PROJECT: REPORT ON

Soil Investigation work for Substation in Mandoli for BSES Yamuna Power Limited

Prepared By:

MEGS GEO ENGINEERING SERVICE

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Prepared for:

BSES YAMUNA POWER LIMITED

CONTENTS

1.0 Introduction

M/s. BSES Yamuna Power Limited is planning to setup a grid substation at Mandoli, Delhi. For the purpose of the design, M/s MEGS Geo Engineering Service has been awarded the work of characterizing the deposits at site and accessing the nature of the formation for the project. A detailed geotechnical exploration at proposed location at Mandoli in Delhi was planned for comprehensive study and to confirm the subsoil conditions and to establish the various soil parameters and its behavior, to assess the general stability of site.

2.0 Purpose of Study

The overall purposes of this study are to evaluate the stratigraphy at the project site for site characterization and to develop geotechnical recommendations for foundation design and construction. To accomplish these purposes, the study was conducted as follows:

2.1. Drilling three (3) boreholes to specified depths through soil, in order to evaluate the stratigraphy at the site and to collect soil samples for laboratory testing.

2.2. Testing selected soil samples in the laboratory to determine pertinent index and engineering properties; and

2.3. Analyzing all field and laboratory data to develop geotechnical recommendations for foundations design and construction.

3.0 Laboratory Tests

A) On soil Samples

(a) Natural moisture content
(b) Dry density
(c) Particle size analysis
(d) Specific Gravity
(e) Atterberg Limits
(f) Direct shear test

B) Chemical Test on Water/Soil sample

(a) pH value
(b) Sulphate content
(c) Chloride content

4.0 Site Exploration:

4.1 The required equipment and team were mobilized to the site for carrying out the required field work. The locations for bore holes and depths adopted were given by the engineer-in-charge. All the boreholes and tests on samples collected were carried out in the presence of the representative of site-in-charge. Borehole location plan are enclosed.

4.2 All the boreholes of 150 mm diameter in soil strata were bored using shell and auger method. Casing was used as per requirement to retain the boreholes.

The details of the various bores/ tests conducted at site are given as below-

4.3 The standard penetration tests were conducted at 1.5 m intervals up to the depth of exploration.

For conducting SPT, IS Code: 2131-1981 was followed. After reaching the required depth of test, the bottom of the bore hole was cleaned properly and spoon is properly and centrally seated in position in the borehole. Standard split spoon sampler attached to lower end of “A” drill rods was driven in the bore holes by means of standard hammer of 63.5 kg falling freely from a height of 75 cm. The sampler was driven 45 cm. and the number of blows

required for each 15 cm. penetration were recorded. The number of blows for the first 15 cm. penetration was considered as seating drive. The number of blows for last 30 cm penetration was designated as SPT 'N' value. SPT soil samples obtained from standard split spoon sampler for all the above standard penetration tests were collected in polythene bags, sealed, labeled and sent to the laboratory for testing.

4.4 The undisturbed soil samples were collected in good quality thin walled seamless tubes, of. dia of 100 mm and length of 450 mm with area ratio less than 15%. The UDS tubes are gently pushed in soil using hydraulic push rig/gently hammering action. After retrieval of UDS tube from the borehole, ends of the tube with sample were sealed with freshly molten wax of minimum 20mm thick, properly labeled, marked an arrow showing upward direction and dispatched to laboratory for testing. At site sample tubes were covered with wet gunny bags.

4.5 On encountering the water table, its depth was recorded everyday in each borehole prior to resumption of day's work. The observation of depth of water table was continued for next seven days in the completed boreholes. When it was fully stabilized, the depth was recorded as depth of water table.

4.6 Ground water samples were collected from bore holes in an airtight clean bottle, properly labeled, sealed and sent to the laboratory of its chemical analysis test. Before collecting ground water sample, it was ensured that no external water was added before collection of samples.

4.7 Soil sample ware collected from bore holes as per approved schedule and chemical test were conducted on it in the laboratory.

5.0 Laboratory Testing

5.1 Grain Size Analysis

For this purpose, an oven dry pulverized soil sample is sieved through the set of sieves 20mm, 10mm, 4.75mm, 2.0m, 1.0m, 600micron, 300micron, 150micron and 75micron. The amounts of soil retained on each sieve are noted down. The % retained, cumulative % retained and % passing are computed by these retained weights.

If the % passing 75-micron sieve is appreciable, Hydrometer method is used to find the % fraction of particle sizes from 75micron to 2micron.

5.2 Liquid Limit

For liquid limit Casagrande apparatus is used. For this test air dry soil sample passing 425micron is taken and mixed with distilled water to give a stiff and homogeneous paste and is left for sufficient time for maturing in an air light container.

A portion of the above paste is kept in the cup of Casagrande apparatus, a groove is cut with groove cutting tool and blows are imported by turning the handle at the rate of 2 revolutions per second. The numbers of blows are counted till the continuous contact of the bottom of the groove occurs.

Few quantity of soil from the close portion of the groove after the contact occurs, are taken and its water content is determined by over drying method.

The liquid limit (WL) is computed by the equation.

$$W_l = W_n (n/25)^e$$

Where Wn=water content (% corresponding to n blows)

e = 0.092 for soils with W_L<50

= 0.12 for soils with W_L>50

5.3 Plastic Limit

For this test sample is prepared in the same way as for liquid limit test. A ball is formed of sub sample weighting about 5 gm. This ball is rolled between the fingers of one hand and the glass

plate with pressure sufficient to reduce the mass into a thread of about 3 mm in 5 to 10 complete forward and back movements. When a diameter of 3 mm is reached, soil is again remolded into a ball.
The process of rolling and remolding is repeated until the thread starts just crumbing at a diameter of 3 mm.

The crumbled thread is immediately transferred to an airtight container for determination of its moisture content by oven drying method.

This water content is termed as plastic limit. (W_P)

5.4 Plasticity Index

The plasticity index Ip is given by

$$I_p=W_L-W_P$$

5.5 Water Content

For this test the soil sample of known quantity (W_m) is taken in a container. The container with this soil sample is placed in an oven for drying at 105-110ºc for 16-24 hours. After drying the dry sample is again weighed to determine the dry weight of sample (W_d)

The moisture content is computed by the following equation:

$$W_n=(W_m-W_d)/W_d$$

5.6 Dry Density & Bulk Density

For determination of bulk density, a sample of known volume 'V' is extracted from the undisturbed sample. Its bulk weight 'W' and moisture content 'Wn' is determined by oven drying method.

The bulk density is determined by following equation

$$\gamma_b=W/V$$

and dry density by

$$\gamma_d=\gamma_b/(1+W_n)$$

5.7 Specific Gravity

The specific gravity of soil sample is determined by density bottle method. For this test 5-10g (w_2) sample of oven dry, cool soil is taken in 50ml capacity density bottle and its weight is noted down. The soil is covered with distilled water and left for sufficient period for suitable soaking. The entrapped air is removed by vacuum. The soil in bottle is filled full with water and it is noted down as w_3. The mass of empty bottle (w_1) and bottle with full distilled water also noted (w_4).

The specific gravity is found by the following equation.

$$G=w_2-w_1/[(w_2-w_1)-(w_3-w_4)]$$

5.8 Direct Shear Test

For this test shear box test apparatus is used. The prepared specimen from remolded/undisturbed sample is placed carefully in the box. The plain grid is kept on top of the specimen with its serrations at right angles to the direction of shear. The upper porous stone is placed on the grid and loading pad on the stone. The box with specimen is gently placed in the container (water jacket). The specimen is submerged with water. The container is mounted with the shear box and the specimen inside, on the shearing machine. The upper part of the box is so adjusted that it touches the proving ring. The jack is brought forward to bear up against the box container. The proving ring dial gauge is set to read zero.

The steel ball is placed in the recess of the loading pad. The loading yoke is set in contact with the steel ball on the loading pad. Vertical displacement dial gauge to read zero in contact with the top of the yoke. The normal load is applied and any change in thickness of specimen is recorded. Shear displacement dial gauge is also set to read zero. The locking screw is now removed and two parts of the shear box are separated by advancing the spacing screws.

The specimen is sheared at constant rate of strain. The readings of the proving ring dial gauge are noted down every 15 seconds for the first one-minute and then every 30 seconds thereafter. The reading of change in the thickness dial gauge and shear displacement dial gauge are also recorded at the same time interval. The test is continued until the specimen fails. The specimen is assumed to fail when the proving ring dial gauge starts receding or at shear displacement of approximately 15% of the length takes place.

The soil is removed from the box and test is repeated on the identical specimen under increased normal load.

For consolidated undrained test the specimen is prepared and set in the apparatus as above and after submergence, the specimen is allowed to consolidate fully under normal loads. The specimen is then sheared as in undrained test. At the end of the test, the specimen is removed and its final water content is determined. The test is repeated on other identical specimen in similar way under increasing normal loads.

For drained test, after completion of consolidation under a particular normal load, specimen is sheared at a slow rate to allow the pore water inside the specimen drain out. Final water content of failed specimen is determined. The test is repeated on other identical specimen after consolidation under increasing normal loads.

5.9 Chemical Analysis of Subsoil Samples

The chemical analysis tests on subsoil sample indicates that the pH value, chloride content and sulphate content are within permissible limits and Ordinary Portland Cement or Portland Slag Cement or Portland Pozzolana Cement can be used for RCC work. The minimum cement content and maximum free water-cement ratio shall be maintained as per IS: 456, 2000. Refer to the Test results attached in this report.

6.0 Geomorphology

The ground water availability in NCT, Delhi is controlled by the hydrogeological situation characterized by occurrence of different landforms developed on different geological formations. Geomorphological map of Delhi is presented in Fig. 3.2. Entire area of NCT, Delhi can be grouped into three broad geomorphic units:

- Rocky surface
- Older Alluvial Plain
- Flood Plain of Yamuna River

Rocky Surface: The rocky surface represents structurally controlled relict linear ridges and isolated hillocks comprising of rocks of Delhi Supergroup and isolated hills mostly occurring in the south- and south-central parts, and extends from Mahipalpur to Wazirabad in the north. Towards south of Mahipalpur the ridge gets bifurcated, one arm extends towards Mandi and further south while the other arm takes a turn towards southeast and extends upto Tughlakabad- Greater Kailash-Nehru Place and Okhla. It attains a maximum elevation of 362 m above m.s.l. which gradually diminishes towards north where rocks are exposed on the western bank of Yamuna near Wazirabad.

Older Alluvial Plain: The gently undulatory terrain on either side of the rocky surface is described as Older Alluvial Plain. This surface is separated from the Yamuna Flood Plain by a bluff. Depending upon the morphological expressions / features, this unit is further divided into different subunits: (i) Najafgarh Older Alluvial Plain (ii) Delhi Older Alluvial Plain and (iii) Maidan Garhi Plain. Najafgarh Older Alluvial Plain occupying western and southwestern part of the region is partly covered by sand dunes and sandy sheets. The gently sloping surface including the covered pediment along the eastern flank of the ridge represents the Delhi Older Alluvial Plain. Maidan Garhi Plain is a relatively higher plain surface and forms part of Chhatarpur

Basin. A narrow zone of badland has formed mostly along the western margins of structural ridges due to intense development of gullies and rills.

Flood Plain of river Yamuna: The low-lying flat surface representing the Flood Plain of river Yamuna occupying northern, northeastern and eastern parts of the NCT is an important geomorphic unit. North of Narela, the width of flood plain varies from 15 to 17 km. The wider Older Yamuna flood plain indicates lateral migration of river Yamuna over large areas. This belt has good potential for ground water development. It forms the erosional terrace. The Yamuna Active Flood Plain represents the wide belt bounded on both the sides by Eastern and Western bunds and is naturally prone to annual/periodic floods being in the flood way and flood fringe zone of river Yamuna. It forms depositional terrace and is characterized by abandoned channels, cut-off meanders, meander scrolls, point bars and channel bars. Presence of number of cut- off meanders in the Yamuna Flood Plain suggests oscillatory shifting of river. The lakes near Bhalsawa, Kondli and Khichdipur are remnants of large meanders.

7.0 Geology

The rock formations exposed in the National Capital Territory of Delhi are mainly quartzite of the Alwar series of the Delhi Supergroup that are interbedded with thin micaceous schist bands. These rocks of Delhi area belong to the Alwar formation of Delhi Super group. Proterozoic rocks occur along the ridge, extending from Harchandpur (Haryana) in the South to Wazirabad (Delhi) in the North. Quaternary sediments directly overlie the Proterozoic rocks. The Stratigraphic succession of these rocks reviewed by Kachroo and Bagchi (1999 is tabulated below:

Holocene	Yamuna channel alluvium	Grey, fine to medium sand, grit with coarse sand, silt and clay	Point bars, channel deposits
	Yamuna Older Flood Plain & Terraces	Grey sand, coarse grit, pebble beds and minor clays	Palaeochannels, meander scrolls, oxbow lakes
	Older Alluvium	Sequence of sand-silt-clay with yellowish brown medium sand with silt, kankar with brown Aeolian sand	Abandoned channels, meander scrolls
----------Unconformity----------			
Neoproterozoic	Post Delhi Intrusives	Pegmatitic, tourmaline-quartz veins and quartz veins	
Mesoproterozoic	Delhi Supergroup	Ajabgarh Group – Bharkol Formatio	Quartzite with minor schist, tuff and ash beds

The highest is the erosional surface forming the top of denudational hills. The second surface is Older Alluvial plain and the third is depositional Younger Alluvial plain (Yamuna). The geomorphologic features have undergone changes due to widespread and uncontrolled urban activity. The geological map of Delhi is illustrated below:

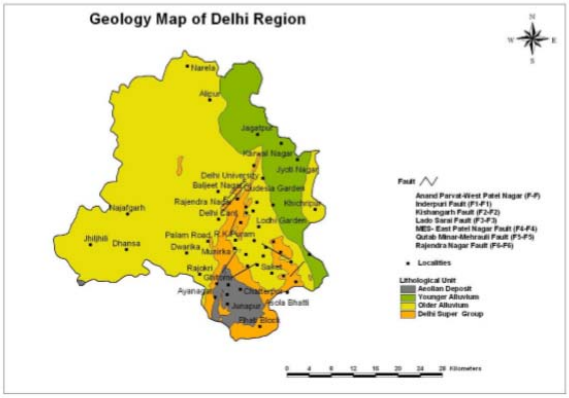

Fig 4.1: Geological map of NCT Delhi

The Quaternary deposits in the form of aeolian and alluvial deposits constitute the major repository of ground water in the area. In the East of the ridge, the thickness of unconsolidated sediments gradually increases away from the ridge. The aeolian deposits are mainly comprised of loam, silty loam and sandy loam. The bedrock is overlain by these deposits. Older alluvial deposits consist mostly of interbedded, lenticular and inter fingering deposits of clay, silt, and sand along with kankar. These deposits overlay the aeolian deposits and are in turn overlain by the newer alluvium, which occurs mostly in the flood plains of river Yamuna.

8.0 Seismology

The site area falls in Seismic **Zone-IV (Zone factor Z=0.24) as per IS: 1893 (Part-1)-2016** in the disaster-prone area map of the country. This means that it is a moderate damage risk zone. The maximum expected intensity of earthquakes in this zone is VII (MSK).

9.0 Findings of Geotechnical Investigation

The classification of subsoil strata met at this site was done according to IS: 1498-1970. The test results can be summarized as below-

Borehole wise Summary

BH-1:

The subsoil strata from 0.0 to 1.4 m consist of filled up soil with gravel underlain by silty fine sand/fine sand to 12.0 m depth. Below this low plastic sandy silt was met to the final explored depth of 15.00 m.

BH-2:

The subsoil strata from 0.0 to 1.45 m consist of filled up soil with gravel underlain by silty fine sand/fine sand to 12.0 m depth. Below this low plastic sandy silt was met to the final explored depth of 15.00 m.

BH-3:

The subsoil strata from 0.0 to 1.4 m consist of filled up soil with gravel underlain by silty fine sand/fine sand to 11.0 m depth. Below this low plastic sandy silt was met to the final explored depth of 15.00 m.

Table no. 1
Bore Hole Wise Details of Subsoil Strata.

Depth, m		Soil Classification	Range of N value	Soil properties
From	To			
0.0	1.4	Filled up	-	-
1.4	4.5	Silty fine sand	9-29	DST c=0.00 kg/cm^2, Ø=30 º
4.5	12.0	Silty fine sand/Fine sand	19-38	DST c=0.00 kg/cm^2, Ø=31 º
12.0	15.0	Sandy silt	41-63	UUT c=1.50 kg/cm^2, Ø=0 º
WATER TABLE: 13.6-14.1 m				

The layer wise properties of the subsoil strata encountered at this site and used in design are given in following table no. 2.

Table No. 2
Layerwise Properties of Subsoil Strata

Depth, m		Soil Classification	Effective unit Weight, gm/cc	Shear Parameters	
From	To			C (kg/cm^2)	Ø (degree)
0.0	1.4	Filled up	1.60	-	-
1.4	4.5	Silty fine sand	1.78	0.00	30
4.5	12.0	Silty fine sand/Fine sand	1.85	0.00	31
12.0	15.0	Sandy silt	1.92	1.50	0

The Detail description of subsoil strata encountered along with various laboratory test results are presented in the respective soil profile in Appendix-A of this report.

The subsoil profile depicting the distribution of the various subsoil strata along the alignment along with N values (observed/corrected) and other strength parameters with depth are given in subsoil profile enclosed with this report.

The SPT Curve & Table (No/Nc), Grain Size Analysis Curve, Mohr Circle Diagrams etc. are enclosed with this report.

Ground Water

The ground water table was met at 13.6 to 14.1 m depth in the borehole below existing ground surface during boring activities at site. However, as the surface water may percolate in heavy rainy season hence for the design purposes effect of ground water table can be considered at 11.0 m from ground surface.

10.0 Proposed Depth & Type of Foundations

As discussed in Section 7.0, filled up soil was met to 1.4~1.45 m depth and silty sand/fine sand is encountered at the site below the fill to 12 m depth. Sandy silt was then met to the maximum explored depth of 15.0 m. Open foundations for the proposed facilities may bear at or below 2.0~3.0 m depth.

We recommend isolated / raft foundation at the minimum foundation embedment depth of 2.0 below EGL for the planned structure.

10.1 Computation of Safe /Allowable Bearing Capacity

Shear and settlement failure criteria as per IS: 6403- 1981, IS: 8009 (part-1)-1976 and IS: 1904-1986 have been considered to compute the safe / allowable bearing capacity of underlying soil strata for proposed structure.

The safe/allowable bearing capacity from both criteria is given as follows:-

10.2 Shear Failure Criterion:

The net safe bearing capacity of sub-soil strata has been computed by considering average of general and local shear failure using the following equation for calculating the net ultimate bearing capacity.

$$Q_{nu} = 2/3\ C\ N'_c\ S_c\ d_c\ i_c + q\ (N_q' - 1)\ S_q d_q i_q + 1/2\ \gamma\ B N_\gamma' S_\gamma d_\gamma\ i_\gamma \times W'$$

The following lowest soil parameters at foundation depth level are selected from bore hole for calculations:

$C=0.0 T/m^2$ $\quad \emptyset=30^\circ$

Average Shear Parameters are computed by the following equation by iteration:

$C_{av}=(C_1h_1+C_2h_2+--------+C_nh_n)/h$

$\tan \emptyset_{av}=(h_1 \tan \emptyset_1+h_2 \tan \emptyset_2+----------+h_n \tan \emptyset_n)/h$

where, $h = 0.5 \times B \times \tan(45 + \emptyset_{av}/2)$ below foundation level

and Ci, Øi, hi-cohesion, angle of friction and thickness of ith layer below foundation level and upto thickness h respectively.

Shape factors have been taken as follows:-

$S_c = S_q = 1 + 0.2\ B/L$, $S_\gamma = 1 - 0.4\ B/L$ (for raft footing)

$i_c = i_q = i_\gamma = 1.0$

Effective density:-

0.00 m to 1.40 m	:	1.60 t/cu.m
1.40 m to 4.50 m	:	1.78 t/cu.m
4.50 m to 12.00 m	:	1.85 t/cu.m
12.00 m to 15.00 m	:	1.92 t/cu.m

Depth factors:

d_c=1+0.2×of/B tan (45º+ $Ø_{av}$/2)

d_q=d_γ=1 to 0.1×D_f/B tan (45º+ $Ø_{av}$/2)

Water correction factor (w)' = 0.60
Factor of safety F.O.S=2.5

Using the above equation and parameters, the following values of net safe bearing capacity have been computed in following table no. 3.

Table no. 3
Net Safe Bearing Capacity Based On Shear Failure Criterion

Depth of foundation below natural ground level (m)	Type of foundation (m)	Width of footing (m)	Net safe bearing capacity (t/m²)
2.0	Open	Width ≤ 3.0 m	26.8
2.5			32.9
3.0			39.2
3.5			45.8
4.0			52.7
2.0	Open/Raft	3.0 m ≥ Width ≤ 6.0 m	34.1
2.5			39.8
3.0			45.6
3.5			51.6
4.0			57.7

10.3 Settlement Failure Criterion

The settlement of sandy layers below the foundation level and up to the zone of Influence are computed by using the chart of settlement vs SPT 'N' given on page 17 of IS 8009, part-I.

For Raft footings, the zone of influence below the foundation depth is considered equal to 2.0B, where B is the width of foundation. The total permissible settlements have been considered as 40 & 50 mm.

The soil parameters have been adopted from the following table no. 4.

Table no. 4
Settlement Parameters (N Observed)

Depth below Ground level (m)	N Observed
0.0-1.4	-
1.4-4.5	9-29
4.5-12.0	19-38
12.0-15.0	41-63

The values of net allowable pressure intensities computed based on the above selected soil parameters are given in following Table no. 5.

Table No. 5:
Net Allowable Pressure Intensity based on settlement failure criterion.

Depth of foundation below NGL (m)	Type of foundation (m)	Width of Foundation (m)	Net Allowable Pressure intensity (t/m²)	
			S=40 mm	S=50 mm
2.0	Open	Width ≤ 3.0 m	12.8	16.0
2.5			14.0	17.5
3.0			15.2	19.0
3.5			17.2	21.5
4.0			19.2	24.0
2.0	Open/Raft	3.0 m ≥ Width ≤ 6.0 m	14.4	18.0
2.5			16.0	20.0
3.0			17.6	22.0
3.5			19.2	24.0
4.0			20.8	26.0

11.0 Conclusion with Recommendations

On the basis of above Geotechnical investigation the following recommendations are suggested:

11.1 The subsoil strata at this site consist of filled up to 1.4 m depth underlain by sand to 12m depth. Sandy silt was then met to the final explored depth of 15 m. The subsoil strata have been described in detail in clause 7.0. .

11.2 On the basis of field and some laboratory test results, and analysis in clause 8.0, the lower values of net safe bearing capacity obtained from shear failure criterion and net allowable pressure intensity obtained from settlement failure criterion can be adopted for design purposes. The recommended value of net safe bearing capacities/net allowable pressure intensities for design purposes, are given in the following table no. 6:-

Table no. 6:
Recommended Values of Net SBC/API

Depth of foundation below NGL (m)	Type of foundation (m)	Width of Foundation (m)	Net Allowable Pressure intensity (t/m^2)		Modulus of Subgrade Reaction, kN/m^3
			S=40 mm	S=50 mm	
2.0	Open	Width ≤ 3.0 m	12.8	16.0	3200
2.5			14.0	17.5	3500
3.0			15.2	19.0	3800
3.5			17.2	21.5	4300
4.0			19.2	24.0	4800
2.0	Open/Raft	3.0 m ≥ Width ≤ 6.0 m	14.4	18.0	3600
2.5			16.0	20.0	4000
3.0			17.6	22.0	4400
3.5			19.2	24.0	4800
4.0			20.8	26.0	5200

11.3 The chemical analysis tests on subsoil sample indicates that the Ordinary Portland Cement or Portland Slag Cement or Portland Pozzolana Cement can be used for RCC work. The minimum cement content and maximum free water-cement ratio shall be maintained as per IS: 456, 2000. refer to the Test Results attached in Appendix-A of this report.

11.4 The slope of the excavated pit may be kept upto 1 vertical on 0.5-0.6 horizontal during excavation. However, if space is constraint then suitably designed bracing and strutting system should be adopted.

11.5 As per IS 1893:2002, the site falls under earthquake Zone-IV. Water table is met at 13.6 to 14.1 m depth below EGL and SPT value exceeds 10 in the top layer . So in our opinion liquefaction may not likely to take place.

11.6 The above recommendations have been made on the basis of in situ tests and laboratory tests conducted on the samples collected from limited number of bore holes bored at the locations given by the client. If during construction, any unusual or abnormal features are noticed, these may be brought to the attention of Geotechnical Consultants for further suggestions.

12.0 Closure

We appreciate the opportunity to submit this Soil Investigation Report. The above recommendations have been made on the basis of in situ tests and laboratory tests conducted on the samples collected from the boreholes explored at the locations (as per location plan). If during excavation, any unusual or abnormal features are noticed, these may be brought to the attention of geotechnical consultant before proceeding with construction work for further suggestions.

For

MEGS Geo Engineering Service

Appendix-A

MEGS Engineer	Project : Soil Investigation work for Substation in Mandoli for BSES Yamuna Power Limited								Borehole Number: 1	Dia of Borehole 150 mm			Start Date 13-02-2025		Borehole Depth, m 15.45 m									
	Client: BSES Yamuna Power Limited			Location Mandoli			Surface Elevation -		Coordinates: -	Water Table, m 14.1 m			End Date 15-02-2025											
											Gradation Analysis				Atterberg Limits					Shear Test Results				
Sample No.	Depth (m)	Standard Penetration Test Value (N-Value)	IS Symbol	Description of Soil		Graphical Symbol	Natural Density gms/cm^3	Dry Density gms/cm^3	Water Content %	Specific Gravity	Gravel %	Sand %	Silt %	Clay %	Liquid %	Plastic %	Plasticity Index %	Shrinkage Limit,%	Test Type	Cohesion Intercept Kg/cm^2	Angle of Internal Friction			
DS1	0.00 0.50			Filled up soil: Light brown silty sand with gravel, brickbats, pitcher pieces	1.40 m																			
SPT1	1.50 1.95	12		Light brown silty sand with gravel																				
UDS1	2.50 2.80						1.78	1.59	11.8										DST	0.0	30.0			
SPT2	3.00 3.45	17	SM																					
SPT3	4.50 4.95	23																						
UDS2	5.50 5.80						1.82	1.62	12.5															
SPT4	6.00 6.45	26																						
SPT5	7.50 7.95	29		Light brown fine sand with gravel	7.5 m																			
UDS3	8.50 8.80						1.85	1.63	13.2										DST	0.0	30.8			
SPT6	9.00 9.45	31	SP-SM																					
SPT7	10.50 10.95	33																						

MEGS Geotechnical Engineer	Project : Soil Investigation work for Substation in Mandoli for BSES Yamuna Power Limited								Borehole Number: 1		Dia of Borehole 150 mm		Start Date 13-02-2025		Borehole Depth, m 15.45 m									
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											Gradation Analysis				Atterberg Limits					Shear Test Results				
Sample No.	Depth (m)	Standard Penetration Test Value (N-Value)	IS Symbol	Description of Soil		Graphical Symbol	Natural Density gms/cm^3	Dry Density gms/cm^3	Water Content %	Specific Gravity	Gravel %	Sand %	Silt %	Clay %	Liquid %	Plastic %	Plasticity Index %	Shrinkage Limit,%	Test Type	Cohesion Intercept Kg/cm^2	Angle of Internal Friction			
UDS4	11.50 11.80		SP-SM	Light grey fine sand	12.0 m		1.88	1.65	14.2															
SPT8	12.00 12.45	42	CL	Light brown sandy silt																				
SPT9	13.50 13.95	45																						
UDS5	14.50 14.80						1.93	1.67	15.4										UCS	1.4				
SPT10	15.00 15.45	52			15.45 m																			

MEGS Engineer	Project : Soil Investigation work for Substation in Mandoli for BSES Yamuna Power Limited								Borehole Number: 2		Dia of Borehole 150 mm		Start Date 15-02-2025		Borehole Depth, m 15.45 m									
	Client: BSES Yamuna Power Limited			Location Mandoli			Surface Elevation -		Coordinates: -		Water Table, m 13.6		End Date 16-02-2025											
											Gradation Analysis				Atterberg Limits				Shear Test Results					
Sample No.	Depth (m)	Standard Penetration Test Value (N-Value)	IS Symbol	Description of Soil		Graphical Symbol	Natural Density gms/cm^3	Dry Density gms/cm^3	Water Content %	Specific Gravity	Gravel %	Sand %	Silt %	Clay %	Liquid %	Plastic %	Plasticity Index %	Shrinkage Limit,%	Test Type	Cohesion Intercept Kg/cm^2	Angle of Internal Friction			
DS1	0.00 0.50			Filled up soil: Light brown silty sand with gravel, brickbats etc.	1.45 m																			
SPT1	1.50 1.95	9		Light brown silty sand with gravel							5	68	27	0										
UDS1	2.50 2.80						1.78	1.58	12.4						Non-Plastic				DST	0.0	29.6			
SPT2	3.00 3.45	16	SM							2.65														
SPT3	4.50 4.95	19																						
UDS2	5.50 5.80						1.82	1.60	13.6		2	76	22	0					DST	0.0	30.4			
SPT4	6.00 6.45	23			6.0 m																			
SPT5	7.50 7.95	28		Light brown fine sand with gravel						2.64					Non-Plastic									
UDS3	8.50 8.80		SP-SM				1.85	1.62	14.5										DST	0.0	31.1			
SPT6	9.00 9.45	35									3	85	12	0										
SPT7	10.50 10.95	47																						

MEGS Engineer	Project : Soil Investigation work for Substation in Mandoli for BSES Yamuna Power Limited							Borehole Number: 2		Dia of Borehole 150 mm		Start Date 15-02-2025		Borehole Depth, m 15.45 m									
	Client: BSES Yamuna Power Limited			Location Mandoli		Surface Elevation -		Coordinates: -		Water Table, m 13.6		End Date 16-02-2025											
										Gradation Analysis				Atterberg Limits					Shear Test Results				
Sample No.	Depth (m)	Standard Penetration Test Value (N-Value)	IS Symbol	Description of Soil	Graphical Symbol	Natural Density gms/cm^3	Dry Density gms/cm^3	Water Content %	Specific Gravity	Gravel %	Sand %	Silt %	Clay %	Liquid %	Plastic %	Plasticity Index %	Shrinkage Limit,%	Test Type	Cohesion Intercept Kg/cm^2	Angle of Internal Friction			
UDS4	11.50 11.80		SP-SM	Light grey fine sand 12.0 m		1.91	1.66	15.1						Non-Plastic									
SPT8	12.00 12.45	59		Light brown sandy silt, low plastic						0	21	68	11	32.2	23.7	8.5							
SPT9	13.50 13.95	60	CL						2.68														
UDS5	14.50 14.80					1.95	1.68	16.0						31.8	22.9	8.9		UCS	1.6				
SPT10	15.00 15.45	63		15.45 m																			

MEGS	Project : Soil Investigation work for Substation in Mandoli for BSES Yamuna Power Limited							Borehole Number: 3		Dia of Borehole 150 mm		Start Date 16-02-2025		Borehole Depth, m 15.45 m										
	Client: BSES Yamuna Power Limited			Location Mandoli			Surface Elevation -			Coordinates: -		Water Table, m 14.1		End Date 17-02-2025										
											Gradation Analysis				Atterberg Limits					Shear Test Results		
Sample No.	Depth (m)	Standard Penetration Test Value (N-Value)	IS Symbol	Description of Soil			Graphical Symbol	Natural Density gms/cm^3	Dry Density gms/cm^3	Water Content %	Specific Gravity	Gravel %	Sand %	Silt %	Clay %	Liquid %	Plastic %	Plasticity Index %	Shrinkage Limit,%	Test Type	Cohesion Intercept Kg/cm^2	Angle of Internal Friction
DS1	0.00 0.50			Filled up soil: Light brown silty sand with gravel, brickbats etc.		1.40 m																
SPT1	1.50 1.95	10		Light brown silty sand with gravel													Non-Plastic					
UDS1	2.50 2.80							1.79	1.60	12.1		1	78	21	0					DST	0.0	30.4
SPT2	3.00 3.45	16	SM								2.64											
SPT3	4.50 4.95	23															Non-Plastic					
UDS2	5.50 5.80							1.83	1.61	13.4												
SPT4	6.00 6.45	25				6.0 m						3	87	10	0							
SPT5	7.50 7.95	34		Light brown fine sand with gravel							2.63											
UDS3	8.50 8.80		SP-SM					1.87	1.64	14.0							Non-Plastic			DST	0.0	31.2
SPT6	9.00 9.45	38										2	86	12	0							
SPT7	10.50 10.95	44				11.0 m																

MEGS Engineer	Project : Soil Investigation work for Substation in Mandoli for BSES Yamuna Power Limited								Borehole Number: 3	Dia of Borehole 150 mm			Start Date 16-02-2025			Borehole Depth, m 15.45 m							
	Client: BSES Yamuna Power Limited			Location Mandoli		Surface Elevation -			Coordinates: -	Water Table, m 14.1			End Date 17-02-2025										
										Gradation Analysis				Atterberg Limits					Shear Test Results		
Sample No.	Depth (m)	Standard Penetration Test Value (N-Value)	IS Symbol	Description of Soil	Graphical Symbol	Natural Density gms/cm^3	Dry Density gms/cm^3	Water Content %	Specific Gravity	Gravel %	Sand %	Silt %	Clay %	Liquid %	Plastic %	Plasticity Index %	Shrinkage Limit,%	Test Type	Cohesion Intercept Kg/cm^2	Angle of Internal Friction
UDS4	11.50 11.80			Light brown sandy silt, low plastic		1.91	1.66	14.8						29.9	21.5	8.4				
SPT8	12.00 12.45	41							2.67											
SPT9	13.50 13.95	50	CL							0	18	69	13							
UDS5	14.50 14.80					1.95	1.69	15.5										UCS	1.5	
SPT10	15.00 15.45	54		15.45 m										31.5	22.4	9.1				

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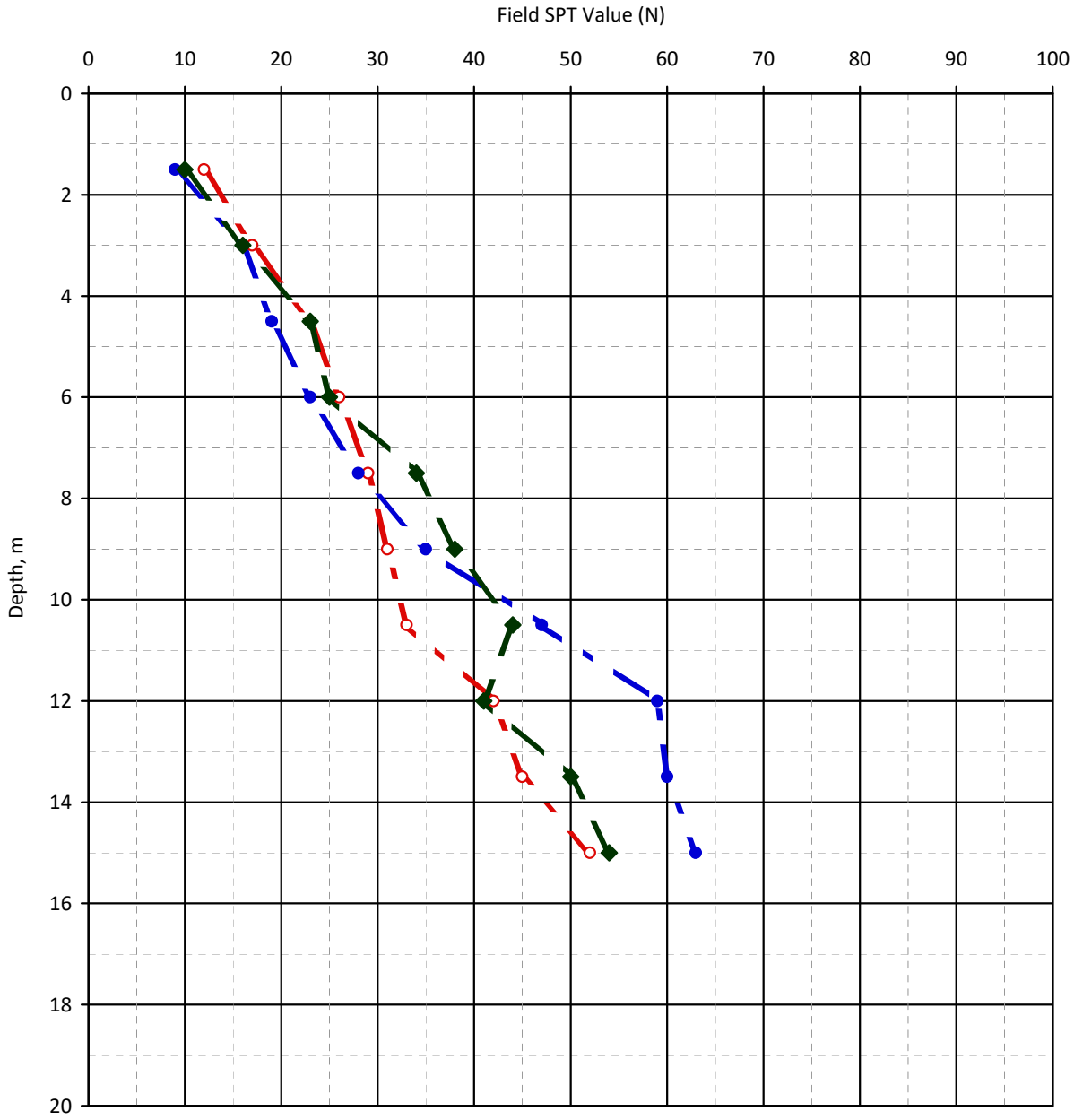
Standard Penetration Test

Project: Soil Investigation work for Grid Substation in Mandoli for BSES Yamuna Power Limited

Borehole Details			
Symbol	Borehole Number	Reduced Level	Location
	BH-1	-	Mandoli
	BH-2	-	
	BH-3	-	



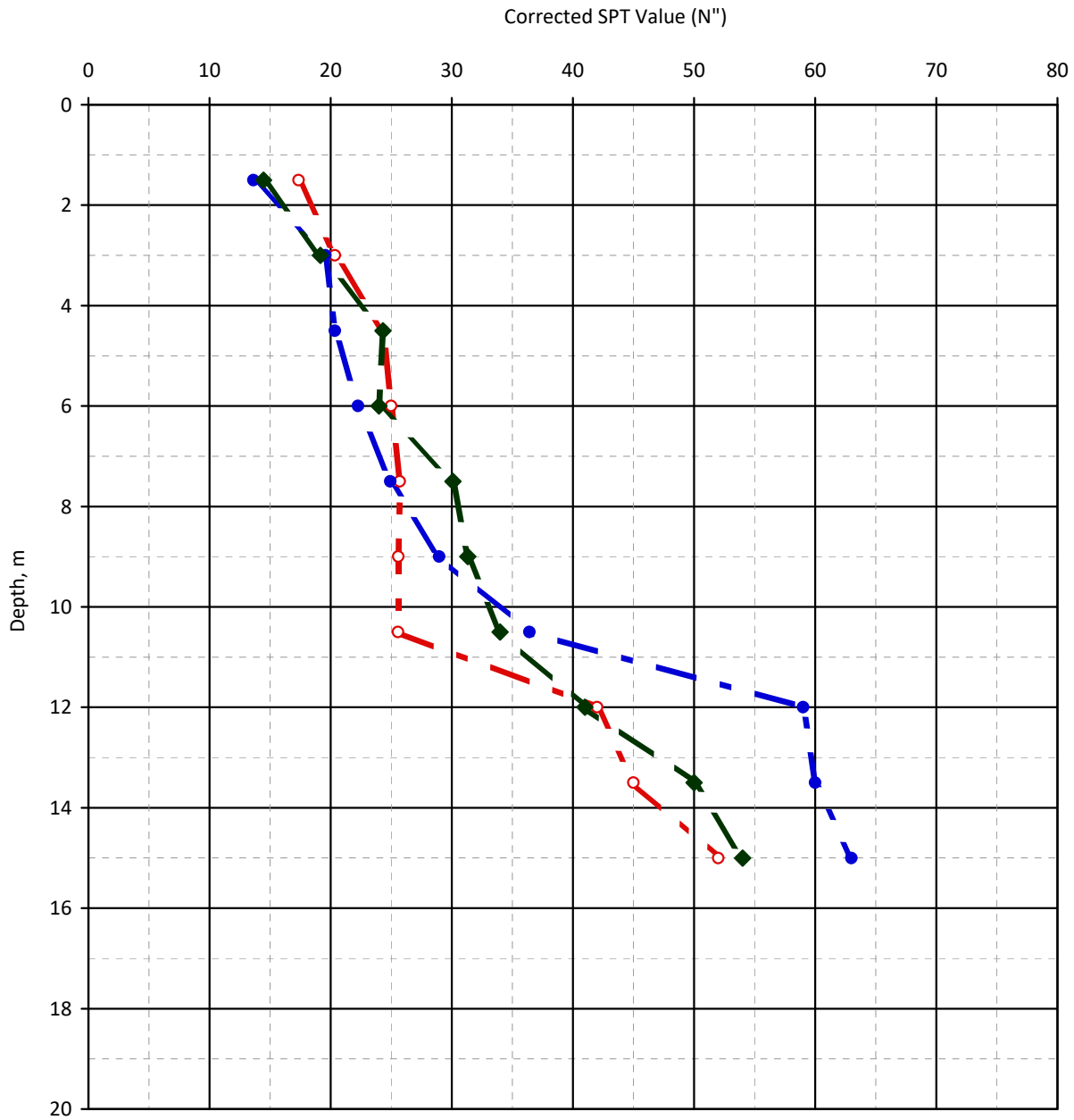
Field SPT Values vs. Depth

MEGS GEO ENGINEERING SERVICE

Standard Penetration Test

Project: Soil Investigation work for Grid Substation in Mandoli for BSES Yamuna Power Limited

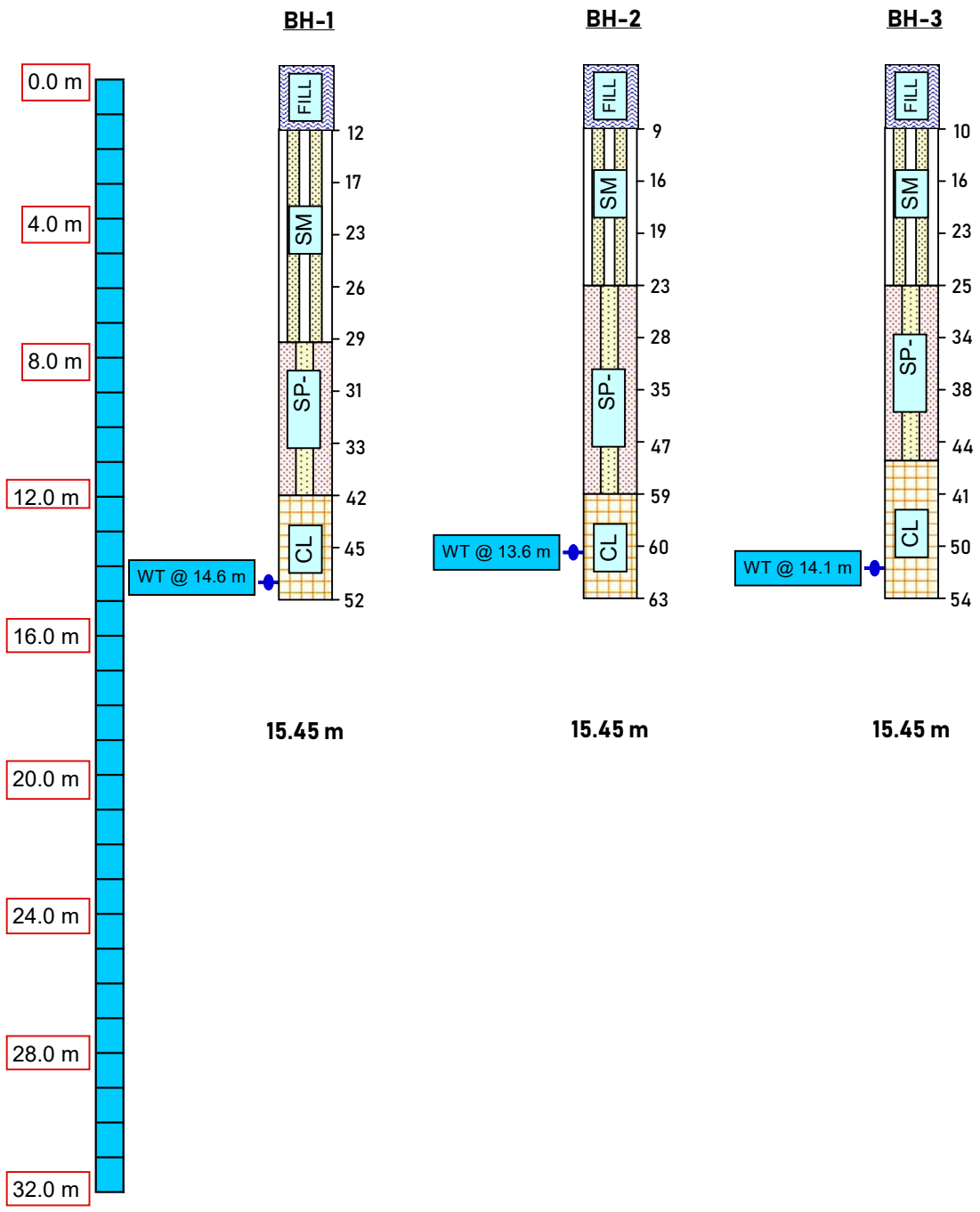
Borehole Details			
Symbol	Borehole Number	Reduced Level	Location
	BH-1	-	Mandoli
	BH-2	-	
	BH-3	-	



Corrected SPT Values vs. Depth

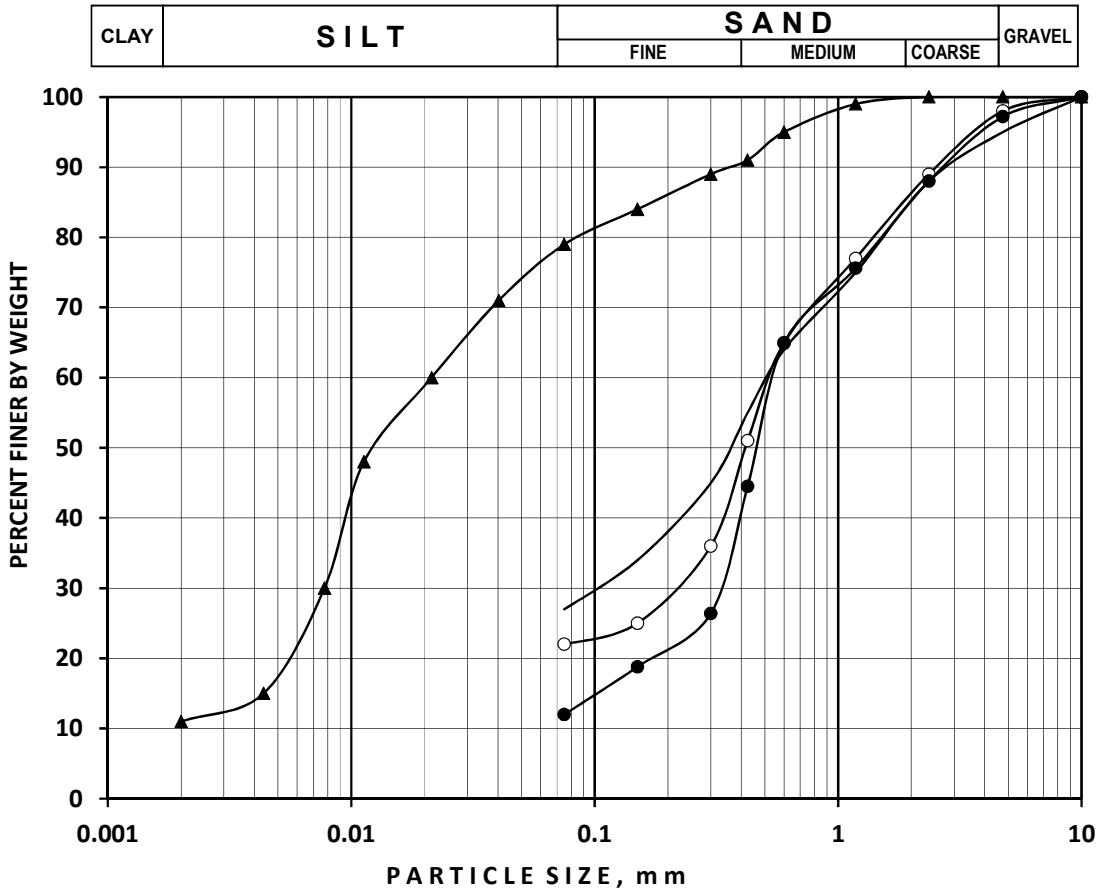
MEGS GEO ENGINEERING SERVICE

Project : Soil Investigation work for Substation in Mandoli for BSES Yamuna Power Limited



Summary of Boreholes

MEGS GEO ENGINEERING SERVICE



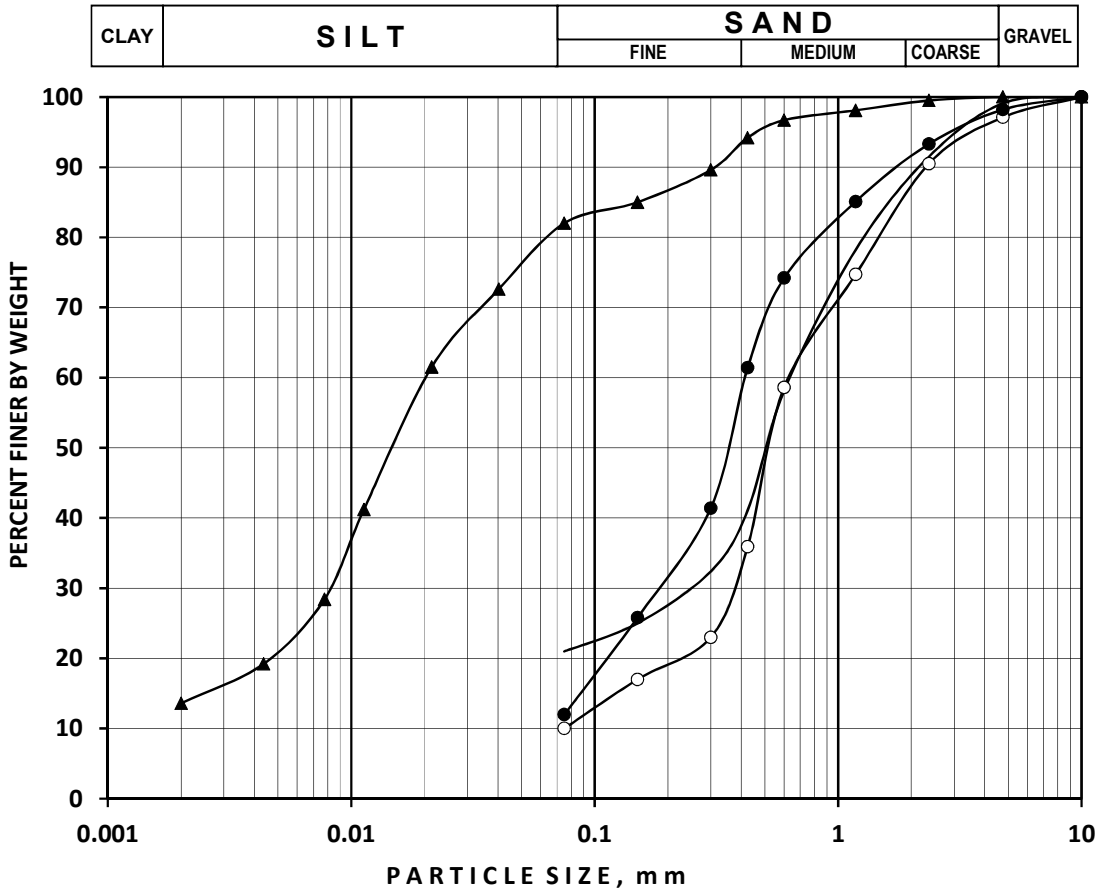
SYMBOL	BORE HOLE	DEPTH m	DESCRIPTION	GRAVEL %	SAND %	SILT %	CLAY %	D_{60}	D_{10}	C_u
———	2	1.5	Silty fine sand with gravel (SM)	5	68	27	0	0.522		
—○—○—	2	5.5	Silty fine sand with gravel (SM)	2	76	22	0	0.538		
—●—●—	2	9.0	Fine sand with gravel (SP-SM)	3	85	12	0	0.558		
—▲—▲—	2	12.0	Sandy silt (CL)	0	21	68	11	0.021		

GRAIN SIZE ANALYSIS

Location: Mandoli

Project: Soil Investigation work for Substation in Mandoli for BSES Yamuna Power Limited

MEGS GEO ENGINEERING SERVICE



SYMBOL	BORE HOLE	DEPTH m	DESCRIPTION	GRAVEL %	SAND %	SILT %	CLAY %	D_{60}	D_{10}	C_u
	3	2.5	Silty fine sand with traces of gravel (SM)	1	78	21	0	0.655		
	3	6.0	Fine sand with gravel (SP-SM)	3	87	10	0	0.650	0.075	
	3	9.0	Fine sand with gravel (SP-SM)	2	86	12	0	0.416		
	3	13.5	Sandy silt (CL)	0	18	69	13	0.021		

GRAIN SIZE ANALYSIS

Location: Mandoli

Project: Soil Investigation work for Substation in Mandoli for BSES Yamuna Power Limited

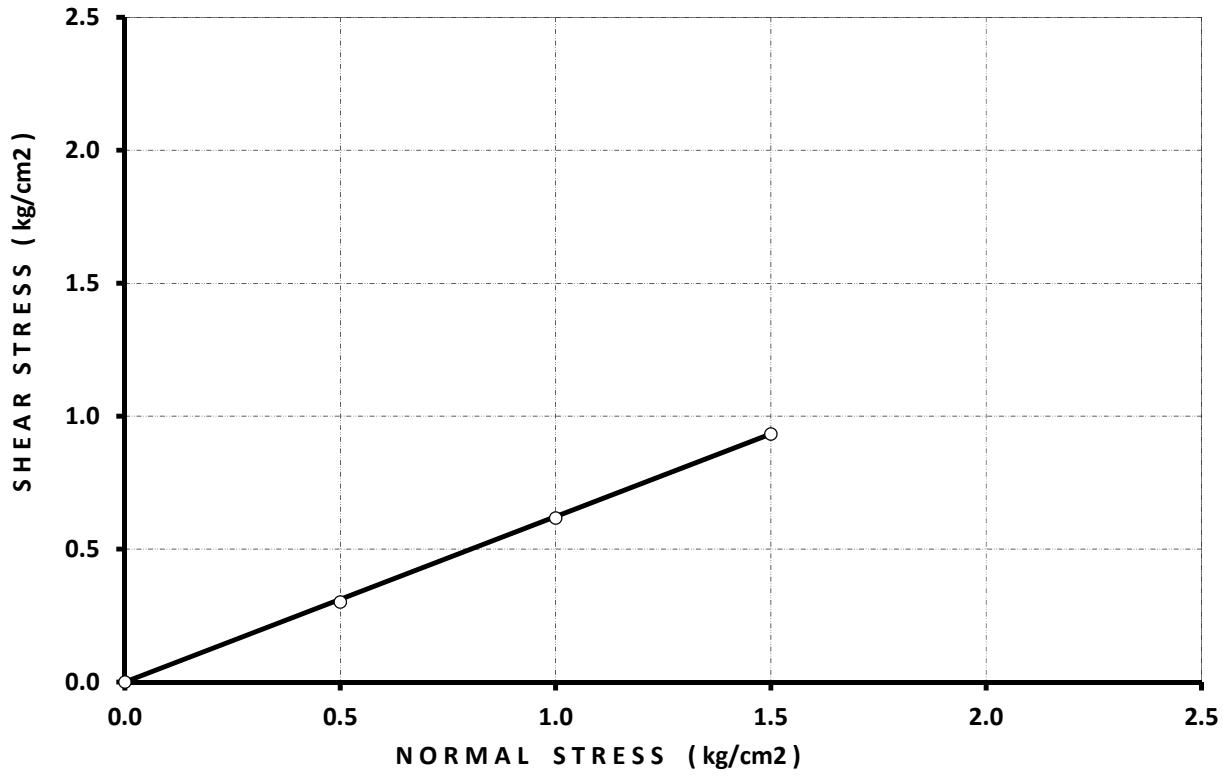
MEGS GEO ENGINEERING SERVICE

DRAINED DIRECT SHEAR TEST

Borehole No.	:	1
Depth, m	:	2.50
Type of test	:	Saturated Consolidated Drained

Dry Density gm/cc	"c" Value kg / cm^2	ϕ, Value DEGREE
1.59	0	30.0

Type of Soil : Silty fine sand



Location: Mandoli

Project : Soil Investigation work for Substation in Mandoli for BSES Yamuna Power Limited

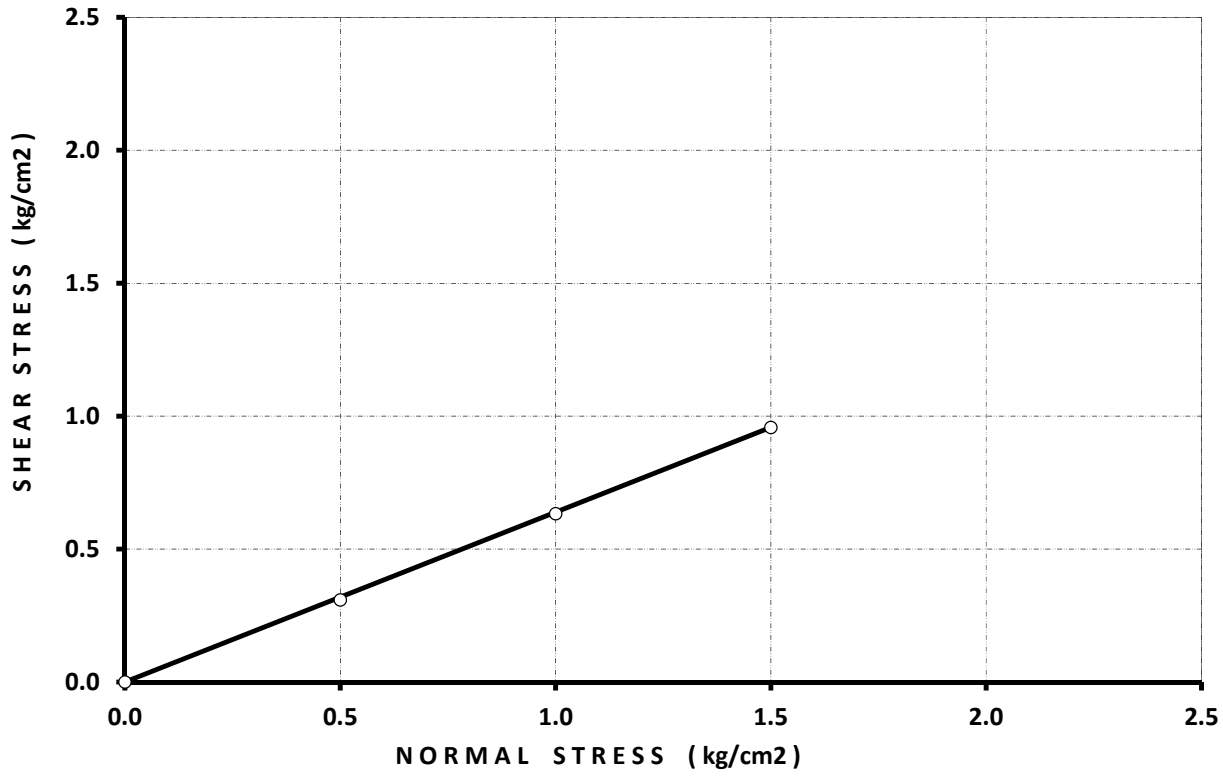
MEGS GEO ENGINEERING SERVICE

DRAINED DIRECT SHEAR TEST

Borehole No.	:	1
Depth, m	:	8.50
Type of test	:	Saturated Consolidated Drained

Dry Density gm/cc	"c" Value kg / cm^2	ϕ, Value DEGREE
1.63	0	30.8

Type of Soil : Fine sand



Location: Mandoli

Project : Soil Investigation work for Substation in Mandoli for BSES Yamuna Power Limited

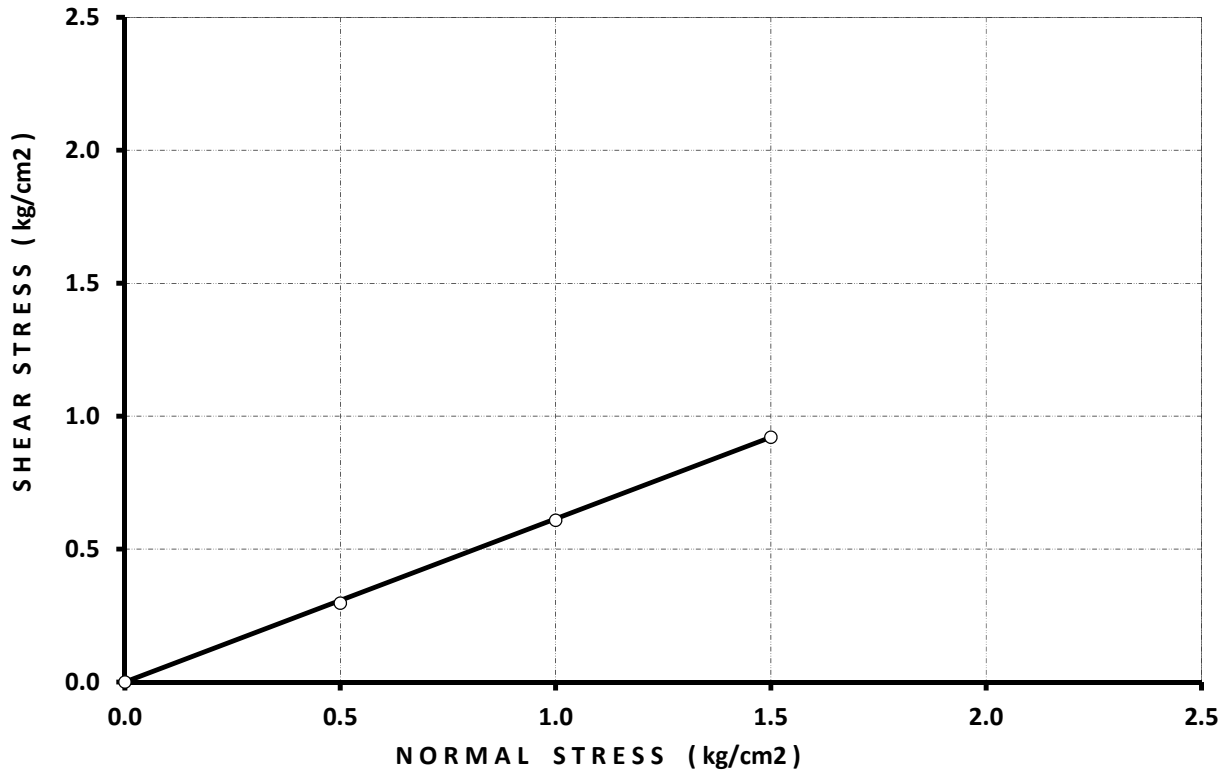
MEGS GEO ENGINEERING SERVICE

DRAINED DIRECT SHEAR TEST

Borehole No.	:	2
Depth, m	:	2.50
Type of test	:	Saturated Consolidated Drained

Dry Density gm/cc	"c" Value kg / cm^2	ϕ, Value DEGREE
1.58	0	29.6

Type of Soil : Silty fine sand



Location: Mandoli

Project : Soil Investigation work for Substation in Mandoli for BSES Yamuna Power Limited

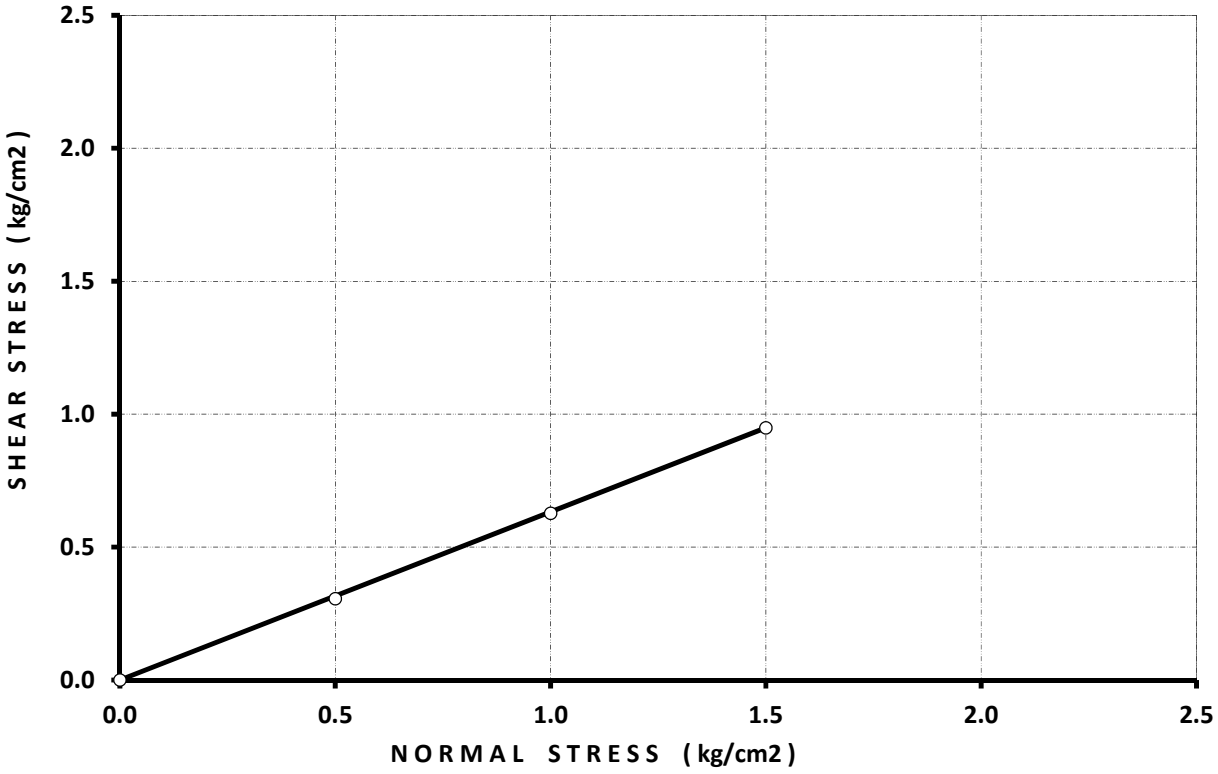
MEGS GEO ENGINEERING SERVICE

DRAINED DIRECT SHEAR TEST

Borehole No.	:	2
Depth, m	:	5.50
Type of test	:	Saturated Consolidated Drained

Dry Density gm/cc	"c" Value kg / cm^2	ϕ, Value DEGREE
1.60	0	30.4

Type of Soil : Silty fine sand



Location: Mandoli

Project : Soil Investigation work for Substation in Mandoli for BSES Yamuna Power Limited

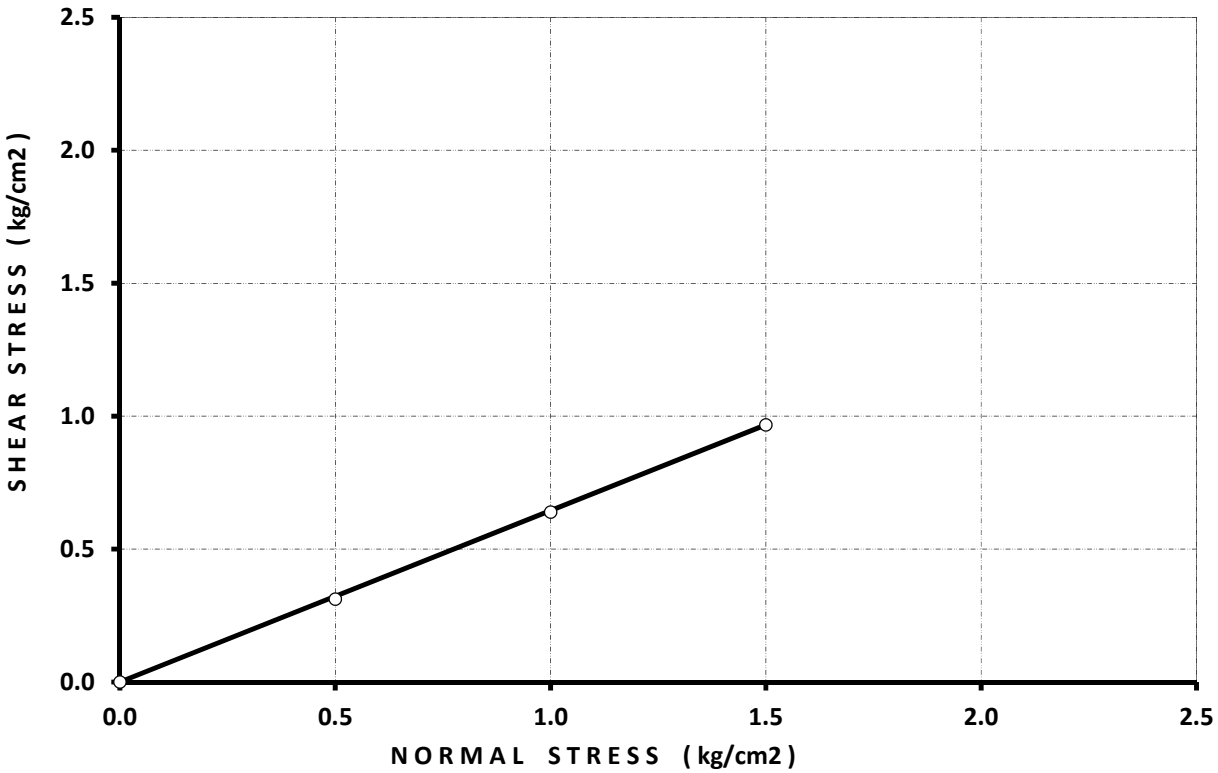
MEGS GEO ENGINEERING SERVICE

DRAINED DIRECT SHEAR TEST

Borehole No.	:	2
Depth, m	:	8.50
Type of test	:	Saturated Consolidated Drained

Dry Density gm/cc	"c" Value kg / cm^2	ϕ, Value DEGREE
1.62	0	31.1

Type of Soil : Fine sand



Location: Mandoli

Project : Soil Investigation work for Substation in Mandoli for BSES Yamuna Power Limited

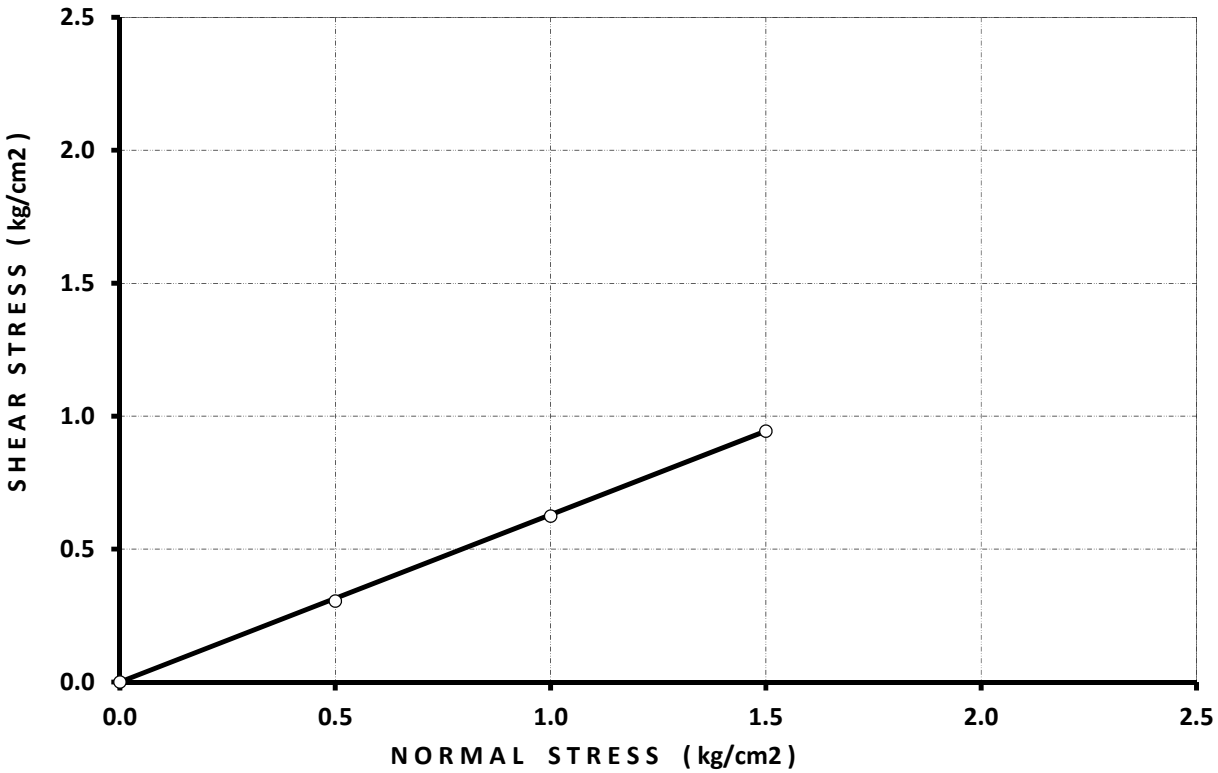
MEGS GEO ENGINEERING SERVICE

DRAINED DIRECT SHEAR TEST

Borehole No.	:	3
Depth, m	:	2.50
Type of test	:	Saturated Consolidated Drained

Dry Density gm/cc	"c" Value kg / cm^2	ϕ, Value DEGREE
1.60	0	30.4

Type of Soil : Silty fine sand



Location: Mandoli

Project : Soil Investigation work for Substation in Mandoli for BSES Yamuna Power Limited

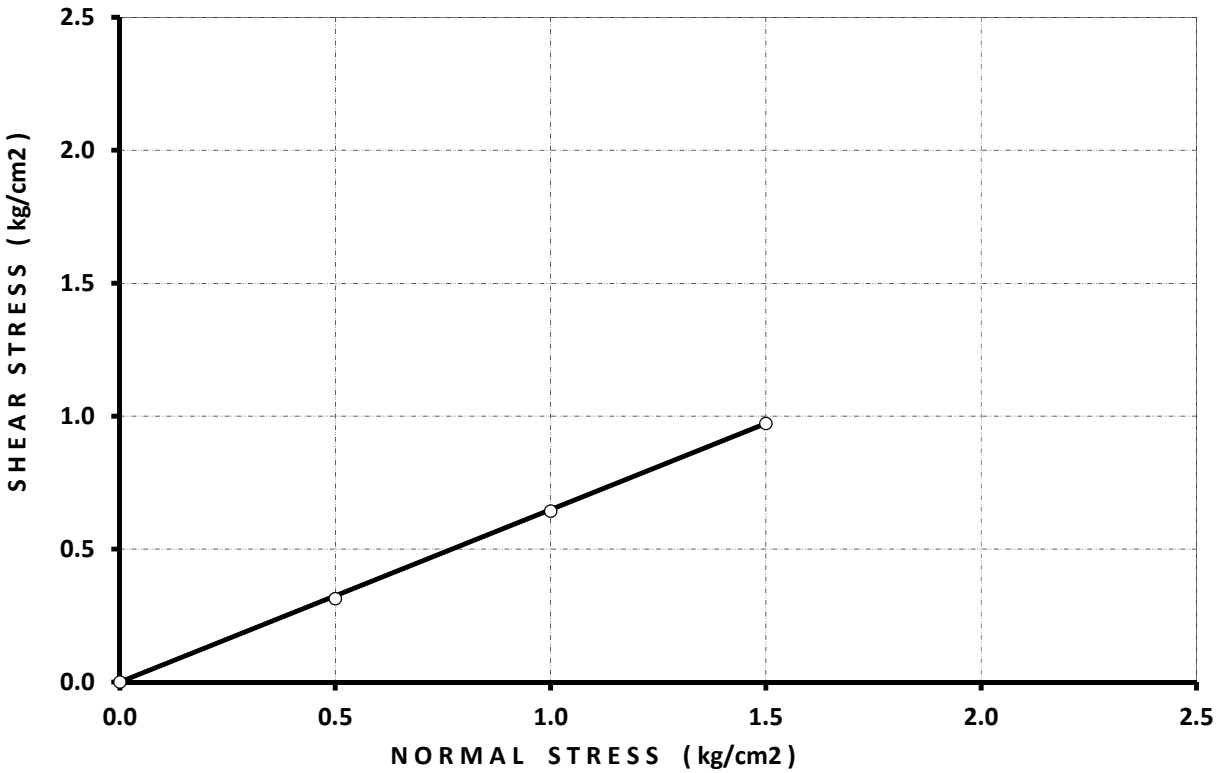
MEGS GEO ENGINEERING SERVICE

DRAINED DIRECT SHEAR TEST

Borehole No.	:	3
Depth, m	:	8.50
Type of test	:	Saturated Consolidated Drained

Dry Density gm/cc	"c" Value kg / cm^2	ϕ, Value DEGREE
1.64	0	31.2

Type of Soil : Fine sand



Location: Mandoli

Project : Soil Investigation work for Substation in Mandoli for BSES Yamuna Power Limited

MEGS GEO ENGINEERING SERVICE

CHEMICAL TEST RESULTS

Test on Soil-Water Extract

Borehole No.	Depth (m)	pH Value	Chloride Content ,%	Sulphate Content ,%
BH-1	1.50	7.75	0.04	0.15
BH-2	3.00	7.90	0.03	0.13
BH-3	1.50	7.65	0.04	0.12

Test on Groundwater Sample

Borehole No.	pH Value	Chloride Content , mg/l	Sulphate Content ,mg/l
BH-1	7.35	115	328
BH-2	7.24	141	371
BH-3	7.51	128	345

Project : Soil Investigation work for Substation in Mandoli for BSES Yamuna Power Limited

Appendix-B

Bearing capacity as per shear criteria (Typical Calculation)

The bearing capacity equation is as follows:

$q_{net\ safe} = (1/FS)\{cN_c\zeta_c d_c + q(N_q-1)\zeta_q d_q + 0.5B\gamma N_\gamma \zeta g d_\gamma R_w\}$

Foundation Depth= 2.0 m

Foundation Width = 6 m

Failure Criteria- Average of Local and General Shear Failure

FS = 2.5, c = 0.0 T/m^2, ϕ = 30 degree

N_c = 30.14, N_q = 18.40, N_γ = 22.40 (IS 6403, Table-1, Clause-5.1.1)-General Shear Failure

N_c' = 15.87, N_q' = 7.11, N_γ' = 6.24 -Local Shear Failure

ζ_c = 1.30, ζ_q = 1.20, ζ_γ = 0.80 (IS 6403, Table-2, Section-5.1.2.1)

d_c = 1.03, d_q = 1.01, d_γ = 1.01 (IS 6403, Section-5.1.2.2)- General Shear Failure

d_c' = 1.02, d_q' = 1.01, d_γ' = 1.01 - Local Shear Failure

R_w = 0.60 q = 3.31 T/m^2 γ= 1.78 T/m^3 B= 6 m

Putting in the above formula, we get

$q_{net\ safe}$= 51.842 (General Shear Failure)

$q_{net\ safe}$= 16.439 (Local Shear Failure)

Taking average of both the values (i.e General and local shear failure)

$q_{net\ safe}$= 34.1 T/m^2

Settlement Analysis (Typical Calculation)

Foundation width = 6 m

Depth of foundation = 2.0 m

Water Table = 14.0 m

Design N-value = 15

Settlement @ 1kg/cm2 for 6 m width footing at N -15 (S_1) (IS:8009-Part-1-1979, clause-9.2.2.1, Figure-9) = 0.0218 m = 21.8 mm

Correction for saturation Rw = 0.6 (water table – 14.0 m)

Corrected S_2 = S_1/R_w - 21.8/0.6

S_2 = 36.3 mm

Now Rigidity Factor = 0.8

Fox's Depth Factor, D_f = 0.91

Total computed Settlement = S_2 x Rigidity Factor x Depth Factor

= 36.3 x 0.8 x 0.91
= 26.43 mm @ 1 Kg/cm^2
= 47.7 mm @ 1.8 kg/cm^2

Net Allowable Bearing Pressure for **47.7 mm (<50 mm) settlement** = 1.8 kg/cm^2 or **18.0 T/m^2**