	15	
			2.0 – 5.0	12.16	7	12	12	
			Strip (L/B=10)	11.91	6	11	11	
		3 - 5	1.0	14.59	7	10	14	
			2.0 – 5.0	11.59	--	5	7	
			Strip (L/B=10)	11.35	--	4	6	
	3.00	Upto 2	1.0	17.60	16	16	16	
			2.0 – 5.0	13.95	12	12	12	
			Strip (L/B=10)	13.66	11	11	11	
		2 – 3	1.0	16.27	16	16	16	
			2.0 – 5.0	12.88	12	12	12	
			Strip (L/B=10)	12.62	11	11	11	
		3 - 5	1.0	15.20	15	15	15	
			2.0 – 5.0	12.03	12	12	12	
			Strip (L/B=10)	11.78	11	11	11	
	4.00	Upto 2	1.0	30.25	30	30	30	
			2.0 – 5.0	24.03	24	24	24	
			Strip (L/B=10)	23.54	22	22	22	
		2 – 3	1.0	27.40	26	26	26	
			2.0 – 5.0	21.74	20	20	20	
			Strip (L/B=10)	21.30	19	19	19	
		3 - 5	1.0	25.11	20	25	25	
			2.0 – 5.0	19.92	11	18	18	
			Strip (L/B=10)	19.51	10	16	18	

Foundation Location	D_f below FGL (M)	Width of Foundation (m)	L/B Ratio	Computed NSBC (t/sqm)	Recommended NABC (t/sqm)			Remarks
					S = 25mm	S = 40mm	S = 75mm	
Boundary Wall (BH-23 & 34)	1.50	Upto 2	1.0	27.79	20	26	26	FGL considered at EGL
			2.0 – 5.0	22.17	12	20	22	
			Strip (L/B=10)	21.73	11	20	20	
		2 – 3	1.0	26.59	14	22	26	
			2.0 – 5.0	21.21	10	18	20	
			Strip (L/B=10)	20.79	9	14	20	
		3 - 5	1.0	25.63	10	16	24	
			2.0 – 5.0	20.44	6	10	15	
			Strip (L/B=10)	20.03	5	8	12	
	2.00	Upto 2	1.0	29.03	26	28	28	
			2.0 – 5.0	23.14	13	22	22	
			Strip (L/B=10)	22.68	12	18	22	
		2 – 3	1.0	27.43	18	26	26	
			2.0 – 5.0	21.86	12	20	20	
			Strip (L/B=10)	21.42	11	16	20	
		3 - 5	1.0	26.14	12	20	26	
			2.0 – 5.0	20.83	10	16	20	
			Strip (L/B=10)	20.42	9	14	20	
	3.00	Upto 2	1.0	31.51	30	30	30	
			2.0 – 5.0	25.08	25	25	25	
			Strip (L/B=10)	24.58	24	24	24	
		2 – 3	1.0	29.11	22	28	28	
			2.0 – 5.0	23.16	13	22	22	
			Strip (L/B=10)	22.69	12	18	22	
		3 - 5	1.0	27.18	16	26	26	
			2.0 – 5.0	21.61	12	20	20	
			Strip (L/B=10)	21.18	11	16	20	
Cooling Tower (BH-24, 29 & 44)	1.00 – 3.00	--	--	--	*			FGL considered RL(+) 216.000M
	4.00	Upto 5	1.0	31.32	30	30	--	
			2.0 – 5.0	24.88	24	24	--	
			Strip (L/B=10)	24.38	22	22	--	
		≥ 6	Raft	30.61	--	30	30	
	5.00 – 6.00	Upto 5	1.0	64.56	40	40	--	
			2.0 – 5.0	51.43	40	40	--	
			Strip (L/B=10)	50.41	40	40	--	
		≥ 6	Raft	62.78	--	40	40	
Service Water Tank & Pump House Area (BH-26 & 27)	2.00	Upto 3	1.0	13.79	8	12	--	FGL considered RL(+) 216.000M
			2.0 – 5.0	10.94	6	10	--	
			Strip (L/B=10)	10.72	5	8	--	
		3 - 5	1.0	13.15	6	10	--	
			2.0 – 5.0	10.43	5	8	--	
			Strip (L/B=10)	10.22	4	6	--	
		≥ 6	Raft	12.98	--	10	12	
	3.00	Upto 3	1.00	14.66	12	14	--	
			2.0 – 5.0	11.60	6	10	--	
			Strip (L/B=10)	11.36	5	8	--	
		3 - 5	1.0	13.70	10	12	--	
			2.0 – 5.0	10.83	6	10	--	
			Strip (L/B=10)	10.60	5	8	--	
		≥ 6	Raft	13.46	--	12	12	
	4.00	Upto 3	1.0	15.54	15	15	--	

Foundation Location	D_f below FGL (M)	Width of Foundation (m)	L/B Ratio	Computed NSBC (t/sqm)	Recommended NABC (t/sqm)			Remarks
					S = 25mm	S = 40mm	S = 75mm	
Service Water Tank & Pump House Area (BH-26 & 27)	4.00	Upto 3	2.0 – 5.0	12.26	12	12	--	FGL considered RL(+) 216.000M
			Strip (L/B=10)	11.99	10	10	--	
		3 - 5	1.0	14.25	14	14	--	
			2.0 – 5.0	11.23	10	10	--	
			Strip (L/B=10)	10.99	9	9	--	
		≥ 6	Raft	13.93	--	12	12	
	5.00	Upto 5	1.0	48.51	40	40	--	
			2.0 – 5.0	38.59	38	38	--	
			Strip (L/B=10)	37.82	36	36	--	
		≥ 6	Raft	47.17	--	40	40	
Clarified Water Storage Tank, Fire Water & Make up Water Pump House & PT Plant Area (BH-32 & 33)	2.00	Upto 3	1.0	19.85	10	16	--	FGL considered RL(+) 216.000M
			2.0 – 5.0	15.79	7	12	--	
			Strip (L/B=10)	15.48	6	10	--	
		3 - 5	1.0	18.92	7	11	--	
			2.0 – 5.0	15.05	5	8	--	
			Strip (L/B=10)	14.75	4	6	--	
		≥ 6	Raft	18.69	--	11	16	
	3.00	Upto 3	1.0	21.08	12	20	--	
			2.0 – 5.0	16.74	10	16	--	
			Strip (L/B=10)	16.39	9	14	--	
		3 - 5	1.0	19.69	9	14	--	
			2.0 – 5.0	15.62	6	10	--	
			Strip (L/B=10)	15.30	5	8	--	
		≥ 6	Raft	19.34	--	14	18	
	4.00	Upto 3	1.0	22.31	15	22	--	
			2.0 – 5.0	17.68	10	16	--	
			Strip (L/B=10)	17.31	9	14	--	
		3 - 5	1.0	20.46	12	18	--	
			2.0 – 5.0	16.19	8	14	--	
			Strip (L/B=10)	15.86	7	11	--	
		≥ 6	Raft	20.00	--	18	20	
Near Construction Store (BH-36)	2.00	Upto 3	1.0	28.94	28	28	--	FGL considered RL(+) 216.000M
			2.0 – 5.0	23.07	22	22	--	
			Strip (L/B=10)	22.61	21	21	--	
		3 - 5	1.0	27.59	22	26	--	
			2.0 – 5.0	21.99	12	20	--	
			Strip (L/B=10)	21.55	10	16	--	
		≥ 6	Raft	27.25	--	26	26	
	3.00	Upto 3	1.0	30.71	30	30	--	
			2.0 – 5.0	24.44	24	24	--	
			Strip (L/B=10)	23.95	22	22	--	
		3 - 5	1.0	28.68	28	28	--	
			2.0 – 5.0	22.81	22	22	--	
			Strip (L/B=10)	22.35	21	21	--	
		≥ 6	Raft	28.17	--	28	28	
	4.00	Upto 5	1.0	62.35	40	40	--	
			2.0 – 5.0	49.71	40	40	--	
			Strip (L/B=10)	48.72	40	40	--	
		≥ 6	Raft	60.92	--	40	40	

Foundation Location	D_f below FGL (M)	Width of Foundation (m)	L/B Ratio	Computed NSBC (t/sqm)	Recommended NABC (t/sqm)			Remarks
					S = 25mm	S = 40mm	S = 75mm	
Administrative Building and O & M Store (BH-37 & 38)	1.00 – 3.00	--	--	--		*		FGL considered RL(+) 218.500M
	4.00	Upto 3	1.0	24.01	16	24	--	
			2.0 – 5.0	19.03	11	18	--	
			Strip (L/B=10)	18.64	10	16	--	
		3 - 5	1.0	22.01	12	20	--	
			2.0 – 5.0	17.44	10	16	--	
			Strip (L/B=10)	17.07	9	14	--	
		≥ 6	Raft	21.51	--	20	20	
	5.00	Upto 3	1.0	25.33	25	25	--	
			2.0 – 5.0	20.05	20	20	--	
			Strip (L/B=10)	19.63	18	18	--	
		3 - 5	1.0	22.83	22	22	--	
			2.0 – 5.0	18.05	18	18	--	
			Strip (L/B=10)	17.67	16	16	--	
		≥ 6	Raft	22.21	--	22	22	
	6.00	Upto 3	1.0	47.25	40	40	--	
			2.0 – 5.0	37.54	36	36	--	
			Strip (L/B=10)	36.77	35	35	--	
		3 - 5	1.0	41.90	40	40	--	
			2.0 – 5.0	33.26	32	32	--	
			Strip (L/B=10)	32.58	30	30	--	
		≥ 6	Raft	40.56	--	40	40	
DM Storage Tank, STP, ETP & Guard Pond Area (BH-39 to 42)	2.00	--	--	--		*		FGL considered RL(+) 218.500M
	3.00	Upto 3	1.0	29.11	22	28	--	
			2.0 – 5.0	23.16	13	22	--	
			Strip (L/B=10)	22.69	12	18	--	
		3 - 5	1.0	27.18	24	26	--	
			2.0 – 5.0	21.61	12	20	--	
			Strip (L/B=10)	21.18	10	16	--	
		≥ 6	Raft	26.70	--	26	26	
	4.00	Upto 5	1.0	62.35	40	40	--	
			2.0 – 5.0	49.71	40	40	--	
			Strip (L/B=10)	48.72	40	40	--	
		≥ 6	Raft	60.92	--	40	40	

Note:

1. NSBC = Computed Net Safe Bearing Capacity, NABC = Recommended Net Allowable Bearing Capacity, FGL = Finished Ground Level
2. S = Limiting Settlement.
3. In case of any loose soil is observed at the founding level the same shall be removed and filled up by PCC upto the required founding level.
4. * - The minimum depth of open foundation shall be 1.50m below FGL subject to at least 1.0m below bottom of fill layer. However ground floor slabs, trenches, pipe pedestals, channels / drains etc. with maximum net allowable bearing capacity of 5 t/sqm shall be supported on open / shallow foundations resting on virgin soil / controlled compacted filled up soil. No major foundation shall be placed on soft / loose soil, ash, brick bats, boulders, kankar, industrial solid waste or any other heterogeneous material. In such case, minimum depth of open foundation shall be 1m below bottom of such fill.
5. # - For foundation placed inside rock, the permissible settlement is considered as 12mm irrespective of foundation types.

5. The discussion on swelling characteristics is given in Section 5.5.

6. Chemical tests were carried out on few soil and water samples so as to detect the **pH value, Sulphate, Chloride etc**. It is seen that the values are on a safe side. So, no special cement will be required for foundation concrete. **Either Ordinary Portland cement or Portland slag cement or Portland Pozzolana cement can be used for the purpose.**

7. The possibility of subsoil liquefaction due to earthquake is given in Section 5.8.

8. The suitability of existing soil for filling and back-filling is given in Section 5.9.

9. The suitability of soil for construction of roads is discussed in Section 5.10.

10. The discussion on excavation scheme to be adopted is given in Section 5.11.

11. The earth pressure coefficient for in-situ active and passive state is given in Section 5.12.

12. Geological report for the zone of investigation is presented in Section -7.

13. 20 (twenty) nos. ERT were performed at the site and the test results are discussed and presented in Volume – 2/Part IB.

14. 4 (four) nos. Cross Hole Shear Tests were performed at the site and the test results are discussed and presented in Volume – 2/Part IB. For dynamic properties of subsoil strata, Cross Hole Shear test results shall be referred. Further the values of poission's ratio, dynamic young's modulus and shear modulus are also mentioned there.

15. 3 (three) nos. Pressure Meter Tests were performed at the site and the test results are discussed and presented in Volume – 2/Part IB.

For C. E. Testing Company Private Limited,

Prepared By	Checked By	Approved By
S. Sarkar	Sudip Nath	
(S. SARKAR)	**(S. NATH)**	**(DR. M. NAYAK)**

7. GEOLOGICAL LOGGING

GEOLOGY

INTRODUCTION

The studied area is situated within the existing premises of Rourkela Steel Plant in the district of Sundargarh, Odisa. The Geo-technical investigation has been carried out for 1x250 MW power plant of NSPCL, Rourkela TPP III. The entire area is plane off artificially. To know the detailed subsurface condition of rock and soil, 47 number of boring followed by drilling have been made systematically according to the required structure. It has been noted that the formation rock has been struck by drilling below the overburden of sedentary soil of variable thickness ranging from about 3.90 to 09.00m from the existing ground level. The overburden soil comprises of silty clay / clayey silt underlies the thick silty sand layer of good quality. The minimum and maximum depth of investigations restricted between 15.0m to 25m below the existing ground level. The average standing water level has been recorded from different bore / drilled holes and the water level lies 1.3m below the ground.

GEOLOGY AND STRUCTURE

The area of interest belongs to the upper part of the Gangpur Group of rocks in Sundargarh district, Orissa. The outcrops of the meta-sedimentary rocks of the Gangpur Group is 'horse-shoe' shaped structure resulting from the deformation of regional synclinorium and almost cover entire Sundargarh district. Younger succession of the Gangpur's occupying the core of synclinorium. The Gangpur volcanic meta-sedimentary sequences are closely associate with banded iron formation and banded manganese formation of Proterozoic age. The depositional basin configurations are the result of several phases of structural deformations. Depositional setting can be accentuated four distinct phases. Phase - I, Volcanic suit associated with vertical displacement, Phase - II, Phyllite – shale (slate) suit associated with manganese mineralization represent deeper level deposit. Phase - III, Banded Iron Formation – a chemical deposit represent stability of the then basin slopes and Phase – IV, upper shale (slate) suit indicates cessation or restricted condition of deposition. The rocks of the Gangpur group deposited on the Iron Ore Group with an unconformity. The entire rocks of the Gangpur have been metamorphosed to low to medium grade amphibolite facies and the intensity of the metamorphism gradually increases from east to west direction. The huge thickness of the Gangpur group has been divided into five formations (Fm) on the basis of lithological similarities, namely Raghunathpur Fm., Liangar Fm., Birmitrapur Fm., and Ghorijhar Fm., (in accending order). Major rocks of the Gangpur group is conglomerate at base, quartzite, slate, carbonaceous slate and quartzite, phyllite and schists. The topmost

bed comprises phyllite and mica schist. Limestone and dolomite also occur in Birmitrapur Formation. The Gangpur group is intruded by basic sill (Dalma traps) and bosses of the Chotonagpur Granite. Such basic rocks have been converted into schistose amphibolite and epidiorites due metamorphism.

REGIONAL STRATIGRAPHY:

Succession of Gangpur group:

Ghorijhar Formation	Staurolite and garnet schists, calc-schists, quartzite and conglomerate
Kumarmunda Formation	Carboniferouss quartzites, slates and phyllite
Birmitrapur Formation	Limestone, dolomite quartzite and phyllite
Laingar Formation	Phyllites, carbonaceous slates and quartzites
Raghunathpally Formation	Conglomerate, quartzite and slates

----------UNCONFORMITY----------

IRON ORE GROUP

The rock encountered during drilling over the entire investigated area is only Phyllite of the Upper Gangpur Group.

SEISMOLOGY OF THE STUDY AREA

According to the seismic map of India the area of interest fall in Zone - II as per IS 1893 (Part- 1): 2002 (Fifth Revision) and Part -4: 2005 correspond to an earthquake intensity of VI, as per modified Meracalli Intensity scale. The Zero peak horizontal ground acceleration (EPGA) is of the order of 0.02 for safe shut down condition and for operating basis average earthquake acceleration spectra (RSM) is 0.10 (Seismic zone factor, Z). The information is

intended to bring out the fact that the site shall be considered to lies on feebly active seismic domain. Hence, suitable seismic coefficient commensurate to seismic Zone-II and Important factor (I=1.5) shall be adopted in the design of the structures.

GENERAL DESCRIPTION OF ENCOUNTERED ROCK:

Phyllite:

The rock encountered by drilling upto maximum investigated depth of about 25.00m from the existing ground level is only Phyllite / schistose Phyllite. The phyllite is a type of foliated metamorphic rock composed of quartz, sericite, mica and chlorite. The rock represents a gradation in the degree of metamorphism between slate and mica-schist. The protolith or parent rock for phyllite is slate or pelite. It's constituent platy minerals are larger than those in slate but are not visible with the naked eye. Due to presence of chlorite and sometimes small graphite crystal, impact a silky or golden sheen to the surface of cleavage / schistosity. The phyllites are said to have “phyllitic texture” and originated in low grade regional metamorphism. Depending on the intensity of weathering the body color of the rock varies from grey / brownish grey to dark grey with different color shades. The rock is dominantly fine to extremely fine grained with high angle foliation (varies from 60°-80°). The phyllite is in general moderately to densely compacted, moderately soft to hard. The strength of the phyllite ranges from weak to strong when fresh and has dominantly medium to low specific gravity. Depending on weathering and orientation of shear planes the strength parameter (UCS) is reduced to a great extent. □

BH No. 01

(00.00 – 05.50)m**:** Overburden.

(05.50 – 25.00)m**:** **Rock Description:** Highly weathered and decomposed (upto 13.00m) to moderately (13.00 – 19.00m), followed by slightly weathered, brownish grey and dark brownish patch (upto 19.00m) to dark grey, fine grained, moderately to densely compacted Phyllite.
Rock Properties: Moderately soft and weak (upto 19.00m) to moderately hard and strong rock.
Structural Condition: Foliated (75°-80° inclination). Thinly spaced, highly fractured (>15 nos./m) to medium spaced and medium fractured (15-8). Two sets of fractures. Dominantly Inclined (foliation parallel) fracture surfaces are apparently smooth, and deeply altered. Horizontal (0°-5°) fracture surfaces are slightly rough, undulated and deeply altered
Description of Core: Recovered core occurs as discontinuous framework upto 09.25m, followed by continuous. Cores are mostly in lengths of 30-100mm with mostly in lengths of <100mm upto 13.00m. Thereafter cores are mostly in lengths of 100-200mm in size with locally 30-100mm core pieces at 13.75 – 16.00m depth.

Rock Mass Structure: The rock mass is very poor to poor in nature, and belongs to Shattered / Crushed (lack of blockiness) category upto 17.50m. Followed by fair and belongs to blocky category.

Partial drill water loss has been noticed for the entire depth.
The formation rock is highly to slightly weathered and huge amount of the rock mass is disintegrated. During drilling the disintegrated rock particles between fractures plains have been removed by drill water. As a result huge core loss occurred.

BH No. 02

(00.00 – 07.00)m**:** Overburden.

(07.00 – 25.00)m**:** **Rock Description:** Highly weathered and partly decomposed (upto 13.25m) to moderately weathered, brownish grey and dark brownish patch (upto 13.25m) to dark grey, fine grained, moderately to densely compacted **Phyllite**.
Rock Properties: Moderately soft and weak (upto 13.25m) to moderately hard and moderately strong rock.
Structural Condition: Foliated (70°-75° inclination). Thinly spaced, highly fractured (>15 nos./m). Two sets of fractures. Dominantly Inclined (foliation parallel) fracture surfaces are apparently smooth, and deeply altered. Horizontal (0°-5°) fracture surfaces are slightly rough, undulated and deeply altered
Description of Core: Recovered core occurs as discontinuous framework. Cores are mostly in lengths of 30-100mm with mostly in lengths of <100mm.

Rock Mass Structure: The rock mass is very poor to poor in nature, and belongs to Shattered / Crushed (lack of blockiness) category.

Partial drill water loss has been noticed for the entire depth.
The formation rock is highly to moderately weathered and huge

amount of the rock mass is disintegrated. During drilling the disintegrated rock particles between fractures plains have been removed by drill water. As a result huge core loss occurred.

BH No. 03

(00.00 – 06.00)m: Overburden.

(06.00 – 25.00)m: **(06.00 – 09.75)m:**

Rock Description: Highly weathered and slightly decomposed, brownish grey with dark brown patch, fine grained, loosely (upto 07.50m) to moderately compacted **Phyllite**.

Rock Properties: Moderately soft and weak rock.

Structural Condition: Foliated (70°-80°). Very closely spaced, highly fractured (>15 nos./m). Two sets of fractures. Dominantly inclined (foliation parallel) fracture surfaces are apparently smooth, and deeply altered. Horizontal (0°-5°) fracture surfaces are slightly rough, undulated and deeply altered.

Description of Core: Recovered core occurs as discontinuous framework. Cores are mostly in lengths of 30-100mm with mostly in lengths of <100mm.

(09.75 – 25.00)m:

Rock Description: Moderately weathered, dark grey with brown patch on open surface, fine grained, tightly compacted **Phyllite**.

Rock Properties: Hard and strong rock.

Structural Condition: Foliated (65°-75°). Very closely to closely spaced, moderately fractured (15-8 nos./m). Two sets of fractures. Dominantly inclined (foliation parallel) fracture surfaces are apparently smooth, and deeply altered. Horizontal (0°-5°) fracture surfaces are slightly rough, undulated and clean.

Description of Core: Recovered core occurs as continuous framework from 11.25m depth. Cores are mostly in lengths of 30-100mm with locally 100-200mm size core present at 11.25 – 14.25m, 17.25 – 18.75m.

Rock Mass Structure: The rock mass is very poor to poor in nature, and belongs to Shattered / Crushed (lack of blockiness) category upto 11.25m depth. Thereafter rock mass is fair belongs to disintegrated category.

Partial drill water loss has been noticed for the entire depth.

The formation rock is highly to moderately weathered and huge to modest amount of the rock mass is disintegrated. During drilling the disintegrated rock particles between fractures plains have been removed by drill water. As a result huge / modest core loss occurred.

BH No. 04

(00.00 – 05.50)m: Overburden.

(05.50 – 25.00)m: **Rock Description:** Highly weathered and slightly decomposed (upto 10.75m), followed by moderately (10.75 – 19.75m) to slightly weathered, brownish grey, fine grained, moderately to densely compacted **Phyllite**.

Rock Properties: Moderately hard and moderately strong (upto 10.75m) to hard and strong rock.

Structural Condition: Foliated (70°-75°). Very closely to closely spaced, highly fractured (>15 nos. to 15-8 nos/m). Two sets of fractures. Dominantly inclined (foliation parallel) fracture surfaces are apparently smooth, and deeply altered. Horizontal (0°-5°) fracture surfaces are slightly rough, undulated and deeply altered.
Description of Core: Recovered core occurs as discontinuous framework upto 15.25m depth. Cores are mostly in lengths of 30-100mm upto 15.25m. Thereafter cores are 100-200mm sizes, with locally 30-100mm sizes at 19.00 – 19.75m depth.

Rock Mass Structure: The rock mass is very poor to poor in nature, and belongs to Shattered / Crushed (lack of blockiness) category. Locally 100-200mm core pieces, fair quality and belongs to disintegrated category at 16.25 – 16.75m, 19.75 – 25.00m.

Partial drill water loss has been noticed for the entire depth.
The formation rock is highly to slightly weathered and huge to modest amount of the rock mass is disintegrated. During drilling the disintegrated rock particles between fractures plains have been removed by drill water. As a result huge to modest core loss occurred.

BH No. 05

(00.00 – 05.50)m**:** Overburden.

(05.50 – 25.00)m**:** **Rock Description:** High (upto 08.50m) to slightly weathered, brownish grey (upto 22.75m) to dark grey, fine grained, moderately to densely compacted **Phyllite**.
Rock Properties: Moderately soft and weak (upto 08.50m) to hard and strong rock.
Structural Condition: Foliated (75°-80°). Very closely (upto 08.50m) to closely/ thickly spaced, highly fractured (>15 nos./m to 8-5 nos/m at places). Two sets of fractures. Dominantly inclined (foliation parallel) fracture surfaces are apparently smooth, and deeply altered (upto 15.00m) to clean. Horizontal (0°-5°) fracture surfaces are slightly rough, undulated and deeply altered.
Description of Core: Recovered core occurs as discontinuous framework upto 08.50mdepth. Cores are mostly in lengths of 30-100mm size with rare 100-300mm cores at 08.50 – 11.25m, 13.00 – 13.75m, 20.50 – 23.50m depth.

Rock Mass Structure: The rock mass is very poor to poor in nature, and belongs to Shattered / Crushed (lack of blockiness) category. Locally rock mass is fair / good belongs to disintegrated / blocky category at 08.50 – 11.25m, 13.00 – 13.75m, 20.50 – 23.50m depth.

Partial drill water loss has been noticed for the entire depth.
The formation rock is moderately to slightly weathered and huge to modest amount of the rock mass is disintegrated. During drilling the disintegrated rock particles between fractures plains have been removed by drill water. As a result core loss occurred.

BH No. 06

(00.00 – 06.50)m**:** Overburden.

(06.50 – 25.00)m**:** **Rock Description:** Highly weathered, brownish grey with dark brownish patch, fine grained, loosely to moderately compacted **Phyllite**.
Rock Properties: Moderately soft and weak rock.
Structural Condition: Foliated (60°-65°). Very closely spaced, highly fractured (>15 nos./m). Two sets of fractures. Dominantly inclined (foliation parallel) fracture surfaces are apparently smooth, and deeply altered. Horizontal (0°-5°) fracture surfaces are slightly rough, undulated and deeply altered.
Description of Core: Recovered core occurs as discontinuous framework and are mostly in lengths of 30-100mm.

Rock Mass Structure: The rock mass is very poor to poor in nature, and belongs to Shattered / Crushed (lack of blockiness) category.

Partial drill water loss has been noticed for the entire depth.
The formation rock is highly weathered and huge amount of the rock mass is disintegrated. During drilling the disintegrated rock particles between fractures plains have been removed by drill water. As a result core loss occurred.

BH No. 07

(00.00 – 07.50)m**:** Overburden.

(07.50 – 25.00)m**:** **Rock Description:** Moderately (upto 23.25m) to slightly weathered, light brownish grey (upto 23.25m) to dark grey, fine grained, densely compacted **Phyllite**.
Rock Properties: Moderately hard and moderately strong rock.
Structural Condition: Foliated (60°-65°). Very closely (upto 20.25m) to closely spaced, highly fractured (>15 nos./m to 15-8 nos/m). Two sets of fractures. Dominantly inclined (foliation parallel) fracture surfaces are apparently smooth, and deeply altered. Horizontal (0°-5°) fracture surfaces are slightly rough, undulated and deeply altered.
Description of Core: Recovered core occurs as discontinuous framework upto 20.25mdepth. Cores are mostly in lengths of 30-100mm upto 20.25m depth. Followed by continuous framework and cores are 100-200mm in size with rare 30-100mm cores at 21.50 – 23.50m depth.

Rock Mass Structure: The rock mass is very poor to poor in nature, and belongs to Shattered / Crushed (lack of blockiness) category upto 20.25m depth. Thereafter rock mass is fair belongs to disintegrated category.

Partial drill water loss has been noticed for the entire depth.
The formation rock is moderately to slightly weathered and huge to modest amount of the rock mass is disintegrated. During drilling the disintegrated rock particles between fractures plains have been removed by drill water. As a result core loss occurred.

BH No. 08

(00.00 – 07.00)m: Overburden.

(07.00 – 20.00)m: **Rock Description:** Highly (upto 12.25m) to moderately (12.25 – 19.00m), followed by slightly weathered, brownish grey, fine grained, moderately to densely compacted **Phyllite**.
Rock Properties: Moderately hard and moderately strong (upto 12.25m) to hard and strong rock.
Structural Condition: Foliated (70°-80°). Very closely to closely spaced, highly fractured (>15 nos. to 15-8 nos/m). Two sets of fractures. Dominantly inclined (foliation parallel) fracture surfaces are apparently smooth, and deeply altered. Horizontal (0°-5°) fracture surfaces are slightly rough, undulated and deeply altered.
Description of Core: Recovered core occurs as discontinuous framework upto 12.25m depth. Cores are mostly in lengths of 30-100mm upto 12.25m. Thereafter cores are 100-300mm sizes, with locally 30-100mm sizes at 16.00 – 16.75m depth.

Rock Mass Structure: The rock mass is very poor to poor in nature, and belongs to Shattered / Crushed (lack of blockiness) category.

Partial drill water loss has been noticed for the entire depth.
The formation rock is highly to slightly weathered and huge to modest amount of the rock mass is disintegrated. During drilling the disintegrated rock particles between fractures plains have been removed by drill water. As a result huge to modest core loss occurred.

BH No. 09

(00.00 – 05.80)m: Overburden.

(05.80 – 25.00)m: **Rock Description:** Highly (upto 11.00m) to moderately (11.00 – 21.00m), followed by slightly weathered, brownish grey (upto 11.00m) to dark grey, fine grained, moderately to densely compacted **Phyllite**.
Rock Properties: Moderately hard and moderately strong (upto 11.00m) to hard and strong rock.
Structural Condition: Foliated (75°-85°). Very closely to thickly (from 11.00m) spaced, highly fractured (>15 nos/m) to slightly fractured (5-1 nos/m). Two sets of fractures. Dominantly inclined (foliation parallel) fracture surfaces are apparently smooth, and deeply altered (upto 21.00m)to clean. Horizontal (0°-5°) fracture surfaces are slightly rough, undulated and deeply altered.
Description of Core: Recovered core occurs as discontinuous framework upto 11.00m depth. Cores are mostly in lengths of 30-100mm upto 24.00m. Thereafter cores are 100-300mm sizes.

Rock Mass Structure: The rock mass is very poor to poor in nature, and belongs to Shattered / Crushed (lack of blockiness) category upto 24.00m depth. Followed by good quality and belongs to blocky category.

Partial drill water loss has been noticed for the entire depth.
The formation rock is highly to slightly weathered and huge to modest amount of the rock mass is disintegrated. During drilling the disintegrated rock particles between fractures plains have been

removed by drill water. As a result huge to modest core loss occurred.

BH No. 10

(00.00 – 07.00)m: Overburden.

(07.00 – 25.00)m: **Rock Description:** Highly (upto 13.00m) to moderately (13.00 – 20.50m), followed by slightly weathered, brownish grey (upto 20.50m) to dark grey, fine grained, moderately to densely compacted **Phyllite**.
Rock Properties: Soft and weak (upto 13.00m) to moderately hard and moderately strong (13.00 – 20.50m), followed by hard and strong rock.
Structural Condition: Foliated (70°-80°). Very closely to thickly (from 20.50m) spaced, highly fractures (>15 nos/m) to slightly fractures (8-5 nos/m from 20.50m depth). Two sets of fractures. Dominantly inclined (foliation parallel) fracture surfaces are apparently smooth, and deeply altered (upto 20.00m)to clean. Horizontal (0°-5°) fracture surfaces are slightly rough, undulated and deeply altered (upto 20.00m depth).
Description of Core: Recovered core occurs as discontinuous framework upto 13.00m depth. Cores are mostly in lengths of 30-100mm upto 20.50m. Thereafter cores are 100-300mm sizes.

Rock Mass Structure: The rock mass is very poor to poor in nature, and belongs to Shattered / Crushed (lack of blockiness) category upto 20.50m depth. Followed by fair / good quality and belongs to blocky category.

Partial drill water loss has been noticed for the entire depth.
The formation rock is highly to slightly weathered and huge to modest amount of the rock mass is disintegrated. During drilling the disintegrated rock particles between fractures plains have been removed by drill water. As a result huge to modest core loss occurred.

BH No. 11

(00.00 – 08.30)m: Overburden.

(08.30 – 25.00)m: **Rock Description:** Highly weathered and decomposed (upto 12.50m) to moderately (12.50 – 18.50m), followed by slightly weathered, brownish grey (upto 18.50m) to dark grey, fine grained, moderately to densely compacted **Phyllite**, with white stringers throughout the depth.
Rock Properties: Moderately soft and weak (upto 12.50m) to moderately hard and moderately strong (12.50 – 18.50m), followed by hard and strong rock.
Structural Condition: Foliated (75°-80°). Very closely / closely to thickly (from 18.50m) spaced, highly fractures (>15 nos/m) to medium fractures (8-5 nos/m from 20.75m depth). Two sets of fractures. Dominantly inclined (foliation parallel) fracture surfaces are apparently smooth, and deeply altered (upto 18.00m)to clean. Horizontal (0°-5°) fracture surfaces are slightly rough, undulated and deeply altered (upto 18.00m depth).
Description of Core: Recovered core occurs as discontinuous framework upto 12.50m depth. Cores are mostly in lengths of 30-100mm upto 20.75m. Thereafter cores are 100-200mm sizes.

Rock Mass Structure: The rock mass is very poor to poor in nature,

and belongs to Shattered / Crushed (lack of blockiness) category upto 18.50m depth. Followed by fair quality and belongs to disintegrated category.

Partial drill water loss has been noticed for the entire depth.
The formation rock is highly to slightly weathered and huge to modest amount of the rock mass is disintegrated. During drilling the disintegrated rock particles between fractures plains have been removed by drill water. As a result huge to modest core loss occurred.

BH No. 12

(00.00 – 09.00)m**:** Overburden.

(09.00 – 25.00)m**:** **Rock Description:** Highly (upto 12.75m) to moderately (12.75 – 18.75m), followed by slightly weathered, brownish grey (upto 18.75m) to dark grey, fine grained, moderately to densely compacted **Phyllite**.
Rock Properties: Moderately hard and moderately strong (upto 18.75m) to hard and strong rock.
Structural Condition: Foliated (65°-75°). Very closely to thickly (from 18.75m) spaced, highly fractured (>15 nos/m) to medium fractured (15-8 to 8-5 nos/m). Two sets of fractures. Dominantly inclined (foliation parallel) fracture surfaces are apparently smooth, and deeply altered (upto 21.00m)to clean. Horizontal (0°-5°) fracture surfaces are slightly rough, undulated and deeply altered.
Description of Core: Recovered core occurs as discontinuous framework upto 12.75m depth. Cores are mostly in lengths of 30-100mm upto 12.75m. Thereafter cores are 100-200mm sizes with (locally 30-100mm at 17.50 – 18.75m) upto 18.75m. From 18.75 m depth cores are mostly in lengths of 100-300mm..

Rock Mass Structure: The rock mass is very poor to poor in nature, and belongs to Shattered / Crushed (lack of blockiness) category upto 12.75m depth. Followed by fair / good quality and belongs to disintegrated / blocky category.

Partial drill water loss has been noticed for the entire depth.
The formation rock is highly to slightly weathered and huge to modest amount of the rock mass is disintegrated. During drilling the disintegrated rock particles between fractures plains have been removed by drill water. As a result huge to modest core loss occurred.

BH No. 13

(00.00 – 07.30)m**:** Overburden.

(07.30 – 25.00)m**:** **Rock Description:** Highly (upto 10.25m) to moderately (10.25 – 14.00m), followed by slightly weathered, brownish grey (upto 14.00m) to dark grey, fine grained, moderately to densely compacted **Phyllite**.
Rock Properties: Moderately hard and moderately strong (upto 14.00m) to hard and strong rock.
Structural Condition: Foliated (60°-65°). Very closely to thickly (from 14.00m) spaced, highly fractured (>15 nos/m) to medium fractured (15-8 to 8-5 nos/m). Two sets of fractures. Dominantly inclined (foliation parallel) fracture surfaces are apparently smooth, and deeply altered (upto 21.50m)to clean. Horizontal (0°-5°) fracture surfaces are

slightly rough, undulated and deeply altered.
Description of Core: Recovered core occurs as discontinuous framework upto 14.00m depth. Cores are mostly in lengths of 30-100mm upto 14.00m. Thereafter cores are 100-300mm sizes with locally 100-200mm at 21.50 – 25.00m depth.

Rock Mass Structure: The rock mass is very poor to poor in nature, and belongs to Shattered / Crushed (lack of blockiness) category upto 14.00m depth. Followed by fair quality and belongs to disintegrated category.

Partial drill water loss has been noticed for the entire depth.
The formation rock is highly to slightly weathered and huge to modest amount of the rock mass is disintegrated. During drilling the disintegrated rock particles between fractures plains have been removed by drill water. As a result huge to modest core loss occurred.

BH No. 14

(00.00 – 07.50)m**:** Overburden.

(07.50 – 25.00)m**:** **Rock Description:** Highly to moderately (upto 21.75m) to slightly weathered, light brownish grey (upto 21.75m) to dark grey, fine grained, moderately (upto 21.75m) to densely compacted **Phyllite**.
Rock Properties: Moderately hard and moderately strong (upto 21.75m) to hard and strong rock.
Structural Condition: Foliated (60°-65°). Closely (upto 21.75m) to thickly spaced, highly fractured (15-8 nos/m) to slightly (8-5 nos/m) fractured. Two sets of fractures. Dominantly inclined (foliation parallel) fracture surfaces are apparently smooth, and deeply altered (upto 22.00m) to clean. Horizontal (0°-5°) fracture surfaces are slightly rough, undulated and deeply altered (upto 21.75m) to clean.
Description of Core: Recovered core occurs as continuous framework. Cores are mostly in lengths of 30-100mm upto 21.75m depth with locally 100-200mm cores at 09.00 – 12.00m, 18.75 – 19.50m. Thereafter cores are 100-300mm in size.

Rock Mass Structure: The rock mass is very poor to poor in nature, and belongs to Shattered / Crushed (lack of blockiness) category upto 21.75m depth. Thereafter rock mass is good belongs to blocky category.

Partial drill water loss has been noticed for the entire depth.
The formation rock is highly to slightly weathered and huge to modest amount of the rock mass is disintegrated. During drilling the disintegrated rock particles between fractures plains have been removed by drill water. As a result core loss occurred.

BH No. 15

(00.00 – 06.10)m**:** Overburden.

(06.10 – 20.00)m**:** **Rock Description:** Highly weathered and decomposed (06.10 – 11.25m), followed by moderately weathered, brownish grey, fine grained, moderately to densely compacted **Phyllite**.
Rock Properties: Moderately soft and weak (upto 11.25m) to

moderately hard and moderately strong rock.
Structural Condition: Foliated (70°-80°). Very closely to thickly (from 11.25m) spaced, highly fractured (>15 nos/m) to medium fractured (8-5 nos/m). Two sets of fractures. Dominantly inclined (foliation parallel) fracture surfaces are apparently smooth, and deeply altered. Horizontal (0°-5°) fracture surfaces are slightly rough, undulated and deeply altered.
Description of Core: Recovered core occurs as discontinuous framework upto 11.25m depth. Cores are mostly in lengths of 30-100mm, locally 100-200mm at 16.50 – 20.00m.

Rock Mass Structure: The rock mass is very poor to poor in nature, and belongs to Shattered / Crushed (lack of blockiness) category upto 16.50m depth. Followed by fair quality and belongs to disintegrated category.

Partial drill water loss has been noticed for the entire depth.
The formation rock is highly to slightly weathered and huge to modest amount of the rock mass is disintegrated. During drilling the disintegrated rock particles between fractures plains have been removed by drill water. As a result huge to modest core loss occurred.

BH No. 16

(00.00 – 07.00)m**:** Overburden.

(07.00 – 25.00)m**:** **Rock Description:** Moderately (upto 14.50m) to slightly weathered (14.50 – 23.00m), followed by fresh, light brownish grey (upto 23.50m) to dark grey, fine grained, densely compacted **Phyllite**.
Rock Properties: Moderately hard and moderately strong (upto 14.50m) to hard and strong rock.
Structural Condition: Foliated (65°-70°). thick to widely spaced, slightly fractured (15-8 to 5-1 nos./m). Two sets of fractures. Dominantly inclined (foliation parallel) fracture surfaces are apparently smooth, and altered (upto 23.00m) to clean. Horizontal (0°-5°) fracture surfaces are slightly rough, undulated and altered (upto 23.00m) to clean.
Description of Core: Recovered core occurs as continuous framework. Cores are mostly in lengths of 30-100mm upto 15.25m depth. Thereafter cores are mostly 100-300mm in size.

Rock Mass Structure: The rock mass is poor to fair in nature, and belongs to disintegrated category upto 15.25m depth. Thereafter rock mass is good and belongs to blocky category.

Partial drill water loss has been noticed for the entire depth.
The formation rock is moderately weathered to fresh and modest to little amount of the rock mass is disintegrated. During drilling the disintegrated rock particles between fractures plains have been removed by drill water. As a result modest to little core loss occurred.

BH No. 17

(00.00 – 07.30)m: Overburden.

(07.30 – 20.00)m: **Rock Description:** Highly (upto 10.25m) to moderately weathered, brownish grey, fine grained, loosely (upto 10.25m) to moderately compacted **Phyllite**.

Rock Properties: Moderately soft and weak (upto 10.25m) to moderately hard and moderately strong rock.

Structural Condition: Foliated (75°-80°). Very closely to closely spaced, highly fractured (>15 nos) to moderately (15-8 nos/m from 15.50m) fractured. Two sets of fractures. Dominantly inclined (foliation parallel) fracture surfaces are apparently smooth, and deeply altered. Horizontal (0°-5°) fracture surfaces are slightly rough, undulated and deeply altered.

Description of Core: Recovered core occurs as discontinuous framework upto 10.25m depth. Cores are mostly in lengths of 30-100mm, with locally 100-200mm sizes at 08.75-11.75m, 14.75-17.75m depth.

Rock Mass Structure: The rock mass is very poor to poor in nature, and belongs to Shattered / Crushed (lack of blockiness) category upto 15.50m depth. Followed by fair quality and belongs to disintegrated category.

Partial drill water loss has been noticed for the entire depth.

The formation rock is highly to moderately weathered and huge to modest amount of the rock mass is disintegrated. During drilling the disintegrated rock particles between fractures plains have been removed by drill water. As a result huge to modest core loss occurred.

BH No. 18

(00.00 – 06.50)m: Overburden.

(06.50 – 20.00)m: **Rock Description:** Highly weathered (upto 18.50m) to moderately weathered, brownish grey, fine grained, moderately to densely compacted **Phyllite**.

Rock Properties: Moderately soft and weak (upto 18.50m) to moderately hard and moderately strong rock.

Structural Condition: Foliated (65°-75°). Very closely to closely spaced, highly fracture (>15 nos/m). Two sets of fractures. Dominantly inclined (foliation parallel) fracture surfaces are apparently smooth, and deeply altered. Horizontal (0°-5°) fracture surfaces are slightly rough, undulated and deeply altered.

Description of Core: Recovered core occurs as discontinuous framework upto 14.00m depth. Cores are mostly in lengths of 30-100mm sizes.

Rock Mass Structure: The rock mass is very poor to poor in nature, and belongs to Shattered / Crushed (lack of blockiness) category.

Partial drill water loss has been noticed for the entire depth.

The formation rock is highly to moderately weathered and huge to modest amount of the rock mass is disintegrated. During drilling the disintegrated rock particles between fractures plains have been

removed by drill water. As a result huge to modest core loss occurred.

BH No. 19

(00.00 – 07.00)m: Overburden.

(07.00 – 20.00)m: **(07.00 – 08.50)m:**

Rock Description: Highly weathered, brownish grey, fine grained, moderately compacted **Phyllite**.

Rock Properties: Moderately hard and weak to moderately strong rock.

Structural Condition: Foliated (65°-70°). Closely spaced, moderately fractured (15-8 nos/m). Two sets of fractures. Dominantly inclined (foliation parallel) fracture surfaces are apparently smooth, and deeply altered. Horizontal (0°-5°) fracture surfaces are slightly rough, undulated and deeply altered.

Description of Core: Recovered core occurs as continuous framework. Cores are mostly in lengths of 30-100mm, with locally 100-200mm sizes at 07.75 – 08.50m depth.

08.50 – 20.00m:

Rock Description: Moderately (upto 13.00m) to slightly weathered, brownish grey (upto 13.00m) to dark grey, fine grained, densely compacted **Phyllite**.

Rock Properties: Moderately hard and moderately strong (upto 13.00m) to hard and strong rock.

Structural Condition: Foliated (65°-70°). Thickly spaced, slightly fractured (8-5 nos/m with locally 15-8 nos/m). Two sets of fractures. Dominantly inclined (foliation parallel) fracture surfaces are apparently smooth, and deeply altered (upto 13.00m) to clean. Horizontal (0°-5°) fracture surfaces are slightly rough, undulated and deeply altered (upto 13.00m) to clean.

Description of Core: Recovered core occurs as continuous framework. Cores are mostly in lengths of 30-100mm.

Rock Mass Structure: The rock mass is poor in nature, and belongs to Shattered / Crushed (lack of blockiness) category, locally fair quality and belongs to blocky category at 15.25 – 20.00m depth.

Partial drill water loss has been noticed for the entire depth.
The formation rock is highly to slightly weathered and huge to modest amount of the rock mass is disintegrated. During drilling the disintegrated rock particles between fractures plains have been removed by drill water. As a result huge to modest core loss occurred.

BH No. 20

(00.00 – 07.00)m: Overburden.

(07.00 – 25.00)m: **Rock Description:** Highly (upto 10.75m) to moderately (10.75 – 15.75m), followed by slightly weathered, brownish grey and dark brownish patch (upto 11.00m) to dark grey, fine grained, moderately to densely compacted **Phyllite**.

Rock Properties: Moderately soft and weak (upto 10.75m) to hard and strong rock.

Structural Condition: Foliated (60°-65° inclination). Thinly spaced, highly fractured (>15 nos./m) upto 10.75m, followed by medium

spaced and medium fractured (15-8). Two sets of fractures. Dominantly Inclined (foliation parallel) fracture surfaces are apparently smooth, and deeply altered. Horizontal (0°-5°) fracture surfaces are slightly rough, undulated and altered

Description of Core: Recovered core occurs as discontinuous framework upto 10.75m, followed by continuous. Cores are mostly in lengths of 30-100mm upto 10.75m. Thereafter cores are mostly in lengths of 100-200mm in size

Rock Mass Structure: The rock mass is very poor to poor in nature, and belongs to Shattered / Crushed (lack of blockiness) category upto 10.75m. Followed by fair and belongs to disintegrated category.

Partial drill water loss has been noticed for the entire depth.
The formation rock is highly to slightly weathered and huge to modest amount of the rock mass is disintegrated. During drilling the disintegrated rock particles between fractures plains have been removed by drill water. As a result core loss occurred.

BH No. 21

(00.00 – 04.50)m: Overburden.

(04.50 – 15.00)m: **Rock Description:** Moderately (upto 09.00m) to slightly weathered, brownish grey to dark grey, fine grained, densely compacted **Phyllite**.
Rock Properties: Moderately hard and moderately strong.
Structural Condition: Foliated (60°-65°). Very closely to thickly spaced, highly fractured (>15 nos/m) to medium (8-5 nos/m from 08.25m) fractures. Two sets of fractures. Dominantly inclined (foliation parallel) fracture surfaces are apparently smooth, and altered. Horizontal (0°-5°) fracture surfaces are slightly rough, undulated and altered.
Description of Core: Recovered core occurs as discontinuous framework upto 08.25m depth. Cores are mostly in lengths of 30-100mm upto 08.25m. Thereafter cores are 100-200mm sizes.

Rock Mass Structure: The rock mass is very poor to poor in nature, and belongs to Shattered / Crushed (lack of blockiness) category upto 08.25m depth. Followed by fair quality and belongs to disintegrated category.

Partial drill water loss has been noticed for the entire depth.
The formation rock is moderately to slightly weathered and modest amount of the rock mass is disintegrated. During drilling the disintegrated rock particles between fractures plains have been removed by drill water. As a result modest amount of core loss occurred.

BH No. 22

(00.00 – 05.30)m: Overburden.

(05.30 – 20.00)m: **Rock Description:** Highly weathered, brownish grey with dark brownish patch, fine grained, loosely to moderately compacted **Phyllite**.
Rock Properties: Moderately hard and weak (upto 10.05m) to

moderately hard and moderately strong rock.
Structural Condition: Foliated (70°-75° inclination). Thinly spaced, highly fractured (>15 nos./m, with locally 15-8 nos/m). Two sets of fractures. Dominantly Inclined (foliation parallel) fracture surfaces are apparently smooth, and deeply altered. Horizontal (0°-5°) fracture surfaces are slightly rough, undulated and altered
Description of Core: Recovered core occurs as continuous framework. Cores are mostly in lengths of 30-100mm, with locally 100-200mm size core pieces found at 12.00 – 13.50m depth.

Rock Mass Structure: The rock mass is very poor to poor in nature, and belongs to Shattered / Crushed (lack of blockiness) category, locally rock quality is fair and belongs to disintegrated category at 12.00 – 13.50m depth.

Partial drill water loss has been noticed for the entire depth.
The formation rock is highly weathered and huge amount of the rock mass is disintegrated. During drilling the disintegrated rock particles between fractures plains have been removed by drill water. As a result huge core loss occurred.

BH No. 23

(00.00 – 06.80)m**:** Overburden.

(06.80 – 15.00)m**:** **Rock Description:** Highly weathered (upto 10.50m) to moderately weathered, brownish grey with dark brown patch, fine grained, moderately to densely compacted **Phyllite**, with white stringers throughout the depth.
Rock Properties: Moderately soft and weak (upto 10.50m) to moderately hard and moderately strong rock.
Structural Condition: Foliated (60°-65°). Very closely to closely spaced, highly fractured (>15 to 15-8 nos/m). Two sets of fractures. Dominantly inclined (foliation parallel) fracture surfaces are apparently smooth, and deeply altered. Horizontal (0°-5°) fracture surfaces are slightly rough, undulated and deeply altered.
Description of Core: Recovered core occurs as discontinuous framework upto 10.50m depth. Cores are mostly in lengths of 30-100mm sizes with pockets of 100-300mm sizes core at 11.25 – 12.00m, 13.50 – 15.00m depth.

Rock Mass Structure: The rock mass is very poor to poor in nature, and belongs to Shattered / Crushed (lack of blockiness) category, locally fair and belongs to disintegrated category at 11.25 – 12.00m, 13.50 – 15.00m depth.

Partial drill water loss has been noticed for the entire depth.
The formation rock is highly to moderately weathered and huge to modest amount of the rock mass is disintegrated. During drilling the disintegrated rock particles between fractures plains have been removed by drill water. As a result huge to modest core loss occurred.

BH No. 24

(00.00 – 06.00)m: Overburden.

(06.00 – 25.00)m: **(06.00 – 12.50)m:**

Rock Description: Almost completely weathered and completely disintegrated with remnants of highly weathered, brownish grey, fine grained, moderately compacted **Phyllite** at 06.00 – 07.50m.

Rock Properties: Soft and very weak to weak rock.

Structural Condition: Foliated (60°-65°). Very closely spaced, highly fractured (>15 nos/m). Two sets of fractures. Dominantly inclined (foliation parallel) fracture surfaces are apparently smooth, and deeply altered. Horizontal (0°-5°) fracture surfaces are slightly rough, undulated and deeply altered.

Description of Core: Recovered core occurs as discontinuous framework. Cores are mostly in lengths of 30-100mm.

12.50 – 25.00m:

Rock Description: Highly (12.50 – 15.00m) to moderately (15.00 – 20.25m), followed by slightly weathered, brownish grey (upto 20.25m) to dark grey, fine grained, densely compacted **Phyllite**.

Rock Properties: Moderately hard and moderately strong (upto 20.25m) to hard and strong rock.

Structural Condition: Foliated (65°-70°). Closely to thickly spaced, highly (>15 nos/m upto 15.00m) to medium fractured (8-5 nos/m). Two sets of fractures. Dominantly inclined (foliation parallel) fracture surfaces are apparently smooth, and deeply altered (upto 20.00m) to clean. Horizontal (0°-5°) fracture surfaces are slightly rough, undulated and deeply altered (upto 20.00m) to clean.

Description of Core: Recovered core occurs as continuous framework. Cores are mostly in lengths of 30-100mm upto 15.00m. Thereafter cores are 100-200mm sizes.

Rock Mass Structure: The rock mass is poor in nature, and belongs to Shattered / Crushed (lack of blockiness) category upto 15.00m depth. Followed by fair quality and belongs to disintegrated category.

Partial drill water loss has been noticed for the entire depth.

The formation rock is completely to slightly weathered and huge to modest amount of the rock mass is disintegrated. During drilling the disintegrated rock particles between fractures plains have been removed by drill water. As a result huge to modest core loss occurred.

BH No. 25

(00.00 – 04.50)m: Overburden.

(04.50 – 05.25)m: Completely weathered, brownish grey, decomposed and completely disintegrated particles of Phyllite.

(05.25 – 06.00)m: Gravels and boulder shaped, milky white, coarse grained Quartzite occurred as secondary inclusion.

(06.00 – 20.00)m: **Rock Description:** High (upto 10.50m) to moderately weathered, brownish grey, fine grained, moderately to densely compacted **Phyllite**.

Rock Properties: Moderately hard and moderately strong (upto 10.50m) to hard and strong rock.

Structural Condition: Foliated (75°-80°). Very closely (upto 10.50m)

to closely spaced, highly fractured (15-8 nos/m to 8-5 nos/m). Two sets of fractures. Dominantly inclined (foliation parallel) fracture surfaces are apparently smooth, and deeply altered (upto 17.00m) to clean. Horizontal (0°-5°) fracture surfaces are slightly rough, undulated and deeply altered (upto 17.00m) to clean. Rare vertical (at 13.00 – 13.50m depth) fracture surfaces are rough, wavy and altered.
Description of Core: Recovered core occurs as continuous framework. Cores are mostly in lengths of 30-100mm upto 15.75m. Thereafter cores are 100-200mm sizes.

Rock Mass Structure: The rock mass is poor in nature, and belongs to Shattered / Crushed (lack of blockiness) category upto 15.75m depth. Followed by fair and belongs to disintegrated category.

Partial drill water loss has been noticed for the entire depth.
The formation rock is highly to moderately weathered and huge to modest amount of the rock mass is disintegrated. During drilling the disintegrated rock particles between fractures plains have been removed by drill water. As a result huge to modest core loss occurred.

BH No. 26

(00.00 – 04.75)m**:** Overburden.

(04.75 – 15.00)m**:** **(04.75 – 07.75)m:**
Rock Description: Almost completely weathered with remnants of highly (at 04.75 – 05.50m, 06.25 – 07.00m depth) weathered, brownish grey, fine grained, loosely compacted **Phyllite**.
Rock Properties: Soft and weak to very weak rock.
Structural Condition: Foliated (70°-80°). Very closely spaced, highly fractured (>15 nos/m). Two sets of fractures. Dominantly inclined (foliation parallel) fracture surfaces are apparently smooth, and deeply altered. Horizontal (0°-5°) fracture surfaces are slightly rough, undulated and deeply altered.
Description of Core: Recovered core occurs as discontinuous framework. Cores are mostly in lengths of 30-100mm.
07.75 – 15.00m:
Rock Description: Moderately weathered, brownish grey, fine grained, moderately to densely compacted **Phyllite**.
Rock Properties: Moderately hard and moderately strong rock.
Structural Condition: Foliated (70°-80°). Closely spaced, highly fractured (>15 nos/m). Two sets of fractures. Dominantly inclined (foliation parallel) fracture surfaces are apparently smooth, and deeply altered. Horizontal (0°-5°) fracture surfaces are slightly rough, undulated and deeply altered.
Description of Core: Recovered core occurs as continuous framework. Cores are mostly in lengths of 30-100mm.

Rock Mass Structure: The rock mass is very poor to poor in nature, and belongs to Shattered / Crushed (lack of blockiness) category.

Partial drill water loss has been noticed for the entire depth.
The formation rock is completely to moderately weathered and huge to modest amount of the rock mass is disintegrated. During drilling the

disintegrated rock particles between fractures plains have been removed by drill water. As a result huge to modest core loss occurred.

BH No. 27

(00.00 – 06.50)m: Overburden.

(06.50 – 20.00)m: **Rock Description:** Highly weathered (upto 08.00m), then abruptly changed to slightly weathered, brownish grey (upto 08.00m) to dark grey, fine grained, moderately to densely compacted **Phyllite**.
Rock Properties: Moderately hard and moderately strong (upto 08.00m) to hard and strong rock.
Structural Condition: Foliated (65°-75°). Very closely (upto 08.00m) to widely spaced, highly fractured (>15 nos/m) to slightly fractured (5-1 nos/m from 08.00m depth). Two sets of fractures. Dominantly inclined (foliation parallel) fracture surfaces are apparently smooth, and deeply altered (upto 08.00m) to clean. Horizontal (0°-5°) fracture surfaces are slightly rough, undulated and deeply altered (upto 09.00m) to clean.
Description of Core: Recovered core occurs as discontinuous framework upto 08.00m to continuous. Cores are mostly in lengths of 30-100mm upto 08.00m. Thereafter cores are 100-300mm sizes.

Rock Mass Structure: The rock mass is poor in nature, and belongs to Shattered / Crushed (lack of blockiness) category upto 08.00m depth. Followed by fair quality and belongs to disintegrated category.

Partial drill water loss has been noticed for the entire depth.
The formation rock is highly to slightly weathered and huge to minor amount of the rock mass is disintegrated. During drilling the disintegrated rock particles between fractures plains have been removed by drill water. As a result huge to minor core loss occurred.

BH No. 28

(00.00 – 04.75)m: Overburden.

(04.75 – 20.00)m: **Rock Description:** Highly weathered and decomposed (upto 10.75m) to moderately (10.75 – 19.00m), followed by slightly weathered, brownish grey and dark brownish patch (upto 19.00m) to dark grey, fine grained, moderately to densely compacted **Phyllite**.
Rock Properties: Moderately soft and weak (upto 10.75m) to hard and strong rock.
Structural Condition: Foliated (75°-80° inclination). Thinly spaced, highly fractured (>15 nos./m upto 10.75m) to thick to widely spaced and medium fractured (8-5 to 15-8 nos/m). Two sets of fractures. Dominantly Inclined (foliation parallel) fracture surfaces are apparently smooth, and deeply altered (upto 19.00m) to clean. Horizontal (0°-5°) fracture surfaces are slightly rough, undulated and deeply altered (upto 19.00m) to clean.
Description of Core: Recovered core occurs as discontinuous framework upto 10.75m, followed by continuous. Cores are mostly in lengths of 30-100mm with mostly in lengths of <100mm upto 10.75m. Thereafter cores are mostly in lengths of 100-300mm in size with locally 30-100mm core pieces at 14.50 – 15.25m, 16.00 – 17.50m depth.

Rock Mass Structure: The rock mass is very poor to poor in nature, and belongs to Shattered / Crushed (lack of blockiness) category upto 10.75m. Followed by fair and belongs to disintegrated (locally poor at 14.50 – 15.25m, 16.00 – 17.50m depth).

Partial drill water loss has been noticed for the entire depth.
The formation rock is highly to slightly weathered and huge to modest amount of the rock mass is disintegrated. During drilling the disintegrated rock particles between fractures plains have been removed by drill water. As a result huge to modest core loss occurred.

BH No. 29

(00.00 – 05.75)m**:** Overburden.

(05.75 – 20.00)m**:** **Rock Description:** Moderately (upto 11.75) to slightly weathered, brownish grey and dark brownish patch, fine grained, densely compacted **Phyllite**.
Rock Properties: Moderately hard and moderately strong (upto 11.75m) to hard and strong rock.
Structural Condition: Foliated (60°-65° inclination). Thinly to closely spaced, highly fractured (>15 nos./m) to medium fractured (8-5 nos/m). Two sets of fractures. Dominantly Inclined (foliation parallel) fracture surfaces are apparently smooth, and deeply altered (upto 12.00m) to slightly altered. Horizontal (0°-5°) fracture surfaces are slightly rough, undulated and deeply altered (upto 12.00m) to deeply altered.
Description of Core: Recovered core occurs as discontinuous framework upto 09.50m, followed by continuous. Cores are mostly in lengths of 30-100mm with mostly in lengths of <100mm upto 09.50m. Thereafter cores are mostly in lengths of 100-200mm in size with locally 30-100mm core pieces at 10.25 – 11.00m, 17.75 – 20.75m depth.

Rock Mass Structure: The rock mass is very poor to poor in nature, and belongs to Shattered / Crushed (lack of blockiness) category upto 09.50m. Followed by fair and belongs to disintegrated category.

Partial drill water loss has been noticed for the entire depth.
The formation rock is moderately weathered and huge to modest amount of the rock mass is disintegrated. During drilling the disintegrated rock particles between fractures plains have been removed by drill water. As a result huge to modest core loss occurred.

BH No. 30

(00.00 – 05.80)m**:** Overburden.

(05.80 – 15.00)m**:** **Rock Description:** Moderately weathered, brownish grey and dark brownish patch, fine grained, moderately to densely compacted **Phyllite**.
Rock Properties: Hard and moderately strong to strong rock.
Structural Condition: Foliated (65°-70° inclination). Closely to thickly spaced, highly fractured (>15 nos./m) to medium fractured (8-5 nos/m). Two sets of fractures. Dominantly Inclined (foliation parallel) fracture surfaces are apparently smooth, and deeply altered.

Horizontal (0°-5°) fracture surfaces are slightly rough, undulated and deeply altered.
Description of Core: Recovered core occurs as continuous framework. Cores are mostly in lengths of 100-200mm with locally 30-100mm core pieces at 13.00 – 14.00m depth.

Rock Mass Structure: The rock mass is poor to fair in nature, and belongs to crushed / disintegrated category.

Partial drill water loss has been noticed for the entire depth.
The formation rock is moderately weathered and huge to modest amount of the rock mass is disintegrated. During drilling the disintegrated rock particles between fractures plains have been removed by drill water. As a result huge to modest core loss occurred.

BH No. 31

(00.00 – 06.85)m**:** Overburden.

(06.85 – 10.50)m**:** Completely weathered, brownish grey, decomposed and disintegrated Phyllite.

(10.50 – 15.00)m**:** **Rock Description:** Moderately (upto 13.50m) to slightly weathered, brownish grey (upto 13.50m) to dark grey, fine grained, moderately to densely compacted **Phyllite**.
Rock Properties: Moderately hard and moderately strong (upto 13.50m) to hard and strong rock.
Structural Condition: Foliated (60°-65°). Very closely to closely (upto 13.50m), then thickly spaced. Highly fractured (>15 nos/m) to slightly fractured (5-1 nos/m from 13.50m). Two sets of fractures. Dominantly inclined (foliation parallel) fracture surfaces are apparently smooth, and deeply altered (upto 13.00m) to clean. Horizontal (0°-5°) fracture surfaces are slightly rough, undulated and deeply altered (upto 13.00m) to clean.
Description of Core: Recovered core occurs as continuous framework. Cores are mostly in lengths of 30-100mm upto 13.50m. Thereafter cores are 100-300mm in sizes.

Rock Mass Structure: The rock mass is very poor to poor in nature, and belongs to Shattered / Crushed (lack of blockiness) category upto 13.50m depth. Followed by good and belongs to blocky category.

Partial drill water loss has been noticed for the entire depth.
The formation rock is completely to slightly weathered and huge to modest amount of the rock mass is disintegrated. During drilling the disintegrated rock particles between fractures plains have been removed by drill water. As a result huge to modest core loss occurred.

BH No. 32

(00.00 – 06.80)m**:** Overburden.

(06.80 – 20.00)m**:** **Rock Description:** Highly weathered (upto 10.50m) to moderately weathered, brownish grey and dark brownish patch (upto 10.50m) to dark grey, fine grained, moderately to densely compacted **Phyllite**.
Rock Properties: Moderately soft and weak (upto 10.50m) to hard and strong rock.

Structural Condition: Foliated (65°-70° inclination). Thinly spaced, highly fractured (>15 nos./m upto 10.50m) to closely spaced and medium fractured (8-5 nos/m). Two sets of fractures. Dominantly Inclined (foliation parallel) fracture surfaces are apparently smooth, and deeply altered. Horizontal (0°-5°) fracture surfaces are slightly rough, undulated and deeply altered.
Description of Core: Recovered core occurs as discontinuous framework upto 10.50m, followed by continuous. Cores are mostly in lengths of 30-100mm with mostly in lengths of <100mm upto 10.50m. Thereafter cores are mostly in lengths of 100-200mm in size.

Rock Mass Structure: The rock mass is very poor to poor in nature, and belongs to Shattered / Crushed (lack of blockiness) category upto 10.50m. Followed by fair and belongs to disintegrated category.

Partial drill water loss has been noticed for the entire depth.
The formation rock is highly to slightly weathered and huge to modest amount of the rock mass is disintegrated. During drilling the disintegrated rock particles between fractures plains have been removed by drill water. As a result huge to modest core loss occurred.

BH No. 33

(00.00 – 08.10)m**:** Overburden.

(08.10 – 20.00)m**:** **Rock Description:** Highly weathered (upto 10.25m), then abruptly changed to slightly weathered, brownish grey and dark brownish patch (upto 10.25m) to dark grey, fine grained, moderately to densely compacted **Phyllite**.
Rock Properties: Moderately soft and weak (upto 10.25m) to hard and strong rock.
Structural Condition: Foliated (60°-65° inclination). Thinly spaced, highly fractured (>15 nos./m upto 10.25m) to thickly spaced and medium fractured (5-1 to 8-5 nos/m). Two sets of fractures. Dominantly Inclined (foliation parallel) fracture surfaces are apparently smooth, and deeply altered (upto 12.00m) to clean. Horizontal (0°-5°) fracture surfaces are slightly rough, undulated and deeply altered (upto 12.00m) to clean.
Description of Core: Recovered core occurs as discontinuous framework upto 10.25m, followed by continuous. Cores are mostly in lengths of 30-100mm with mostly in lengths of <100mm upto 10.25m. Thereafter cores are mostly in lengths of 100-300mm with pockets of 30-100mm in size at 17.75 – 19.50m depth.

Rock Mass Structure: The rock mass is very poor to poor in nature, and belongs to Shattered / Crushed (lack of blockiness) category upto 10.25m. Followed by fair and belongs to disintegrated category.

Partial drill water loss has been noticed for the entire depth.
The formation rock is highly to slightly weathered and huge to modest amount of the rock mass is disintegrated. During drilling the disintegrated rock particles between fractures plains have been removed by drill water. As a result huge to modest core loss occurred.

BH No. 34

(00.00 – 05.90)m: Overburden.

(05.90 – 20.00)m: **Rock Description:** Highly weathered (upto 09.50m) to moderately weathered, brownish grey and dark brownish patch (upto 09.50m) to dark grey, fine grained, moderately to densely compacted **Phyllite**.
Rock Properties: Moderately soft and weak (upto 09.50m) to hard and strong rock.
Structural Condition: Foliated (60°-65° inclination). Thinly spaced, highly fractured (>15 nos./m upto 09.50m) to thickly spaced and medium fractured (8-5 nos/m). Two sets of fractures. Dominantly Inclined (foliation parallel) fracture surfaces are apparently smooth, and deeply altered (upto 10.00m) to clean. Horizontal (0°-5°) fracture surfaces are slightly rough, undulated and deeply altered (upto 10.00m) to clean.
Description of Core: Recovered core occurs as discontinuous framework upto 09.50m, followed by continuous. Cores are mostly in lengths of 30-100mm with mostly in lengths of <100mm, with pockets of 100-200mm in size at 11.00 – 13.25m, 15.50 – 17.00m, 19.25 – 20.00mn depth.

Rock Mass Structure: The rock mass is very poor to poor in nature, and belongs to Shattered / Crushed (lack of blockiness) category. Locally fair and belongs to disintegrated category at 10.25 – 12.50m, 19.25 – 20.00m depth.

Partial drill water loss has been noticed for the entire depth.
The formation rock is highly to moderately weathered and huge to modest amount of the rock mass is disintegrated. During drilling the disintegrated rock particles between fractures plains have been removed by drill water. As a result huge to modest core loss occurred.

BH No. 35

(00.00 – 07.20)m: Overburden.

(07.20 – 25.00)m: **Rock Description:** Highly weathered (upto 09.25m) to moderately (09.25 – 21.25m), followed by slightly weathered, brownish grey and dark brownish patch (upto 21.25m) to dark grey, fine grained, moderately to densely compacted **Phyllite**.
Rock Properties: Moderately soft and weak (upto 09.25m) to hard and strong rock.
Structural Condition: Foliated (60°-65° inclination). Thinly spaced, highly fractured (>15 nos./m upto 21.25m) to thick to widely spaced and medium fractured (5-1 nos/m). Two sets of fractures. Dominantly Inclined (foliation parallel) fracture surfaces are apparently smooth, and deeply altered (upto 21.25m) to clean. Horizontal (0°-5°) fracture surfaces are slightly rough, undulated and deeply altered (upto 21.25m) to clean.
Description of Core: Recovered core occurs as discontinuous framework upto 09.25m, followed by continuous. Cores are mostly in lengths of 30-100mm with mostly in lengths of <100mm upto 21.25m. Thereafter cores are mostly in lengths of 100-300mm in size.

Rock Mass Structure: The rock mass is very poor to poor in nature,

and belongs to Shattered / Crushed (lack of blockiness) category upto 21.25m. Followed by fair and belongs to disintegrated category.

Partial drill water loss has been noticed for the entire depth.
The formation rock is highly to slightly weathered and huge to modest amount of the rock mass is disintegrated. During drilling the disintegrated rock particles between fractures plains have been removed by drill water. As a result huge to modest core loss occurred.

BH No. 36

(00.00 – 05.60)m**:** Overburden.

(05.60 – 20.00)m**:** **Rock Description:** Highly weathered (upto 11.50m) to moderately (11.50 – 19.00m), followed by slightly weathered, brownish grey and dark brownish patch (upto 19.00m) to dark grey, fine grained, moderately to densely compacted **Phyllite**.
Rock Properties: Moderately soft and weak (upto 11.50m) to hard and strong rock.
Structural Condition: Foliated (70°-75° inclination). Thinly spaced, highly fractured (>15 nos./m upto 11.50m) to thickly spaced and medium fractured (8-5 nos/m). Two sets of fractures. Dominantly Inclined (foliation parallel) fracture surfaces are apparently smooth, and deeply altered (upto 19.00m) to clean. Horizontal (0°-5°) fracture surfaces are slightly rough, undulated and deeply altered (upto 19.00m) to clean.
Description of Core: Recovered core occurs as discontinuous framework upto 11.50m, followed by continuous. Cores are mostly in lengths of 30-100mm with mostly in lengths of <100mm upto 18.25m. Thereafter cores are mostly in lengths of 100-200mm.

Rock Mass Structure: The rock mass is very poor to poor in nature, and belongs to Shattered / Crushed (lack of blockiness) category upto 18.25m. Followed by fair and belongs to disintegrated category.

Partial drill water loss has been noticed for the entire depth.
The formation rock is highly to slightly weathered and huge to modest amount of the rock mass is disintegrated. During drilling the disintegrated rock particles between fractures plains have been removed by drill water. As a result huge to modest core loss occurred.

BH No. 37

(00.00 – 04.80)m**:** Overburden.

(04.80 – 20.00)m**:** **Rock Description:** Highly weathered and slightly decomposed (upto 07.75m) to moderately weathered, brownish grey and dark brownish patch (upto 07.75m) to brownish grey, fine grained, moderately to densely compacted **Phyllite**.
Rock Properties: Moderately soft and weak (upto 07.75m) to moderately hard and moderately strong rock.
Structural Condition: Foliated (65°-70° inclination). Thinly spaced, highly fractured (>15 nos./m upto 07.75m) to thick / widely spaced and slightly fractured (5-1 nos/m). Two sets of fractures. Dominantly Inclined (foliation parallel) fracture surfaces are apparently smooth, and deeply altered (upto 07.75m) to clean. Horizontal (0°-5°) fracture

surfaces are slightly rough, undulated and deeply altered (upto 08.00m) to clean.
Description of Core: Recovered core occurs as discontinuous framework upto 07.75m, followed by continuous. Cores are mostly in lengths of 30-100mm with mostly in lengths of <100mm. Locally cores are 100-200mm in size at 07.75 – 08.50, 11.50 – 13.75m, 16.75 – 17.50m.

Rock Mass Structure: The rock mass is very poor to poor in nature, and belongs to Shattered / Crushed (lack of blockiness) category. Locally rock mass is fair and belongs to disintegrated category at 07.75 – 08.50, 11.50 – 13.75m, 16.75 – 17.50m.

Partial drill water loss has been noticed for the entire depth.
The formation rock is highly to moderately weathered and huge to modest amount of the rock mass is disintegrated. During drilling the disintegrated rock particles between fractures plains have been removed by drill water. As a result huge to modest core loss occurred.

BH No. 38

(00.00 – 07.60)m**:** Overburden.

(07.60 – 08.25)m**:** Completely weathered, brownish grey, decomposed and disintegrated Phyllite.

(08.25 – 20.00)m**:** **Rock Description:** Highly weathered (upto 12.75m) to moderately weathered, brownish grey and dark brownish patch (upto 12.75m) to brownish grey, fine grained, moderately to densely compacted **Phyllite**.
Rock Properties: Moderately soft and weak (upto 12.75m) to moderately hard and moderately strong rock.
Structural Condition: Foliated (70°-75° inclination). Thinly spaced, highly fractured (>15 nos./m upto 12.75m) to thickly spaced and medium fractured (8-5 nos/m). Two sets of fractures. Dominantly Inclined (foliation parallel) fracture surfaces are apparently smooth, and deeply altered (upto 16.00m) to clean. Horizontal (0°-5°) fracture surfaces are slightly rough, undulated and deeply altered (upto 16.00m) to clean.
Description of Core: Recovered core occurs as discontinuous framework upto 12.75m, followed by continuous. Cores are mostly in lengths of 30-100mm with mostly in lengths of <100mm.

Rock Mass Structure: The rock mass is very poor to poor in nature, and belongs to Shattered / Crushed (lack of blockiness) category.

Partial drill water loss has been noticed for the entire depth.
The formation rock is highly to moderately weathered and huge to modest amount of the rock mass is disintegrated. During drilling the disintegrated rock particles between fractures plains have been removed by drill water. As a result huge to modest core loss occurred.

BH No. 39

(00.00 – 03.90)m**:** Overburden.

(03.90 – 15.00)m**:** **Rock Description:** Completely (upto 06.75mm) to highly weathered,

brownish grey and dark brownish patch, fine grained, loosely (upto 06.75m) to moderately compacted **Phyllite**.
Rock Properties: Soft and very weak (upto 06.75m) to moderately hard and moderately strong rock.
Structural Condition: Foliated (75°-85° inclination). Very thinly to thinly spaced, highly fractured (>15 nos./m. Two sets of fractures. Dominantly Inclined (foliation parallel) fracture surfaces are apparently smooth, and deeply altered. Horizontal (0°-5°) fracture surfaces are slightly rough, undulated and deeply altered.
Description of Core: Recovered core occurs as discontinuous framework. Cores are mostly in lengths of 30-100mm with mostly in lengths of <100mm.

Rock Mass Structure: The rock mass is very poor (upto 06.75m) to poor in nature, and belongs to Shattered / Crushed (lack of blockiness) category.

Partial drill water loss has been noticed for the entire depth.
The formation rock is completely to highly weathered and huge amount of the rock mass is disintegrated. During drilling the disintegrated rock particles between fractures plains have been removed by drill water. As a result huge core loss occurred.

BH No. 40

(00.00 – 04.25)m**:** Overburden.

(04.25 – 20.00)m**:** **(04.25 – 10.00)m:**
Rock Description: Completely (upto 06.25m) to highly weathered, brownish grey, fine grained, loosely compacted **Phyllite**.
Rock Properties: Soft and very weak (upto 06.25m) to weak rock.
Structural Condition: Foliated (60°-65°). Very closely spaced, highly fractured (>15 nos/m). Two sets of fractures. Dominantly inclined (foliation parallel) fracture surfaces are apparently smooth, and deeply altered. Horizontal (0°-5°) fracture surfaces are slightly rough, undulated and deeply altered.
Description of Core: Recovered core occurs as discontinuous framework. Cores are mostly in lengths of 30-100mm.
10.00 – 20.00m:
Rock Description: Moderately (upto 13.75m) to slightly weathered, brownish grey (upto 13.75m) to dark grey, fine grained, densely compacted **Phyllite**.
Rock Properties: Hard and moderately strong (upto 13.75m) to strong rock.
Structural Condition: Foliated (60°-65°). Thickly spaced, medium fractured (8-5 to 5-1 nos/m). Two sets of fractures. Dominantly inclined (foliation parallel) fracture surfaces are apparently smooth, and deeply altered (upto 13.75m) to clean. Horizontal (0°-5°) fracture surfaces are slightly rough, undulated and deeply altered (upto 13.75m) to clean.
Description of Core: Recovered core occurs as continuous framework. Cores are mostly in lengths of 30-100mm upto 11.50m. Thereafter cores are mostly in lengths of 100-300mm.

Rock Mass Structure: The rock mass is poor in nature, and belongs

to Shattered / Crushed (lack of blockiness) category upto 11.50m. Thereafter rock mass is good in nature, and belongs to blocky category.

Partial drill water loss has been noticed for the entire depth.
The formation rock is completely to slightly weathered and huge to modest amount of the rock mass is disintegrated. During drilling the disintegrated rock particles between fractures plains have been removed by drill water. As a result huge to modest core loss occurred.

BH No. 41

(00.00 – 04.30)m**:** Overburden.

(04.30 – 20.00)m**:** **Rock Description:** High (upto 13.25m), then abruptly changed to slightly weathered, brownish grey (upto 10.25m) to dark grey, fine grained, moderately to densely compacted **Phyllite**.
Rock Properties: Moderately soft and moderately strong (upto 13.25m) to hard and strong rock.
Structural Condition: Foliated (75°-85°). Thinly (upto 13.25m) to thickly spaced, highly fractured (>15 nos/m) to medium fractured (8-5 nos/m from 13.25m depth). Two sets of fractures. Dominantly inclined (foliation parallel) fracture surfaces are apparently smooth, and deeply altered (upto 14.25m) to clean. Horizontal (0°-5°) fracture surfaces are slightly rough, undulated and deeply altered (upto 14.25m) to clean.
Description of Core: Recovered core occurs as discontinuous framework upto 13.25m, followed by continuous framework. Cores are mostly in lengths of 30-100mm upto 13.25m. Thereafter cores are 100-300mm sizes with locally 30-100mm at 15.50 – 16.25nm, 18.00 – 18.50m depth.

Rock Mass Structure: The rock mass is poor in nature, and belongs to Shattered / Crushed (lack of blockiness) category upto 13.25m depth. Followed by fair and belongs to disintegrated category.

Partial drill water loss has been noticed for the entire depth.
The formation rock is highly to slightly weathered and huge to modest amount of the rock mass is disintegrated. During drilling the disintegrated rock particles between fractures plains have been removed by drill water. As a result huge to modest core loss occurred.

BH No. 42

(00.00 – 04.40)m**:** Overburden.

(04.40 – 15.00)m**:** **Rock Description:** High (upto 08.00m) to moderately (08.00–14.00m), followed by slightly weathered, brownish grey (upto 14.00m) to dark grey, fine grained, moderately to densely compacted **Phyllite**.
Rock Properties: Moderately soft and moderately strong (upto 08.00m) to hard and strong rock.
Structural Condition: Foliated (70°-80°). Closely (upto 12.00m) to thickly spaced, highly fractured (>15 nos/m). Two sets of fractures. Dominantly inclined (foliation parallel) fracture surfaces are apparently smooth, and deeply altered (upto 14.00m) to clean. Horizontal (0°-5°) fracture surfaces are slightly rough, undulated and deeply altered (upto 14.00m) to clean.

Description of Core: Recovered core occurs as continuous framework. Cores are mostly in lengths of 30-100mm upto 12.00m. Thereafter cores are 100-300mm sizes.

Rock Mass Structure: The rock mass is poor in nature, and belongs to Shattered / Crushed (lack of blockiness) category upto 13.25m depth. Followed by fair and belongs to disintegrated category.

Partial drill water loss has been noticed for the entire depth.
The formation rock is highly to slightly weathered and huge to modest amount of the rock mass is disintegrated. During drilling the disintegrated rock particles between fractures plains have been removed by drill water. As a result huge to modest core loss occurred.

BH No. 43

(00.00 – 06.00)m: Overburden.

(06.00 – 25.00)m: **Rock Description:** Highly weathered and slightly decomposed (upto 11.25m) to moderately weathered, brownish grey (upto 14.25m) to dark grey, fine grained, moderately to densely compacted **Phyllite**.
Rock Properties: Soft and weak (upto 11.25m) to hard and moderately strong (upto 08.00m), followed by hard and strong rock.
Structural Condition: Foliated (65°-70°). Very closely (upto 11.25m) to thickly spaced, highly fractured (>15 nos/m) to medium fractured (8-5 nos/m from 11.25m depth). Two sets of fractures. Dominantly inclined (foliation parallel) fracture surfaces are apparently smooth, and deeply altered (upto 15.00m) to clean. Horizontal (0°-5°) fracture surfaces are slightly rough, undulated and deeply altered (upto 15.00m) to clean.
Description of Core: Recovered core occurs as discontinuous framework upto 11.25m to continuous. Cores are mostly in lengths of 30-100mm.

Rock Mass Structure: The rock mass is poor in nature, and belongs to Shattered / Crushed (lack of blockiness) category.

Partial drill water loss has been noticed for the entire depth.
The formation rock is highly to moderately weathered and huge to minor amount of the rock mass is disintegrated. During drilling the disintegrated rock particles between fractures plains have been removed by drill water. As a result huge to modest core loss occurred.

BH No. 44

(00.00 – 06.30)m: Overburden.

(06.25 – 07.00)m: Completely weathered, brownish grey, decomposed and completely disintegrated particles of Phyllite.

(07.00 – 25.00)m: **Rock Description:** High (upto 08.50m) to moderately (08.50–16.75m), followed by slightly weathered, brownish grey (upto 16.75m) to dark grey, fine grained, moderately to densely compacted **Phyllite**.
Rock Properties: Moderately soft and moderately strong (upto 08.50m) to hard and strong rock.
Structural Condition: Foliated (65°-70°). Very closely (upto 08.50m) to thickly spaced, highly fractured (>15 nos/m to 8-5 nos/m). Two sets

of fractures. Dominantly inclined (foliation parallel) fracture surfaces are apparently smooth, and deeply altered (upto 20.00m) to clean. Horizontal (0°-5°) fracture surfaces are slightly rough, undulated and deeply altered (upto 20.00m) to clean.
Description of Core: Recovered core occurs as continuous framework. Cores are mostly in lengths of 30-100mm upto 08.50m. Thereafter cores are 100-300mm sizes, with locally 30-100mm sizes at 16.00–16.75m, 22.00–23.50m depth.

Rock Mass Structure: The rock mass is poor in nature, and belongs to Shattered / Crushed (lack of blockiness) category upto 13.75m depth. Followed by fair and belongs to disintegrated category.

Partial drill water loss has been noticed for the entire depth.
The formation rock is highly to slightly weathered and huge to modest amount of the rock mass is disintegrated. During drilling the disintegrated rock particles between fractures plains have been removed by drill water. As a result huge to modest core loss occurred.

BH No. 45

(00.00 – 05.50)m**:** Overburden.

(05.50 – 25.00)m**:** **Rock Description:** Highly (upto 11.50m) to moderately weathered, brownish grey to dark grey, fine grained, moderately (upto 12.00m) to densely compacted **Phyllite**.
Rock Properties: Moderately soft and weak (upto 11.50m) to moderately hard and moderately strong.
Structural Condition: Foliated (60°-65°). Very closely to closely spaced, high (>15 nos/m) to medium fractures (15-8 nos/m from 23.50m). Two sets of fractures. Dominantly inclined (foliation parallel) fracture surfaces are apparently smooth, and deeply altered (upto 23.50m) to clean. Horizontal (0°-5°) fracture surfaces are slightly rough, undulated and altered.
Description of Core: Recovered core occurs as discontinuous framework upto 11.50m depth. Cores are mostly in lengths of 30-100mm upto 23.50m. Thereafter cores are 100-200mm sizes.

Rock Mass Structure: The rock mass is very poor to poor in nature, and belongs to Shattered / Crushed (lack of blockiness) category upto 23.50m depth. Followed by fair quality and belongs to disintegrated category.

Partial drill water loss has been noticed for the entire depth.
The formation rock is highly to moderately weathered and huge to modest amount of the rock mass is disintegrated. During drilling the disintegrated rock particles between fractures plains have been removed by drill water. As a result huge to modest core loss occurred.

BH No. 46

(00.00 – 07.20)m**:** Overburden.

(07.20 – 25.00)m**:** **Rock Description:** Highly weathered and decomposed (upto 08.00m) to moderately (08.00 – 18.50m), followed by slightly weathered, brownish grey (upto 18.50m) to dark grey, fine grained, moderately to

densely compacted **Phyllite**, with white stringers throughout the depth.
Rock Properties: Moderately soft and weak (upto 08.00m) to moderately hard and moderately strong (08.00 – 18.50m), followed by hard and strong rock.
Structural Condition: Foliated (75°-80°). Very closely / closely to thickly (from 18.50m) spaced, highly fractures (>15 nos/m) to medium fractures (8-5 nos/m from 18.50m depth). Two sets of fractures. Dominantly inclined (foliation parallel) fracture surfaces are apparently smooth, and deeply altered (upto 17.00m)to clean. Horizontal (0°-5°) fracture surfaces are slightly rough, undulated and deeply altered (upto 17.00m depth).
Description of Core: Recovered core occurs as discontinuous framework upto 08.00m depth. Cores are mostly in lengths of 30-100mm upto 18.50m. Thereafter cores are 100-200mm sizes.

Rock Mass Structure: The rock mass is very poor to poor in nature, and belongs to Shattered / Crushed (lack of blockiness) category upto 18.50m depth. Followed by fair quality and belongs to disintegrated category.

Partial drill water loss has been noticed for the entire depth.
The formation rock is highly to slightly weathered and huge to modest amount of the rock mass is disintegrated. During drilling the disintegrated rock particles between fractures plains have been removed by drill water. As a result huge to modest core loss occurred.

BH No. 47

(00.00 – 06.90)m: Overburden.

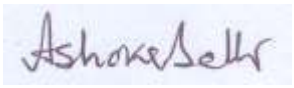
(06.90 – 25.00)m: **Rock Description:** Highly (upto 19.75m) to moderately weathered, brownish grey (upto 19.75m) to dark grey, fine grained, moderately (upto 19.75m) to densely compacted **Phyllite**.
Rock Properties: Soft and weak (upto 11.25m) to moderately hard and moderately strong (11.25 – 19.75m), followed by hard and strong rock.
Structural Condition: Foliated (70°-75°). Very closely to closely spaced, highly fractured (>15 to 15-8 nos/m). Two sets of fractures. Dominantly inclined (foliation parallel) fracture surfaces are apparently smooth, and deeply altered (upto 23.25m) to clean. Horizontal (0°-5°) fracture surfaces are slightly rough, undulated and altered.
Description of Core: Recovered core occurs as discontinuous framework upto 11.25m depth, followed by continuous framework. Cores are mostly in lengths of 30-100mm, with pockets of 100-200mm sizes at 23.25 – 25.00m depth.

Partial drill water loss has been noticed for the entire depth.
Rock Mass Structure: The rock mass is very poor to poor in nature, and belongs to Shattered / Crushed (lack of blockiness) category upto 23.25m depth. Followed by fair quality and belongs to disintegrated category.

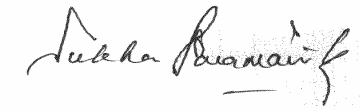
Partial drill water loss has been noticed for the entire depth.
The formation rock is highly to moderately weathered and huge to

modest amount of the rock mass is disintegrated. During drilling the disintegrated rock particles between fractures plains have been removed by drill water. As a result huge to modest core loss occurred.

For C. E. Testing Company private limited,



(Dr. A. Seth, Geologist)



(Mr. S.Paramanik, Geologist)

.

Sample Bearing Capacity Calculation

Foundation around Chimney Area, Depth of foundation = 4m below FGL (FGL= 218.500M)

The founding level falls inside hard clay layer i.e layer I.
Average N = 48, corresponding cohesion from N value = 1.78 kg/sqcm & Φ = 0°
So, use C = 1.50 kg/sqcm & Φ = 0°
Assume size of foundation = 35m dia
So, equivalent width of foundation = 31.02m

Cohesion, C = 15.00 t/sqm
Using $\phi = 0$ degree, the bearing capacity factors are:
$N_c = 5.14$
$N_q = 1.00$
$N_\gamma = 0.00$
Use,
Depth of Foundation = D_f = 4 M (below FGL)
Diameter of Foundation = B = 35 M
Overburden Pressure = q =4.000 (Depth) x 0.90 (Submerged density) = 3.60 t/sqm (assuming water table is flushing with the ground)
The Shape factors are [IS:6403 - 1981]
$S_c = 1.30$ $S_q = 1.20$ $S_\gamma = 0.60$
The Depth factors are [IS:6403 - 1981]
$D_c = 1.02$ $D_q = 1.00$ $D_\gamma = 1.00$
Computed Net Ultimate Bearing Capacity = 103.33 t/sqm
Using a factor of safety of 2.5, Net Safe Bearing Capacity = 41.33 t/sqm

The above bearing capacity should be checked against settlement criteria. This is shown below.

Determination of Deformation Parameters

Stratum I (from 4.00m to 6.00m)

Total soil modulus, $E_s = 4.4 \times N = 211.2$ kg/sqcm
Undrained Young's modulus, $E_u = K \times C = 500 \times 1.5 = 750$ kg/sqcm
Again, $1/E_s = 1/E_u + 1/E_d$ giving drained young's modulus, $E_d = 293.99$ kg/sqcm
Now, we have, $E_d = E_u/3 = 250$ kg/sqcm
Considering the above, let us use $E_d = 270$ kg/sqcm
From E_d, $m_{vc} = 1/G.E_d = 0.0067$ sqcm/kg [Geological Factor, G = 0.55& μ = 0.35]
Again from SPT "N", $m_{vc} = 1/5N = 0.0042$ sqcm/kg
Thus average $m_{vc} = (0.0067+0.0042)/2 = 0.0055$ sqcm/kg

Stratum I (from 6.00m to 7.00m)

Use C = 2.00 kg/sqcm

Total soil modulus, $E_s = 4.4 \times N = 440$ kg/sqcm
Undrained Young's modulus, $E_u = K \times C = 500 \times 2.0 = 1000$ kg/sqcm
Again, $1/E_s = 1/E_u + 1/E_d$ giving drained young's modulus, $E_d = 785.71$ kg/sqcm
Now, we have, $E_d = E_u/3 = 333.33$ kg/sqcm
Considering the above, let us use $E_d = 550$ kg/sqcm
From E_d, $m_{vc} = 1/G.E_d = 0.0036$ sqcm/kg [Geological Factor, G = 0.50 & μ = 0.35]
Again from SPT "N", $m_{vc} = 1/5N = 0.0020$ sqcm/kg
Thus average $m_{vc} = (0.0036+0.0020)/2 = 0.0028$ sqcm/kg

Stratum IV & V

Use Young's modulus for layer IV & V = 2000 kg/sqcm & 4000 kg/sqcm respectively

SETTLEMENT CALCULATION

Settlement Analysis

A) General Data:

Width of foundation =	31.02	m
Length of foundation =	31.02	m
Depth of foundation =	4.0	m
Net Base Pressure =	3.2	kg/sqcm

B) Subsoil Properties:

Layer - I

Young's Modulus =	750	kg/sqcm
Poisson Ratio, μ =	0.35	
Top of Stratum =	4.00	m
End of Stratum =	5.02	m
Geological factor, G =	0.55	
m_{vc} =	0.0055	sqcm/kg

Layer - I

Young's Modulus =	1000	kg/sqcm
Poisson Ratio, μ =	0.35	
Top of Stratum =	5.02	m
End of Stratum =	6.02	m
Geological factor, G =	0.50	
m_{vc} =	0.0028	sqcm/kg

C) Calculation of Immediate Settlement:

Settlement at center

M = L' / B' =	1.000	
N = H / B' =	0.066	
I_1 =	0.001	
I_2 =	0.015	
$I_s = I_1 + \{(1-2\mu) / (1-\mu)\} I_2$ =	0.008	
Immediate settlement S_i = $[q_o \times B' \times (1-\mu^2) \times m \times I_s] / E_s$	0.188	cm

Settlement at center

M = L' / B' =	1.000	
N = H / B' =	0.062	
I_1 =	0.001	
I_2 =	0.015	
$I_s = I_1 + \{(1-2\mu) / (1-\mu)\} I_2$ =	0.0077	
Immediate settlement S_i = $[q_o \times B' \times (1-\mu^2) \times m \times I_s] / E_s$	0.1294	cm

Settlement at corner

M = L' / B' =	1.00	
N = H / B' =	0.033	
I_1 =	0.000243	
I_2 =	0.007970	
$I_s = I_1 + \{(1-2\mu) / (1-\mu)\} I_2$ =	0.004	
Immediate settlement S_i =	0.046	cm

Settlement at corner

M = L' / B' =	1.00	
N = H / B' =	0.031	
I_1 =	0.000	
I_2 =	0.008	
$I_s = I_1 + \{(1-2\mu) / (1-\mu)\} I_2$ =	0.0037	
Immediate settlement S_i =	0.0314	cm

Average S_i for Stratum I= 1.17 mm

Average S_i for Stratum I= 0.804 mm

Layer - IV

Young's Modulus =	2000	kg/sqcm
Poisson Ratio, μ =	0.35	
Top of Stratum =	6.02	m
End of Stratum =	14.519	m
Geological factor, G =	1	
m_{vc} =	0.0000	sqcm/kg

Settlement at center

M = L' / B' =	1.000	
N = H / B' =	0.515	
I_1 =	0.051	
I_2 =	0.075	
$I_s = I_1 + \{(1-2\mu) / (1-\mu)\} I_2$ =	0.086	
Immediate settlement S_i =	0.701	cm
$[q_o \times B' \times (1-\mu^2) \times m \times I_s] / E_s$		

Settlement at corner

M = L' / B' =	1.000	
N = H / B' =	0.257	
I_1 =	0.014	
I_2 =	0.050	
$I_s = I_1 + \{(1-2\mu) / (1-\mu)\} I_2$ =	0.037	
Immediate settlement S_i =	0.153	cm

Average S_i for Stratum IV= 4.27 mm

Total immediate settlement = 10.47 mm

Layer - V

Young's Modulus =	4000	kg/sqcm
Poisson Ratio, μ =	0.25	
Top of Stratum =	14.519	m
End of Stratum =	35.02	m
Geological factor, G =	1	
m_{vc} =	0.0000	sqcm/kg

Settlement at center

M = L' / B' =	1.000	
N = H / B' =	0.987	
I_1 =	0.140	
I_2 =	0.083	
$I_s = I_1 + \{(1-2\mu) / (1-\mu)\} I_2$ =	0.195	
Immediate settlement S_i =	0.678	cm
$[q_o \times B' \times (1-\mu^2) \times m \times I_s] / E_s$		

Settlement at corner

M = L' / B' =	1.000	
N = H / B' =	0.494	
I_1 =	0.048	
I_2 =	0.073	
$I_s = I_1 + \{(1-2\mu) / (1-\mu)\} I_2$ =	0.097	
Immediate settlement S_i =	0.168	cm

Average S_i for Stratum V= 4.23 mm

(for all the four layers)

D) Calculation of Consolidation Settlement:

Strata	From (M)	To (M)	Thickness (M)	Mid depth (M)	Δ P (kg/sqcm)	m_{vc}, sqcm/kg	G	S_c (cm)
Layer - I	4.00	4.51	0.51	0.25	3.15	0.0055	0.55	0.49
	4.51	5.02	0.51	0.76	3.05	0.0055	0.55	0.47
Layer - I	5.02	5.52	0.50	1.27	2.95	0.0028	0.50	0.21
	5.52	6.02	0.50	1.77	2.86	0.0028	0.50	0.20

Hence, Total Consolidation Settlement = 13.62 mm

So, Total Settlement = 24.09 mm
Foxe's Depth correction Factor = 0.97
Rigidity Correction Factor = 0.80
Corrected total settlement = 18.78 mm

However let us restrict the bearing capacity to 30t/sqm for depth of foundation of 4.0m below FGL with a limiting settlement of 25mm.

Foundation around Chimney Area, Depth of foundation = 6.60m below FGL (FGL= 218.500M)

The founding level falls inside weathered rock layer with moderate CR value and nil RQD.
As per cl. 706.3.1.1.2 of IRC:78-2014, weathered rock may be treated as soil.
Now from literature we know that the c and φ values of a rock specimen is in the range of c = 35 to 175 kg/sqcm and Φ is seldom less than 40 degree [Bowles, J. E., Foundation Analysis and Design, pp-278, 5th Edition]. Neglecting the cohesion value, to be in the safer side use Φ = 34° for bearing capacity calculation.
Assume size of foundation = 35m dia
So, equivalent width of foundation = 31.02m

Cohesion, C = 0.00 t/sqm
Using ϕ = 34 degree, the bearing capacity factors are:
N_c = 42.16
N_q = 29.44
N_γ = 41.06
Use,
Depth of Foundation = D_f = 6.6 M (below FGL)
Diameter of Foundation = B = 35 M
Overburden Pressure = q =6.600 (Depth) x 0.90 (Submerged density) = 5.94 t/sqm (assuming water table is flushing with the ground)
The Shape factors are [IS:6403 - 1981]
S_c = 1.30 S_q = 1.20 S_γ = 0.60
The Depth factors are [IS:6403 - 1981]
D_c = 1.07 D_q = 1.04 D_γ = 1.04
Computed Net Ultimate Bearing Capacity = 613.16 t/sqm
Using a factor of safety of 2.5, Net Safe Bearing Capacity = 245.27 t/sqm

The above bearing capacity should be checked against settlement criteria. This is shown below.

Determination of Deformation Parameters

Stratum IV & V

Use Young's modulus for layer IV & V = 2000 kg/sqcm & 4000 kg/sqcm respectively

SETTLEMENT CALCULATION

Settlement Analysis

A) General Data:

Width of foundation =	31.02	m
Length of foundation =	31.02	m
Depth of foundation =	6.6	m
Net Base Pressure =	4.5	kg/sqcm

B) Subsoil Properties:

Layer - IV			**Layer - V**		
Young's Modulus =	2000	kg/sqcm	Young's Modulus =	4000	kg/sqcm
Poisson Ratio, μ =	0.25		Poisson Ratio, μ =	0.25	
Top of Stratum =	6.60	m	Top of Stratum =	14.52	m
End of Stratum =	14.52	m	End of Stratum =	37.62	m
Geological factor, G =	1.00		Geological factor, G =	1.00	
m_{vc} =	0.0000	sqcm/kg	m_{vc} =	0.0000	sqcm/kg

C) Calculation of Immediate Settlement:

Settlement at center

M = L' / B' =	1.000		M = L' / B' =	1.000	
N = H / B' =	0.511		N = H / B' =	1.187	
I_1 =	0.051		I_1 =	0.175	
I_2 =	0.074		I_2 =	0.081	
$I_s = I_1 + \{(1-2\mu) / (1-\mu)\} I_2$ =		0.100	$I_s = I_1 + \{(1-2\mu) / (1-\mu)\} I_2$ =		0.229
Immediate settlement S_i =		1.312 cm	Immediate settlement S_i =		1.193 cm
$[q_o \times B' \times (1-\mu^2) \times m \times I_s] / E_s$			$[q_o \times B' \times (1-\mu^2) \times m \times I_s] / E_s$		

Settlement at corner

M = L' / B' =	1.00		M = L' / B' =	1.00	
N = H / B' =	0.255		N = H / B' =	0.593	
I_1 =	0.014098		I_1 =	0.065	
I_2 =	0.049535		I_2 =	0.079	
$I_s = I_1 + \{(1-2\mu) / (1-\mu)\} I_2$ =		0.047	$I_s = I_1 + \{(1-2\mu) / (1-\mu)\} I_2$ =		0.118
Immediate settlement S_i =		0.308 cm	Immediate settlement S_i =		0.307 cm

Average S_i for Stratum IV=	8.10 mm		Average S_i for Stratum V=	7.50 mm	
Total immediate settlement =		15.60 mm	(for both the layer)		
Foxe's Depth correction Factor =		0.95			
Rigidity Correction =		0.80			
Corrected total settlement =		**11.84 mm**			

So, use a net allowable bearing capacity of 45t/sqm for depth of foundation of 6.60m below FGL with a limiting settlement of 12mm.

Foundation around Boiler & Mill Bunker Area, Depth of foundation = 4m below FGL (FGL= 218.500M)

The founding level falls inside hard clay layer i.e layer I.
Design N = 17, corresponding cohesion from N value = 0.91 kg/sqcm & Φ = 0°
However, considering the N value, use C = 0.80 kg/sqcm
Assume size of foundation = 5m x 5m

Cohesion, C = 8.00 t/sqm
Using $\phi = 0$ degree, the bearing capacity factors are:
$N_c = 5.14$
$N_q = 1.00$
$N_\gamma = 0.00$
Use,
Depth of Foundation = D_f = 4 M (below FGL)
Size of Foundation = B = 5 M Square
Overburden Pressure = q =4.000 (Depth) x 0.90 (Submerged density) = 3.60 t/sqm (assuming water table is flushing with the ground)
The Shape factors are [IS:6403 - 1981]
$S_c = 1.30$ $S_q = 1.20$ $S_\gamma = 0.80$
The Depth factors are [IS:6403 - 1981]
$D_c = 1.16$ $D_q = 1.00$ $D_\gamma = 1.00$
Computed Net Ultimate Bearing Capacity = 62.78 t/sqm
Using a factor of safety of 2.5, Net Safe Bearing Capacity = 25.11 t/sqm

The above bearing capacity should be checked against settlement criteria. This is shown below.

Determination of Deformation Parameters

Stratum I (from 4.00m to 5.00m)

Total soil modulus, $E_s = 4.4 \times N = 74.80$ kg/sqcm
Undrained Young's modulus, $E_u = K \times C = 400 \times 0.80 = 320$ kg/sqcm
Again, $1/E_s = 1/E_u + 1/E_d$ giving drained young's modulus, $E_d = 97.62$ kg/sqcm
Now, we have, $E_d = E_u/3 = 106.67$ kg/sqcm
Considering the above, let us use $E_d = 100$ kg/sqcm
From E_d, $m_{vc} = 1/G.E_d = 0.0143$ sqcm/kg [Geological Factor, G = 0.70 & μ = 0.35]
Again from SPT "N", $m_{vc} = 1/5N = 0.0118$ sqcm/kg
Thus average $m_{vc} = (0.0143+0.0118)/2 = 0.0130$ sqcm/kg

Stratum I (from 5.00m to 9.00m)

Design N = 45, corresponding cohesion from N value = 1.67 kg/sqcm
Use C = 1.45 kg/sqcm
Total soil modulus, $E_s = 4.4 \times N = 198$ kg/sqcm
Undrained Young's modulus, $E_u = K \times C = 500 \times 1.45 = 725$ kg/sqcm
Again, $1/E_s = 1/E_u + 1/E_d$ giving drained young's modulus, $E_d = 272.39$ kg/sqcm
Now, we have, $E_d = E_u/3 = 241.67$ kg/sqcm
Considering the above, let us use $E_d = 250$ kg/sqcm
From E_d, $m_{vc} = 1/G.E_d = 0.0067$ sqcm/kg [Geological Factor, G = 0.60 & μ = 0.35]
Again from SPT "N", $m_{vc} = 1/5N = 0.0044$ sqcm/kg
Thus average $m_{vc} = (0.0067+0.0044)/2 = 0.0056$ sqcm/kg

Stratum IV

Use Young's modulus for layer IV = 2000 kg/sqcm

SETTLEMENT CALCULATION

Settlement Analysis

A) General Data:

Width of foundation =	5.0	m
Length of foundation =	5.0	m
Depth of foundation =	4.0	m
Net Base Pressure =	2.4	kg/sqcm

B) Subsoil Properties:

Layer - I			**Layer - I**			**Layer - IV**		
Young's Modulus =	320	kg/sqcm	Young's Modulus =	725	kg/sqcm	Young's Modulus =	2000	kg/sqcm
Poisson Ratio, μ =	0.35		Poisson Ratio, μ =	0.35		Poisson Ratio, μ =	0.25	
Top of Stratum =	4.00	m	Top of Stratum =	4.63	m	Top of Stratum =	8.631	m
End of Stratum =	4.63	m	End of Stratum =	8.63	m	End of Stratum =	14	m
Geological factor, G =	0.70		Geological factor, G =	0.60		Geological factor, G =	1	
m_{vc} =	0.0130	sqcm/kg	m_{vc} =	0.0056	sqcm/kg	m_{vc} =	0.0000	sqcm/kg

C) Calculation of Immediate Settlement:

Settlement at center		*Settlement at center*		*Settlement at center*	
M = L' / B' =	1.000	M = L' / B' =	1.000	M = L' / B' =	1.000
N = H / B' =	0.252	N = H / B' =	1.421	N = H / B' =	1.115
I_1 =	0.014	I_1 =	0.212	I_1 =	0.163
I_2 =	0.049	I_2 =	0.076	I_2 =	0.082
$I_s = I_1 + \{(1-2\mu) / (1-\mu)\} I_2$ =	0.036	$I_s = I_1 + \{(1-2\mu) / (1-\mu)\} I_2$ =	0.248	$I_s = I_1 + \{(1-2\mu) / (1-\mu)\} I_2$ =	0.217
Immediate settlement S_i =	0.240 cm	Immediate settlement S_i =	0.639 cm	Immediate settlement S_i =	0.127 cm
$[q_o \times B' \times (1-\mu^2) \times m \times I_s] / E_s$		$[q_o \times B' \times (1-\mu^2) \times m \times I_s] / E_s$		$[q_o \times B' \times (1-\mu^2) \times m \times I_s] / E_s$	

Settlement at corner		*Settlement at corner*		*Settlement at corner*	
M = L' / B' =	1.00	M = L' / B' =	1.00	M = L' / B' =	1.000
N = H / B' =	0.126	N = H / B' =	0.710	N = H / B' =	0.557
I_1 =	0.003549	I_1 =	0.087	I_1 =	0.059
I_2 =	0.027989	I_2 =	0.082	I_2 =	0.077
$I_s = I_1 + \{(1-2\mu) / (1-\mu)\} I_2$ =	0.016	$I_s = I_1 + \{(1-2\mu) / (1-\mu)\} I_2$ =	0.125	$I_s = I_1 + \{(1-2\mu) / (1-\mu)\} I_2$ =	0.110
Immediate settlement S_i =	0.054 cm	Immediate settlement S_i =	0.161 cm	Immediate settlement S_i =	0.032 cm

Average S_i for Stratum I=	1.47 mm	Average S_i for Stratum I=	4.00 mm	Average S_i for Stratum IV=	0.80 mm
Total immediate settlement =	6.27 mm	(for all the three layers)			

D) Calculation of Consolidation Settlement:

Strata	From (M)	To (M)	Thickness (M)	Mid depth (M)	Δ P (kg/sqcm)	m_{vc}, sqcm/kg	G	S_c (cm)
Layer - I	4.00	4.32	0.32	0.16	2.26	0.0130	0.70	0.65
	4.32	4.63	0.32	0.47	2.00	0.0130	0.70	0.58
Layer - I	4.63	6.63	2.00	1.63	1.36	0.0056	0.60	0.92
	6.63	8.63	2.00	3.63	0.81	0.0056	0.60	0.54
Hence, Total Consolidation Settlement =								26.81 mm

So, Total Settlement =	33.07 mm
Foxe's Depth correction Factor =	0.77
Corrected total settlement =	**25.44 mm**

So, use a net allowable bearing capacity of 24t/sqm for depth of foundation of 4.0m below FGL with a limiting settlement of 25mm.

Foundation around Power House, TG, Compressor Building Area, Depth of foundation = 5m below FGL (FGL= 218.500M)

The founding level falls inside hard clay layer i.e layer I.
Design N = 22, corresponding cohesion from N value = 1.02 kg/sqcm & Φ = 0°
From laboratory TRSH-UU test results, C = 0.90 kg/sqcm
Thus average C = 0.96 kg/sqcm & Φ = 0°
Hence use C = 0.95 kg/sqcm & Φ = 0°
Assume size of foundation = 5m x 5m

Cohesion, C = 9.50 t/sqm
Using ϕ = 0 degree, the bearing capacity factors are:
N_c = 5.14; N_q = 1.00 & N_γ = 0.00
Use,
Depth of Foundation = D_f = 5 M (below FGL)
Size of Foundation = B = 5 M Square
Overburden Pressure = q =5.000 (Depth) x 0.90 (Submerged density) = 4.50 t/sqm (assuming water table is flushing with the ground)
The Shape factors are [IS:6403 - 1981]
S_c = 1.30 S_q = 1.20 S_γ = 0.80
The Depth factors are [IS:6403 - 1981]
D_c = 1.20 D_q = 1.00 D_γ = 1.00
Computed Net Ultimate Bearing Capacity = 77.14 t/sqm
Using a factor of safety of 2.5, Net Safe Bearing Capacity = 30.86 t/sqm

The above bearing capacity should be checked against settlement criteria. This is shown below.

Determination of Deformation Parameters

Stratum I (Upto 5.50m)

Total soil modulus, E_s = 4.4 x N = 96.80 kg/sqcm
Undrained Young's modulus, E_u = K x C = 400 x 0.95 = 380 kg/sqcm
Again, $1/E_s = 1/E_u + 1/E_d$ giving drained young's modulus, E_d = 129.89 kg/sqcm
Now, we have, $E_d = E_u/3$ = 126.67 kg/sqcm
Considering the above, let us use E_d = 125 kg/sqcm
From E_d, $m_{vc} = 1/G.E_d$ =0.0123 sqcm/kg [Geological Factor, G = 0.65 & μ = 0.35]
Again from SPT "N", m_{vc} = 1/5N = 0.0091 sqcm/kg
Now, let us consider the m_{vc} value for the pressure range between 0.50 to 2.00 kg/sqcm

Sample No.	0.50 – 1.00kg/sqcm	1.00 - 2.00kg/sqcm
BH-14/UDS-02	0.0093	0.0121
BH-20/UDS-01	0.0115	0.0119
Weighted average m_{vc} over the pressure range	**0.0115**	

Giving more weightage to the laboratory test results,
Use m_{vc} = [2 x 0.0115 + 1 x 0.0123 + 1 x 0.0091]/4 = 0.0111 sqcm/kg

Stratum I (from 5.50m to 7.50m)

Use C = 2.00 kg/sqcm
Total soil modulus, E_s = 4.4 x N = 440 kg/sqcm
Undrained Young's modulus, E_u = K x C = 500 x 2.0 = 1000 kg/sqcm
Again, $1/E_s = 1/E_u + 1/E_d$ giving drained young's modulus, E_d = 785.71 kg/sqcm
Now, we have, $E_d = E_u/3$ = 333.33 kg/sqcm
Considering the above, let us use E_d = 550 kg/sqcm
From E_d, $m_{vc} = 1/G.E_d$ =0.0036 sqcm/kg [Geological Factor, G = 0.50 & μ = 0.35]
Again from SPT "N", m_{vc} = 1/5N = 0.0020 sqcm/kg
Thus average m_{vc} = (0.0036+0.0020)/2 = 0.0028 sqcm/kg

Stratum IV

Use Young's modulus for layer IV = 2000 kg/sqcm

SETTLEMENT CALCULATION

Settlement Analysis

A) General Data:

Width of foundation =	5.0	m
Length of foundation =	5.0	m
Depth of foundation =	5.0	m
Net Base Pressure =	3.0	kg/sqcm

B) Subsoil Properties:

Layer - I			**Layer - I**			**Layer - IV**		
Young's Modulus =	380	kg/sqcm	Young's Modulus =	1000	kg/sqcm	Young's Modulus =	2000	kg/sqcm
Poisson Ratio, μ =	0.35		Poisson Ratio, μ =	0.35		Poisson Ratio, μ =	0.25	
Top of Stratum =	5.00	m	Top of Stratum =	5.96	m	Top of Stratum =	7.964	m
End of Stratum =	5.964	m	End of Stratum =	7.964	m	End of Stratum =	15	m
Geological factor, G =	0.65		Geological factor, G =	0.50		Geological factor, G =	1	
m_{vc} =	0.0111	sqcm/kg	m_{vc} =	0.0028	sqcm/kg	m_{vc} =	0.0000	sqcm/kg

C) Calculation of Immediate Settlement:

Settlement at center		*Settlement at center*		*Settlement at center*	
M = L' / B' =	1.000	M = L' / B' =	1.000	M = L' / B' =	1.000
N = H / B' =	0.386	N = H / B' =	0.671	N = H / B' =	1.767
I_1 =	0.031	I_1 =	0.080	I_1 =	0.259
I_2 =	0.065	I_2 =	0.081	I_2 =	0.069
$I_s = I_1 + \{(1-2\mu) / (1-\mu)\} I_2$ =	0.061	$I_s = I_1 + \{(1-2\mu) / (1-\mu)\} I_2$ =	0.117	$I_s = I_1 + \{(1-2\mu) / (1-\mu)\} I_2$ =	0.305
Immediate settlement S_i =	0.420 cm	Immediate settlement S_i =	0.258 cm	Immediate settlement S_i =	0.269 cm
$[q_o \times B' \times (1-\mu^2) \times m \times I_s] / E_s$		$[q_o \times B' \times (1-\mu^2) \times m \times I_s] / E_s$		$[q_o \times B' \times (1-\mu^2) \times m \times I_s] / E_s$	

Settlement at corner		*Settlement at corner*		*Settlement at corner*	
M = L' / B' =	1.00	M = L' / B' =	1.00	M = L' / B' =	1.000
N = H / B' =	0.193	N = H / B' =	0.335	N = H / B' =	0.883
I_1 =	0.008177	I_1 =	0.024	I_1 =	0.120
I_2 =	0.039960	I_2 =	0.060	I_2 =	0.084
$I_s = I_1 + \{(1-2\mu) / (1-\mu)\} I_2$ =	0.027	$I_s = I_1 + \{(1-2\mu) / (1-\mu)\} I_2$ =	0.051	$I_s = I_1 + \{(1-2\mu) / (1-\mu)\} I_2$ =	0.176
Immediate settlement S_i =	0.092 cm	Immediate settlement S_i =	0.056 cm	Immediate settlement S_i =	0.078 cm

Average S_i for Stratum I=	2.56 mm	Average S_i for Stratum I=	1.57 mm	Average S_i for Stratum IV=	1.73 mm
Total immediate settlement =	5.87 mm	(for all the three layers)			

D) Calculation of Consolidation Settlement:

Strata	From (M)	To (M)	Thickness (M)	Mid depth (M)	Δ P (kg/sqcm)	m_{vc}, sqcm/kg	G	S_c (cm)
Layer - I	5.00	5.48	0.48	0.24	2.73	0.0111	0.65	0.95
	5.48	5.96	0.48	0.72	2.29	0.0111	0.65	0.80
Layer - I	5.96	6.96	1.00	1.46	1.79	0.0028	0.50	0.25
	6.96	7.96	1.00	2.46	1.35	0.0028	0.50	0.19

Hence, Total Consolidation Settlement = 21.86 mm

So, Total Settlement = 27.73 mm
Foxe's Depth correction Factor = 0.73
Corrected total settlement = 20.14 mm

So, use a net allowable bearing capacity of 30t/sqm for depth of foundation of 5.0m below FGL with a limiting settlement of 25mm.

Foundation around Transformer Yard Area, Depth of foundation = 2m below FGL (FGL= 218.500M)

The founding level falls inside stiff clay layer i.e layer IA.
Design N = 12, corresponding cohesion from N value = 0.74 kg/sqcm & Φ = 0°
From laboratory TRSH-UU test results, C = 0.66 kg/sqcm & Φ = 6°
Thus average C = 0.70 kg/sqcm & Φ = 3°
Hence use C = 0.70 kg/sqcm & Φ = 0°
Assume size of foundation = 5m x 5m

Cohesion, C = 7.00 t/sqm
Using ϕ = 0 degree, the bearing capacity factors are:
N_c = 5.14
N_q = 1.00
N_γ = 0.00
Use,
Depth of Foundation = D_f = 2 M (below FGL)
Size of Foundation = B = 5 M Square
Overburden Pressure = q =2.000 (Depth) x 0.90 (Submerged density) = 1.80 t/sqm (assuming water table is flushing with the ground)
The Shape factors are [IS:6403 - 1981]
S_c = 1.30 S_q = 1.20 S_γ = 0.80
The Depth factors are [IS:6403 - 1981]
D_c = 1.08 D_q = 1.00 D_γ = 1.00
Computed Net Ultimate Bearing Capacity = 50.92 t/sqm
Using a factor of safety of 2.5, Net Safe Bearing Capacity = 20.37 t/sqm

The above bearing capacity should be checked against settlement criteria. This is shown below.

Determination of Deformation Parameters

Stratum IA

Total soil modulus, E_s = 4.4 x N = 52.80 kg/sqcm
Undrained Young's modulus, E_u = K x C = 350 x 0.70 = 245 kg/sqcm
Again, $1/E_s = 1/E_u + 1/E_d$ giving drained young's modulus, E_d = 67.30 kg/sqcm
Now, we have, $E_d = E_u/3$ = 81.67 kg/sqcm
Considering the above, let us use E_d = 70 kg/sqcm
From E_d, $m_{vc} = 1/G.E_d$ =0.0190 sqcm/kg [Geological Factor, G = 0.75 & μ = 0.35]
Again from SPT "N", m_{vc} = 1/5N = 0.0167 sqcm/kg
Now, let us consider the m_{vc} value for the pressure range between 0.25 to 1.00 kg/sqcm

Sample No.	0.25 – 0.50kg/sqcm	0.50 - 1.00kg/sqcm
BH-17/UDS-01	0.0100	0.0052
Weighted average m_{vc} over the pressure range	**0.0068**	

Giving more weightage to the laboratory test results,
Use m_{vc} = [2 x 0.0068 + 1 x 0.0190 + 1 x 0.0167]/4 = 0.0123 sqcm/kg

Stratum I

Average N = 54, corresponding cohesion from N value = 2.00 kg/sqcm
Use C = 1.50 kg/sqcm & Φ = 0°
Total soil modulus, E_s = 4.4 x N = 237.60 kg/sqcm
Undrained Young's modulus, E_u = K x C = 500 x 1.50 = 750 kg/sqcm
Again, $1/E_s = 1/E_u + 1/E_d$ giving drained young's modulus, E_d = 347.78 kg/sqcm
Now, we have, $E_d = E_u/3$ = 250 kg/sqcm
Considering the above, let us use E_d = 295 kg/sqcm
From E_d, $m_{vc} = 1/G.E_d$ =0.0062 sqcm/kg [Geological Factor, G = 0.55 & μ = 0.35]
Again from SPT "N", m_{vc} = 1/5N = 0.0037 sqcm/kg
Thus average m_{vc} = (0.0062+0.0037)/2 = 0.0049 sqcm/kg

Stratum II

The Average field "N" = 55
After correction for Overburden Pressure and Dilatancy, Final Corrected "N" = 36
Treating the sand to be normally consolidated sand, $E_s = 5(N+15) = 255$ kg/sqcm
Treating the sand to be over consolidated sand, $E_s = 400 + 10.5N = 778.00$ kg/sqcm
Thus average $E_s = 517$ kg/sqcm
Considering the above, use $E_s = 510$ kg/sqcm

Stratum IV

Use Young's modulus for layer IV = 2000 kg/sqcm

SETTLEMENT CALCULATION

Settlement Analysis

A) General Data:

Width of foundation =	5.0	m
Length of foundation =	5.0	m
Depth of foundation =	2.0	m
Net Base Pressure =	1.8	kg/sqcm

B) Subsoil Properties:

Layer - IA

Young's Modulus =	245	kg/sqcm
Poisson Ratio, μ =	0.35	
Top of Stratum =	2.00	m
End of Stratum =	3.077	m
Geological factor, G =	0.75	
m_{vc} =	0.0123	sqcm/kg

Layer - I

Young's Modulus =	750	kg/sqcm
Poisson Ratio, μ =	0.35	
Top of Stratum =	3.077	m
End of Stratum =	7.077	m
Geological factor, G =	0.55	
m_{vc} =	0.0049	sqcm/kg

C) Calculation of Immediate Settlement:

Settlement at center

M = L' / B' =	1.000		
N = H / B' =	0.431		
I_1 =	0.037		
I_2 =	0.069		
$I_s = I_1 + \{(1-2\mu) / (1-\mu)\} I_2$ =		0.069	
Immediate settlement S_i =		0.446	cm

$[q_o \times B' \times (1-\mu^2) \times m \times I_s] / E_s$

Settlement at center

M = L' / B' =	1.000		
N = H / B' =	1.316		
I_1 =	0.196		
I_2 =	0.078		
$I_s = I_1 + \{(1-2\mu) / (1-\mu)\} I_2$ =		0.2325	
Immediate settlement S_i =		0.4029	cm

$[q_o \times B' \times (1-\mu^2) \times m \times I_s] / E_s$

Settlement at corner

M = L' / B' =	1.00		
N = H / B' =	0.215		
I_1 =	0.010150		
I_2 =	0.043603		
$I_s = I_1 + \{(1-2\mu) / (1-\mu)\} I_2$ =		0.030	
Immediate settlement S_i =		0.098	cm

Average S_i for Stratum IA= 2.72 mm

Settlement at corner

M = L' / B' =	1.00		
N = H / B' =	0.658		
I_1 =	0.077		
I_2 =	0.081		
$I_s = I_1 + \{(1-2\mu) / (1-\mu)\} I_2$ =		0.1146	
Immediate settlement S_i =		0.0993	cm

Average S_i for Stratum I= 2.511 mm

Layer - II

Young's Modulus =	510	kg/sqcm
Poisson Ratio, μ =	0.25	
Top of Stratum =	7.077	m
End of Stratum =	7.377	m
Geological factor, G =	1	
m_{vc} =	0.0000	sqcm/kg

Settlement at center

M = L' / B' =	1.000	
N = H / B' =	0.060	
I_1 =	0.001	
I_2 =	0.014	
$I_s = I_1 + \{(1-2\mu) / (1-\mu)\} I_2$ =	0.010	
Immediate settlement S_i =	0.017	cm

$[q_o \times B' \times (1- \mu^2) \times m \times I_s] / E_s$

Settlement at corner

M = L' / B' =	1.000	
N = H / B' =	0.030	
I_1 =	0.000	
I_2 =	0.007	
$I_s = I_1 + \{(1-2\mu) / (1-\mu)\} I_2$ =	0.005	
Immediate settlement S_i =	0.004	cm

Average S_i for Stratum II= 0.10 mm

Total immediate settlement = 5.78 mm

Layer - IV

Young's Modulus =	2000	kg/sqcm
Poisson Ratio, μ =	0.25	
Top of Stratum =	7.377	m
End of Stratum =	12	m
Geological factor, G =	1	
m_{vc} =	0.0000	sqcm/kg

Settlement at center

M = L' / B' =	1.000	
N = H / B' =	0.891	
I_1 =	0.122	
I_2 =	0.084	
$I_s = I_1 + \{(1-2\mu) / (1-\mu)\} I_2$ =	0.177	
Immediate settlement S_i =	0.072	cm

$[q_o \times B' \times (1- \mu^2) \times m \times I_s] / E_s$

Settlement at corner

M = L' / B' =	1.000	
N = H / B' =	0.446	
I_1 =	0.040	
I_2 =	0.070	
$I_s = I_1 + \{(1-2\mu) / (1-\mu)\} I_2$ =	0.086	
Immediate settlement S_i =	0.018	cm

Average S_i for Stratum IV= 0.45 mm

(for all the four layers)

D) Calculation of Consolidation Settlement:

Strata	From (M)	To (M)	Thickness (M)	Mid depth (M)	Δ P (kg/sqcm)	m_{vc}, sqcm/kg	G	S_c (cm)
Layer - IA	2.00	2.54	0.54	0.27	1.62	0.0123	0.75	0.81
	2.54	3.08	0.54	0.81	1.33	0.0123	0.75	0.66
Layer - I	3.08	5.08	2.00	2.08	0.90	0.0049	0.55	0.48
	5.08	7.08	2.00	4.08	0.55	0.0049	0.55	0.29

Hence, Total Consolidation Settlement = 22.47 mm

So, Total Settlement = 28.25 mm

Foxe's Depth correction Factor = 0.89

Corrected total settlement = 25.11 mm

So, use a net allowable bearing capacity of 18t/sqm for depth of foundation of 2.0m below FGL with a limiting settlement of 25mm.

Foundation around Switch Yard Area, Depth of foundation = 3m below FGL (FGL= 218.500M)

The founding level falls inside medium clay layer i.e layer IB.
Design N = 6, corresponding cohesion from N value = 0.50 kg/sqcm & Φ = 0°
Hence use C = 0.50 kg/sqcm & Φ = 0°
Assume size of foundation = 6m x 6m

Cohesion, C = 5.00 t/sqm
Using $\phi = 0$ degree, the bearing capacity factors are:
$N_c = 5.14$
$N_q = 1.00$
$N_\gamma = 0.00$
Use,
Depth of Foundation = D_f = 3 M (below FGL)
Size of Foundation = B = 6 M Square
Overburden Pressure = q =3.000 (Depth) x 0.90 (Submerged density) = 2.70 t/sqm (assuming water table is flushing with the ground)
The Shape factors are [IS:6403 - 1981]
$S_c = 1.30$ $S_q = 1.20$ $S_\gamma = 0.80$
The Depth factors are [IS:6403 - 1981]
$D_c = 1.10$ $D_q = 1.00$ $D_\gamma = 1.00$
Computed Net Ultimate Bearing Capacity = 37.32 t/sqm
Using a factor of safety of 2.5, Net Safe Bearing Capacity = 14.93 t/sqm

The above bearing capacity should be checked against settlement criteria. This is shown below.

Determination of Deformation Parameters

Stratum IB

Total soil modulus, $E_s = 4.4 \times N = 26.40$ kg/sqcm
Undrained Young's modulus, $E_u = K \times C = 350 \times 0.50 = 175$ kg/sqcm
Again, $1/E_s = 1/E_u + 1/E_d$ giving drained young's modulus, $E_d = 31.09$ kg/sqcm
Now, we have, $E_d = E_u/3 = 58.33$ kg/sqcm
Considering the above, let us use $E_d = 40$ kg/sqcm
From E_d, $m_{vc} = 1/G.E_d = 0.0294$ sqcm/kg [Geological Factor, G = 0.85 & μ = 0.35]
Again from SPT "N", $m_{vc} = 1/5N = 0.0333$ sqcm/kg
Now, let us consider the m_{vc} value for the pressure range between 0.25 to 1.00 kg/sqcm

Sample No.	0.25 – 0.50kg/sqcm	0.50 - 1.00kg/sqcm
BH-19/UDS-01	0.0116	0.0129
Weighted average m_{vc} over the pressure range	**0.0125**	

Giving more weightage to the laboratory test results,
Use $m_{vc} = [2 \times 0.0125 + 1 \times 0.0294 + 1 \times 0.0333]/4 = 0.0219$ sqcm/kg

Stratum I

Design N = 31, corresponding cohesion from N value = 1.19 kg/sqcm
Use C = 1.05 kg/sqcm & Φ = 0°
Total soil modulus, $E_s = 4.4 \times N = 136.40$ kg/sqcm
Undrained Young's modulus, $E_u = K \times C = 500 \times 1.05 = 525$ kg/sqcm
Again, $1/E_s = 1/E_u + 1/E_d$ giving drained young's modulus, $E_d = 184.28$ kg/sqcm
Now, we have, $E_d = E_u/3 = 175$ kg/sqcm
Considering the above, let us use $E_d = 175$ kg/sqcm
From E_d, $m_{vc} = 1/G.E_d = 0.0095$ sqcm/kg [Geological Factor, G = 0.60 & μ = 0.35]
Again from SPT "N", $m_{vc} = 1/5N = 0.0065$ sqcm/kg
Thus average $m_{vc} = (0.0095+0.0065)/2 = 0.0080$ sqcm/kg

Stratum II

The Average field "N" = 100
After correction for Overburden Pressure and Dilatancy, Final Corrected "N" = 62
Treating the sand to be over consolidated sand, E_s = 400 + 10.5N = 1051.00 kg/sqcm
However, let us restrict the E_s value to 750 kg/sqcm

Stratum IV

Use Young's modulus for layer IV = 2000 kg/sqcm

SETTLEMENT CALCULATION

Settlement Analysis

A) General Data:

Width of foundation =	6.0	m
Length of foundation =	6.0	m
Depth of foundation =	3.0	m
Net Base Pressure =	1.4	kg/sqcm

B) Subsoil Properties:

Layer - IB			**Layer - I**		
Young's Modulus =	175	kg/sqcm	Young's Modulus =	525	kg/sqcm
Poisson Ratio, μ =	0.35		Poisson Ratio, μ =	0.35	
Top of Stratum =	3.00	m	Top of Stratum =	3.46	m
End of Stratum =	3.46	m	End of Stratum =	6.00	m
Geological factor, G =	0.70		Geological factor, G =	0.60	
m_{vc} =	0.0219	sqcm/kg	m_{vc} =	0.0080	sqcm/kg

C) Calculation of Immediate Settlement:

Settlement at center

M = L' / B' =	1.000		M = L' / B' =	1.000	
N = H / B' =	0.155		N = H / B' =	0.785	
I_1 =	0.005		I_1 =	0.101	
I_2 =	0.033		I_2 =	0.083	
$I_s = I_1 + \{(1-2\mu) / (1-\mu)\} I_2$ =		0.021	$I_s = I_1 + \{(1-2\mu) / (1-\mu)\} I_2$ =		0.1398
Immediate settlement S_i =		0.174 cm	Immediate settlement S_i =		0.3643 cm
$[q_o \times B' \times (1-\mu^2) \times m \times I_s] / E_s$			$[q_o \times B' \times (1-\mu^2) \times m \times I_s] / E_s$		

Settlement at corner

M = L' / B' =	1.00		M = L' / B' =	1.00	
N = H / B' =	0.077		N = H / B' =	0.392	
I_1 =	0.001341		I_1 =	0.032	
I_2 =	0.017991		I_2 =	0.065	
$I_s = I_1 + \{(1-2\mu) / (1-\mu)\} I_2$ =		0.010	$I_s = I_1 + \{(1-2\mu) / (1-\mu)\} I_2$ =		0.0619
Immediate settlement S_i =		0.041 cm	Immediate settlement S_i =		0.0806 cm

Average S_i for Stratum IB= 1.07 mm

Average S_i for Stratum I= 2.224 mm

Layer - II

Young's Modulus =	750	kg/sqcm
Poisson Ratio, μ =	0.25	
Top of Stratum =	6.00	m
End of Stratum =	7	m
Geological factor, G =	1	
m_{vc} =	0.0000	sqcm/kg

Settlement at center

M = L' / B' =	1.000	
N = H / B' =	0.222	
I_1 =	0.011	
I_2 =	0.045	
$I_s = I_1 + \{(1-2\mu) / (1-\mu)\} I_2$ =	0.041	
Immediate settlement S_i = $[q_o \times B' \times (1-\mu^2) \times m \times I_s] / E_s$	0.057	cm

Settlement at corner

M = L' / B' =	1.000	
N = H / B' =	0.111	
I_1 =	0.003	
I_2 =	0.025	
$I_s = I_1 + \{(1-2\mu) / (1-\mu)\} I_2$ =	0.019	
Immediate settlement S_i =	0.014	cm

Average S_i for Stratum II= 0.35 mm

Total immediate settlement = 4.52 mm

Layer - IV

Young's Modulus =	2000	kg/sqcm
Poisson Ratio, μ =	0.25	
Top of Stratum =	7	m
End of Stratum =	15	m
Geological factor, G =	1	
m_{vc} =	0.0000	sqcm/kg

Settlement at center

M = L' / B' =	1.000	
N = H / B' =	1.600	
I_1 =	0.238	
I_2 =	0.073	
$I_s = I_1 + \{(1-2\mu) / (1-\mu)\} I_2$ =	0.286	
Immediate settlement S_i = $[q_o \times B' \times (1-\mu^2) \times m \times I_s] / E_s$	0.135	cm

Settlement at corner

M = L' / B' =	1.000	
N = H / B' =	0.800	
I_1 =	0.104	
I_2 =	0.083	
$I_s = I_1 + \{(1-2\mu) / (1-\mu)\} I_2$ =	0.160	
Immediate settlement S_i =	0.038	cm

Average S_i for Stratum IV= 0.86 mm

(for all the four layers)

D) Calculation of Consolidation Settlement:

Strata	From (M)	To (M)	Thickness (M)	Mid depth (M)	Δ P (kg/sqcm)	m_{vc}, sqcm/kg	G	S_c (cm)
Layer - IB	3.00	3.23	0.23	0.12	1.35	0.0219	0.70	0.48
	3.23	3.46	0.23	0.35	1.25	0.0219	0.70	0.44
Layer - I	3.46	4.73	1.27	1.10	1.00	0.0080	0.60	0.61
	4.73	6.00	1.27	2.37	0.72	0.0080	0.60	0.44
Hence, Total Consolidation Settlement =								19.71 mm

So, Total Settlement = 24.23 mm

Foxe's Depth correction Factor = 0.85

Applying Rigidity correction Factor = 0.80

Corrected total settlement = 16.48 mm

So, use a net allowable bearing capacity of 14t/sqm for depth of foundation of 3.0m below FGL with a limiting settlement of 40mm.

Foundation around Cooling Tower Area, Depth of foundation = 4m below FGL (FGL= 216.000M)

The founding level falls inside very stiff clay layer i.e layer I.
Average N = 24, corresponding cohesion from N value = 1.06 kg/sqcm & Φ = 0°
Hence use C = 1.00 kg/sqcm & Φ = 0°
Assume size of foundation = 5m x 5m

Cohesion, C = 10.00 t/sqm
Using $\phi = 0$ degree, the bearing capacity factors are:
$N_c = 5.14$; $N_q = 1.00$ & $N_\gamma = 0.00$
Use,
Depth of Foundation = D_f = 4 M (below FGL)
Size of Foundation = B = 5 M Square
Overburden Pressure = q =4.000 (Depth) x 0.90 (Submerged density) = 3.60 t/sqm (assuming water table is flushing with the ground)
The Shape factors are [IS:6403 - 1981]
$S_c = 1.30$ $S_q = 1.20$ $S_\gamma = 0.80$
The Depth factors are [IS:6403 - 1981]
$D_c = 1.16$ $D_q = 1.00$ $D_\gamma = 1.00$
Computed Net Ultimate Bearing Capacity = 78.30 t/sqm
Using a factor of safety of 2.5, Net Safe Bearing Capacity = 31.32 t/sqm

The above bearing capacity should be checked against settlement criteria. This is shown below.

Determination of Deformation Parameters

Stratum I (upto 4.00m)

Total soil modulus, $E_s = 4.4 \times N = 105.60$ kg/sqcm
Undrained Young's modulus, $E_u = K \times C = 500 \times 1.00 = 500$ kg/sqcm
Again, $1/E_s = 1/E_u + 1/E_d$ giving drained young's modulus, $E_d = 133.87$ kg/sqcm
Now, we have, $E_d = E_u/3 = 166.67$ kg/sqcm
Considering the above, let us use $E_d = 150$ kg/sqcm
From E_d, $m_{vc} = 1/G.E_d = 0.0111$ sqcm/kg [Geological Factor, G = 0.60 & μ = 0.35]
Again from SPT "N", $m_{vc} = 1/5N = 0.0083$ sqcm/kg
Now, let us consider the m_{vc} value for the pressure range between 0.25 to 1.00 kg/sqcm

Sample No.	0.25 – 0.50kg/sqcm	0.50 - 1.00kg/sqcm
BH-44/UDS-01	0.0200	0.0225
Weighted average m_{vc} over the pressure range	**0.0217**	

Giving more weightage to the laboratory test results,
Use $m_{vc} = [2 \times 0.0217 + 1 \times 0.0111 + 1 \times 0.0083]/4 = 0.157$ sqcm/kg

Stratum I (4.00m to 5.75m)

Use C = 2.00 kg/sqcm & Φ = 0°
Total soil modulus, $E_s = 4.4 \times N = 440$ kg/sqcm
Undrained Young's modulus, $E_u = K \times C = 500 \times 2.0 = 1000$ kg/sqcm
Again, $1/E_s = 1/E_u + 1/E_d$ giving drained young's modulus, $E_d = 785.71$ kg/sqcm
Now, we have, $E_d = E_u/3 = 333.33$ kg/sqcm
Considering the above, let us use $E_d = 550$ kg/sqcm
From E_d, $m_{vc} = 1/G.E_d = 0.0036$ sqcm/kg [Geological Factor, G = 0.50 & μ = 0.35]
Again from SPT "N", $m_{vc} = 1/5N = 0.0020$ sqcm/kg
Thus average $m_{vc} = (0.0036+0.0020)/2 = 0.0028$ sqcm/kg

Stratum III & IV

Use Young's modulus for layer III & IV = 1000 kg/sqcm & 2000 kg/sqcm respectively

SETTLEMENT CALCULATION

Settlement Analysis

A) General Data:

Width of foundation =	5.0	m
Length of foundation =	5.0	m
Depth of foundation =	4.0	m
Net Base Pressure =	3.0	kg/sqcm

B) Subsoil Properties:

Layer - I

Young's Modulus =	500	kg/sqcm
Poisson Ratio, μ =	0.35	
Top of Stratum =	4.00	m
End of Stratum =	4.26	m
Geological factor, G =	0.60	
m_{vc} =	0.0157	sqcm/kg

Layer - I

Young's Modulus =	1000	kg/sqcm
Poisson Ratio, μ =	0.35	
Top of Stratum =	4.26	m
End of Stratum =	6.01	m
Geological factor, G =	0.50	
m_{vc} =	0.0028	sqcm/kg

C) Calculation of Immediate Settlement:

Settlement at center

M = L' / B' =	1.000	
N = H / B' =	0.103	
I_1 =	0.002	
I_2 =	0.023	
$I_s = I_1 + \{(1-2\mu) / (1-\mu)\} I_2$ =	0.013	
Immediate settlement S_i =	0.069	cm

$[q_o \times B' \times (1-\mu^2) \times m \times I_s] / E_s$

Settlement at corner

M = L' / B' =	1.00	
N = H / B' =	0.051	
I_1 =	0.000594	
I_2 =	0.012256	
$I_s = I_1 + \{(1-2\mu) / (1-\mu)\} I_2$ =	0.006	
Immediate settlement S_i =	0.016	cm

Average S_i for Stratum I= 0.43 mm

Settlement at center

M = L' / B' =	1.000	
N = H / B' =	0.666	
I_1 =	0.079	
I_2 =	0.081	
$I_s = I_1 + \{(1-2\mu) / (1-\mu)\} I_2$ =	0.1161	
Immediate settlement S_i =	0.2908	cm

$[q_o \times B' \times (1-\mu^2) \times m \times I_s] / E_s$

Settlement at corner

M = L' / B' =	1.00	
N = H / B' =	0.333	
I_1 =	0.023	
I_2 =	0.059	
$I_s = I_1 + \{(1-2\mu) / (1-\mu)\} I_2$ =	0.0507	
Immediate settlement S_i =	0.0635	cm

Average S_i for Stratum I= 1.771 mm

Layer - III

Young's Modulus =	1000	kg/sqcm
Poisson Ratio, μ =	0.25	
Top of Stratum =	6.01	m
End of Stratum =	8.257	m
Geological factor, G =	1	
m_{vc} =	0.0000	sqcm/kg

Settlement at center

M = L' / B' =	1.000	
N = H / B' =	0.642	
I_1 =	0.074	
I_2 =	0.080	
$I_s = I_1 + \{(1-2\mu) / (1-\mu)\} I_2$ =	0.128	
Immediate settlement S_i =	0.257	cm
$[q_o \times B' \times (1-\mu^2) \times m \times I_s] / E_s$		

Settlement at corner

M = L' / B' =	1.000	
N = H / B' =	0.321	
I_1 =	0.022	
I_2 =	0.058	
$I_s = I_1 + \{(1-2\mu) / (1-\mu)\} I_2$ =	0.060	
Immediate settlement S_i =	0.061	cm

Average S_i for Stratum III= 1.59 mm

Total immediate settlement = 4.92 mm

Layer - IV

Young's Modulus =	2000	kg/sqcm
Poisson Ratio, μ =	0.25	
Top of Stratum =	8.257	m
End of Stratum =	14	m
Geological factor, G =	1	
m_{vc} =	0.0000	sqcm/kg

Settlement at center

M = L' / B' =	1.000	
N = H / B' =	1.241	
I_1 =	0.184	
I_2 =	0.080	
$I_s = I_1 + \{(1-2\mu) / (1-\mu)\} I_2$ =	0.237	
Immediate settlement S_i =	0.180	cm
$[q_o \times B' \times (1-\mu^2) \times m \times I_s] / E_s$		

Settlement at corner

M = L' / B' =	1.000	
N = H / B' =	0.620	
I_1 =	0.070	
I_2 =	0.080	
$I_s = I_1 + \{(1-2\mu) / (1-\mu)\} I_2$ =	0.123	
Immediate settlement S_i =	0.047	cm

Average S_i for Stratum IV= 1.14 mm

(for all the four layers)

D) Calculation of Consolidation Settlement:

Strata	From (M)	To (M)	Thickness (M)	Mid depth (M)	Δ P (kg/sqcm)	m_{vc}, sqcm/kg	G	S_c (cm)
Layer - I	4.00	4.13	0.13	0.06	2.92	0.0157	0.60	0.35
	4.13	4.26	0.13	0.19	2.78	0.0157	0.60	0.34
Layer - I	4.26	5.13	0.88	0.69	2.31	0.0028	0.50	0.28
	5.13	6.01	0.88	1.57	1.74	0.0028	0.50	0.21
Hence, Total Consolidation Settlement =								11.87 mm

So, Total Settlement = 16.79 mm

Foxe's Depth correction Factor = 0.77

Corrected total settlement = 12.92 mm

So, use a net allowable bearing capacity of 30t/sqm for depth of foundation of 4.0m below FGL with a limiting settlement of 25mm.

LIST OF REFERENCES

List of References

1) Relation between Total Soil Modulus, E_s & N

Ref. to “History of Soil penetration testing” by B. B. Broms & N. Flodin in “Penetration Testing 1988”, ISPOT-1: vol.1, p – 185

2) Relation between Undrained Young’s Modulus, E_u, K & C

Quoting Bowles (1987), the conventional laboratory test like UC or UU produces a low value of soil modulus. Only CK_0U will produce a reasonable value of E_s. The most common method is to use the relation with SPT for cohesion less soils and with cohesion (shear strength) for cohesive soils. Considering this and being in the conservative side we use, E_u = 500 x C, for C value = 2.00kg/sqcm.

C	K
<0.25	250
0.25 - <0.50	300
0.50 - <0.75	350
0.75 - <1.00	400
≥1.00	500

3) Relation between E_d & E_u

Refer to “Cone Penetration Testing" by A.C.Meigh, pp. No. – 53

4) Geological Factor, G

The geological Factor, G is nothing but Consolidation Settlement Reduction Factor, λ. as per IS: 8009 (Part I) – 1976, Table 1 and taken as 0.50

5) Poission Ratio, μ

Ref. to “Foundation Analysis and Design by Joseph E. Bowles, 5th Edition” P – 123, Table 2-7

6) Relation between m_{vc} & N

Refer to “Standard Penetration Test, State-of-the-art-Report” by Ivan K. Nixon in Penetration testing 1” Edited by A.Verrujt, F.L.beringen & E.H.De Leeuw, pp. No. 11

Relation between SPT "N" & E_s

Penetration Testing 1988, ISOPT-1, De Ruiter (ed.)
© 1988 Balkema, Rotterdam, ISBN 90 6191 801 4

History of soil penetration testing

Bengt B.Broms
Nanyang Technological Institute, Singapore
Nils Flodin
Royal Institute of Technology, Stockholm, Sweden

ABSTRACT: The development of dynamic and static penetration testing methods has been reviewed. A large number of different tools are now used for the investigation in-situ of the shear strength and the deformation properties of both soils and rocks as described in the paper.

1 INTRODUCTION

1.1 Penetration Testing Methods

A large number of different static and dynamic penetration tests are used today as described by Sanglerat (1972). The most common are :

- o Standard penetration test (SPT)
- o Cone penetration test (CPT)
- o Weight sounding test (WST)
- o Ram sounding test (DPA and DPB)

European reference standards have been adopted by ISSMFE in 1977 for these methods.

Penetrometers are generally used in Europe during the exploratory phase of a soil investigation to determine the soil conditions in general such as the depth, thickness and lateral extent of the various strata so that an evaluation of different possible foundation methods can be made such as spread footings, rafts, piles or caissons or if it is possible to improve the soil conditions e.g. by preloading, with excavation and replacement, stone columns, pressure berms, lime or cement columns or with embankment piles. In the Scandinavian countries and Finland the weight penetrometer (WST) is common. This method is very fast and inexpensive and a large number of soundings can be carried out within a short time. In Holland, the Dutch Cone Penetrometer (CPT) is used for the same purpose while in U.K., Germany, Spain, Portugal, France, Italy and Greece different types of dynamic penetrometers are often utilized (SPT and DP) because of the limited penetration depth of CPT in dense or hard soils.

Penetration tests are also very valuable during the detailed exploration phase especially in silt, sand and gravel so that the compressibility of the soil in the different strata can be estimated. It is also possible to get an indication of the shear strength so that the ultimate bearing capacity of footings and piles can be assessed. In most cases the settlements will govern the design rather than the ultimate bearing capacity of the soil.

Electrical cone penetrometers and pore pressure probes (piezocones) are mainly used during the detailed exploration phase. These penetrometers are relatively delicate and can easily be damaged by stones or boulders in the soil. The maximum capacity and the maximum depth of the electrical cone penetrometers are limited. It is difficult or not possible in most cases to penetrate very dense or cemented layers. Predrilling or precoring may be required.

1.2 Design Values

Dynamic penetrometers are generally used to estimate the ultimate bearing capacity of piles and of caissons. With CPT or WST it is often not possible to reach the required depth. Therefore Standard penetration tests (SPT) or ram soundings (DPA or DPB) are used.

Design parameters cannot as a rule be determined from the penetration

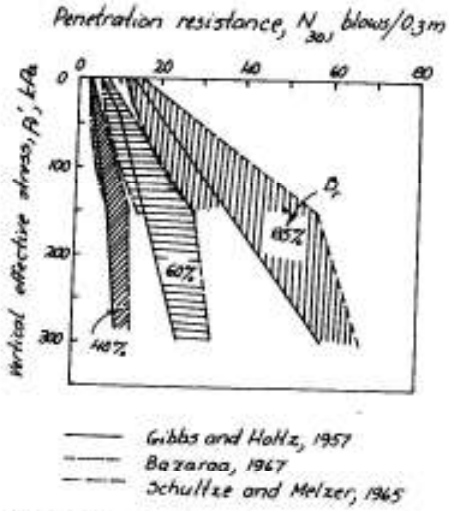


Fig 29 Relationship between N_{30}, P'_{vo} and D_r (after Marcuson and Bieganousky, 1977)

Meyerhof proposed in 1965 that the allowable load as calculated from the equations given above could be increased by 50% without exceeding a maximum settlement of 25 mm.

Meyerhof (1965) suggested also the following relationship between the coefficient of subgrade reaction k_s and N_{30} for a 0.3 m wide plate

$$k_s = q/s = 0.75\ N_{30}\ (MN/m^3) \qquad (6)$$

where q is the applied load (MPa) and s is the settlement (m). The relationship $[B/(B + 0.3)]^2$ has been used by Meyerhof to estimate the settlement of a footing with the width B as proposed by Peck et al (1953). At e.g. $N_{30} = 10$ and q = 0.1 MPa then s = 0.0075 m or 7.5 mm.

Schultze and Menzenbach (1961) found for sands that the compression modulus (M) could be correlated with the penetration resistance N_{30}

$$M = 7.1 + 0.49\ N_{30}\ (MPa) \qquad (7)$$

Stroud and Butler (1975) proposed the relationship

$$M = f\ N_{30}\ (MPa) \qquad (8)$$

The coefficient f was reported to vary between about 0.45 MPa for materials with medium plasticity to about 0.60 MPa at $I_p < 20$. Stroud (1974) proposed a constant value of 0.44 MPa on f.

SPT has also been used to estimate the settlements of footings in sand as well as in overconsolidated clays as summarized by Sutherland (1977).

Simons and Menzies (1977) have suggested for granular soils the following simple relationship

$$s = 3qB/N_{30} \qquad (9)$$

for a footing with the width B.

In USSR (Trofimenkov, 1974) an equivalent modulus of elasticity E_s = (35 to 50) log N_{30} is used to estimate the settlements of footings on sand based on the results from SPT. Parry (1971) proposed the relationship $E_s = 5\ N_{30}$ while Webb (1969) suggested the expression

$$E_s = 0.537\ (N_{30} + 15)\ (MPa) \qquad (10)$$

for saturated fine to medium sand and

$$E_s = 0.358\ (N_{30} + 5)\ (MPa) \qquad (11)$$

for a saturated clayey fine sand.

Correlations have been published for granular soils by e.g. Meyerhof (1956) Peck et al (1974), Muromachi et al (1974), Tassios and Anagnostopolous (1974), Mitchell et al (1978) and by others between the penetration resistance (N_{30}) and the effective angle of internal friction (ϕ'). Muromachi et al, (1974) proposed the following relationship

$$\phi' = 20^\circ + 3.5\ \sqrt{N_{30}} \qquad (12)$$

where N_{30} (blows/0.3 m) is the measured penetration resistance. The accuracy of this equation is reported to be about $\pm 5^\circ$. The correlation with ϕ is in general more consistant than with the relative density (de Mello, 1971).

The relationship proposed by Mitchell et al (1978) is shown in Fig 30. It can be seen that the effective overburden pressure has a large effect on the interpretation of the results. It should be noted that the scatter of the results is relatively large. It is, therefore, often preferrable to evaluate the bearing capacity of e.g. footings and piles directly from the measured penetration resistance (N_{30}) without using the angle of internal friction. The results may otherwise be misleading.

Meyerhof showed in 1956 that SPT can also be used to evaluate the bearing capacity of piles. The undrained shear

Relation between E_u & E_d

CIRIA Ground Engineering Report: In-situ Testing

Cone penetration testing

methods and interpretation

A. C. Meigh, OBE, DSc(Eng), FCGI CEng FICE, MASCE, FGS
Woodward-Clyde Consultants

CIRIA Construction Industry Research and Information Association

Butterworths
London Boston Durban
Singapore Sydney Toronto Wellington

strains of some 0.1 to 0.2% associated with settlements. Simpson *et al.* (1979) suggest, for London Clay:

$$E_u = 1000\, c_{u(lab)}$$

6.4.5 Drained Young's modulus

There are no data available relating drained Young's modulus, E' to q_c from the CPT. In theory, E' can be derived from E_u, using appropriate values of Poisson's ratio, ν, but this is not borne out in practice.

6.4.6 Drained Young's modulus of London Clay

For London Clay, Butler (1975) suggests that the vertical drained Young's modulus can be taken as:

$$E'_v = 130 c_{u(lab)} = 0.325 E_u$$

In terms of undrained shear strength from plate-loading tests, this gives:

$$E'_v = 130\,(1 + 0.04Z)\, c_{u(PLT)}$$

where Z is the depth in metres below the top of the London Clay.
At shallow depth, this is equivalent to a value of

$$\alpha_{E'_v} = E'_v / q_c = 4.8 \pm 0.5$$

6.5 Synopsis: parameters in cohesive soils

6.5.1 Undrained shear strength

(a) Normally-consolidated clays
If reference tip (R) is used:
$N_k^* = 15 \pm 4$ (Figure 22b)

where $q_c = N_k^* s_u^* + \sigma_{vo}$

and s_u^* is vane shear strength with the Bjerrum correction (Figure 21)

Refer to Section 6.2.
Refer to Section 6.2.1.

For very young deposits and recent fills, the average value of N_k^* may be less than 15.

Considerably higher values and wide scatter have been reported for a case of low I_p (< 20%) and very low s_u (< 5 kN/m²).

Some clays of high sensitivity have shown very low N_k^* values.

If mantle cone (M) used:

$N_k = 17.5$ (range: 15 to 21)
(Figure 23a)

where $q_c = N_k s_u + \sigma_{vo}$
and s_u is uncorrected vane shear strength.

Refer to Section 6.2.2.

TABLE 2-7
Values or value ranges for Poisson's ratio μ

Type of soil	μ
Clay, saturated	0.4–0.5
Clay, unsaturated	0.1–0.3
Sandy clay	0.2–0.3
Silt	0.3–0.35
Sand, gravelly sand	−0.1–1.00
commonly used	0.3–0.4
Rock	0.1–0.4 (depends somewhat on type of rock)
Loess	0.1–0.3
Ice	0.36
Concrete	0.15
Steel	0.33

Another material property concept is the *bulk modulus* E_b, which is defined as the ratio of hydrostatic stress to the volumetric strain ϵ_v and is given as

$$E_b = \frac{2}{3}G' \frac{1+\mu}{1-2\mu} = \frac{E_s}{3(1-2\mu)} \qquad (f)$$

For an *elastic* material the shear modulus G' cannot be (−), so Eq. (*a*) sets the lower limit of $\mu > -1$. Equation (*f*) sets the upper limit at $\mu < 0.5$. It appears that the range of μ for soils (that are not "elastic") is from about −0.1 to 1.00. Table 2-7 gives a range of values for select materials. It is very common to use the following values for soils:

μ	Soil type
0.4–0.5	Most clay soils
0.45–0.50	Saturated clay soils
0.3–0.4	Cohesionless—medium and dense
0.2–0.35	Cohesionless—loose to medium

Although it is common to use $\mu = 0.5$ for saturated clay soils, the reader should be aware that this represents a condition of no volume change under the applied stress σ_z. Over time, however, volume change does occur as the pore fluid drains. Equation (*e*) defines the Poisson's ratio that develops initially ($\epsilon_v = 0$) and also later when $\epsilon_v > 0$. Since the strain is produced from stress and Fig. 1-1 indicates a vertical variation, it necessarily follows that μ is stress-dependent from Eq. (*e*).

A special case in geotechnical work is that of *plane strain.* This arises where strains occur parallel to two of the coordinate axes (say the x and z) but the strain is zero perpendicular to the x-z plane (along the y axis). If we set $\epsilon_y = 0$ in the set of equations for Hooke's law [(Eqs. (2-64)] and solve for the resulting values of E_s and μ, we obtain the following:

$$E_s' = \frac{E_s}{1-\mu^2} \qquad \mu' = \frac{\mu}{1-\mu} \qquad (2\text{-}65)$$

Relation between "N" and m_{vc}

Proceedings of the Second European Symposium on Penetration Testing / Amsterdam / 24-27 May 1982

Standard penetration test
State-of-the-art report

IVAN K.NIXON
Engineering Laboratory Equipment Ltd., Hemel Hempstead, UK

SYNOPSIS

Important developments have taken place since ESOPT 1974 both with respect to the test method as well as the interpretation of the results. The considerable amount of research into the method being undertaken in the USA and Japan is reviewed against the new European Standard for the test. Japan has raised an objection to the specified rod size. Driving techniques have been closely examined in the search for a more precise standard in the USA. In reviewing the correlations with the various soil parameters particular attention is given to large scale laboratory experiments on the relationship between SPT N value, overburden pressure and relative density in sands that has emphasised the need for consideration of the other factors involved. Outline descriptions are given of eleven new methods for estimating settlement in granular soils and the results of a comparative study between eighteen methods. The test is important for estimating the danger of liquefaction and statistical methods are being suggested. Examples are included for compaction control by SPT. Besides its application in soils the test is widely used in Britain when investigating weak rocks and techniques have been proposed to aid pile design.

1 HISTORICAL BACKGROUND OF SPT

1.1 Scope of report

This review of the Standard Penetration Test (SPT) is intended to present the principal developments, both in the method of execution and its interpretation, that have taken place over the past 8 - 10 years, set against the earlier background. The datum has been arbitrarily taken for convenience as an undefined combination of three milestones in the subject; the very comprehensive state-of-the-art report on the SPT (de Mello 1971), the first edition of the standard reference book on the penetrometer (Sanglerat 1972) and the Proceedings of the First European Symposium on Penetration Testing (1974).

1.2 Origin and growth of the SPT

The Standard Penetration Test - originated about 1927 (Fletcher 1965), developed by Raymond Concrete Pile Company (Mohr 1943) and publicized by Terzaghi and Peck (1948) - has been in use for some 55 years. It is practised worldwide and to a greater extent than any other soil test. Horn (1979) has reported that 'the SPT has been and is likely to remain a keystone in soil exploration practice in North America'. It was used on 40 out of 49 US nuclear power plant site investigations made between 1954 and 1975 that he reviewed, and far exceeded in use all other samplers. Mori (1979) has reported that to his knowledge '... in Japan more than 90% of borings during the preliminary investigation phase are carried out with SPT', where it has been in use since 1953.

Despite continual criticism of the crudity of the test the number of papers published on it has flowed unabated over the years and since about 1972 the rate has increased with additional research into the dynamics of the test arising partly from the need to evaluate the liquefaction potential when siting major onshore and offshore structures using SPT data (Schmertmann 1978).

1.3 Advantages of the SPT

For a balanced viewpoint on the SPT it is appropriate, before starting to consider in some depth the weaknesses of the test, just to record its several advantages:

Equipment is relatively simple and rugged
Procedure is easy to execute and permits frequent tests
Sampling facility is included
Suits practically all soils and weak rocks
Covenient both above and below the water table

No other insitu test combines this range of flexibility.

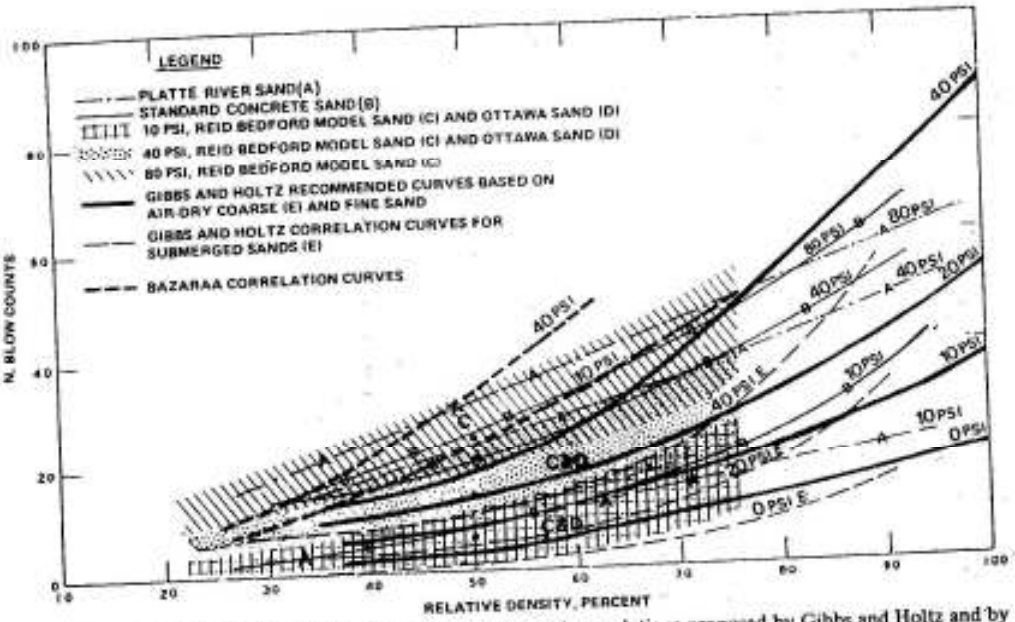


Fig. 8 Summarized WES results of N value v. D_r compared with correlations proposed by Gibbs and Holtz and by Bazaraa. (after Marcuson 1978)

for the sands used for the WES research projects referred to earlier.

3.5 Deformability

Six different proposals, suggested between 1965 and 1974, for predicting deformability from N values, together with the relevant soil type and basis of the method, have been listed by Mitchell and Gardner (1975) in their state-of-the-art report on insitu measurement of volume change characteristics. The methods were found to be widely divergent.

A review of the existing correlations has also been made by Natarajan and Tolia (1979) who concluded that relative density and the overburden effect should both be taken into account. Working at the Central Road Research Institute, New Delhi, it is understood that tests are planned in sandy soils to relate the compressibility with various confining pressures at different values of relative density.

Schultze and Biedermann (1977) have described the results of a series of comparative tests between various penetration tests and two types of pressuremeter over a range of fine grained soils in several countries. Analysis suggested the overburden pressure had no influence on the results. The pressuremeter modulus (E_p) with which the N values were compared is more closely related to a shear modulus, corresponding to a deviatoric stress field, which is customarily used to estimate settlement.

Difficulties frequently occur when sampling glacial tills (including "boulder clays"), consisting typically of varying amounts of coarse particles from sand size to boulders, often with some silt and clay. An opportunity was therefore taken to compare available oedometer tests on 100 mm diameter samples with SPT N values from 17 different sites (Stroud and Butler 1975) and it was found that a simple correlation appeared to exist for the coefficient of volume compressibility of the form

$$m_v = \frac{1}{fN} \quad \text{where N is SPT value} \qquad (3)$$

Values of .f ranged from about 450 kN/m^2 for materials of medium plasticity, to over 600 kN/m^2 for materials with a plasticity index less than 20. They also considered that for overconsolidated clays and boulder clays the final settlement could be adequatley predicted using N values by means of quasi-elastic analysis and the vertical drained elastic modulus.

ANNEXURE-2

FORMAT FOR NO DEVIATION CERTIFICATE
(To be submitted in the bidder's letter head)

BHARAT HEAVY ELECTRICALS LIMITED,
Power Sector - Eastern Region,
Plot no 9/1, DJ Block, Sector – II, Salt Lake City,
Kolkata – 700 091

Sub	No Deviation Certificate.	
Job	DESIGN, ENGINEERING, MANUFACTURING, SUPPLY, ERECTION & COMMISSIONING OF INDUCED DRAFT COOLING TOWER (IDCT) FOR 1X250 MW NSPCL, PP-II EXPANSION, ROURKELA, ODISHA.	
Ref	1.0	Tender no PSER:SCT: RKL-M1779:16
	2.0	BHEL's NIT, vide reference no PSER:SCT:RKL-M1779:5264, Dated 17-10-2016.
	3.0	BHEL's TCN-01, vide reference PSER:SCT:RKL-M1779:TCN-01, dated 26-10-2016.
	4.0	BHEL's TCN-02, vide reference PSER:SCT:RKL-M1779:TCN-02, dated 28-10-2016.
	5.0	BHEL's TCN-03, vide reference PSER:SCT:RKL-M1779:TCN-03, dated 04-11-2016.
	6.0	BHEL's TCN-04, vide reference PSER:SCT:RKL-M1779:TCN-04, dated 08-11-2016.
	7.0	BHEL's TCN-05, vide reference PSER:SCT:RKL-M1779:TCN-05, dated 10-11-2016.
	8.0	BHEL's TCN-06, vide reference PSER:SCT:RKL-M1779:TCN-06, dated 11-11-2016.
	9.0	All other pertinent issues till date.

Dear Sirs,

With reference to above, this is to confirm that as per tender conditions, we have visited site before submission of our offer and noted the job content & site conditions etc. We also confirm that we have not changed/ modified the tender documents as appeared in the website/ issued by you and in case of such observance at any stage, it shall be treated as null and void.

We hereby confirm that we have not taken any deviation from tender clauses together with other references as enumerated in the above referred NIT. We hereby confirm our unqualified acceptance to all terms & conditions, unqualified compliance to technical specification, integrity pact (if applicable) and acceptance to reverse auctioning process.

In the event of observance of any deviation in any part of our offer at a later date whether implicit or explicit, the deviations shall stand null & void.

We confirm to have submitted offer in accordance with tender instructions and as per aforesaid references.

Thanking you,

Yours faithfully,

(Signature, date & seal of authorized representative of the bidder)