NAME OF WORK: GEOTECHNICAL SOIL INVESTIGATION OF ARJAN GARH (NEAR ARJAN GARH METRO STATION)

GEOTECHNICAL REPORT

CLIENT: -

BSES	BSES RAJDHANI POWER LIMITED 1ST FLOOR; C-BLOCK, BSES BHAWAN, NEHRU PLACE DELHI, -110019. TELEPHONE: 91-011 -39999444

SOIL CONSULTANT:-

	M/S SWATI STRUCTURE SOLUTIONS PVT. LTD. KH NO.7/9, GROUND FLOOR, NANGLOI, JAT HARSUKH BLK, PREM NAGAR, DELHI- 110041

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ABBREVIATION

BH	Borehole
ERT	Earth resistivity testing
IS	Indian standard
N Values	No of blows/30cm from standard penetration test
γ_d	Dry Density of Soil
N_m	Uncorrected SPT blow count
Q_{ab}	Allowable Net Bearing capacity
C	Cohesion in N/mm^2
B	Width of footing in m
D	Depth of Foundation in m
G	Specific Gravity
e	Void ratio
d_q, dr, d_c	Depth factors
S_q, S_c, $S\gamma$	Shape factors
I_q, Ir, I_c	Inclination factors
N'_c, N'_q, N'r,	Bearing capacity factor
q	Total surcharge at the base level of foundation
W'	Water table correction factor
Φ	Angle of shearing resistance of soil
N_R	Recorded standard penetration value
N_C	Corrected standard penetration value
k	Modulus of sub-grade reaction
EGL	Existing Ground Level
Qu	Ultimate bearing capacity
qs	Safe Bearing Capacity

1.0 INTRODUCTION

The work of geotechnical investigation for Arjan garh (Near arjan garh metro station) has been assigned to M/S Swati Structure Solutions Pvt. Ltd., having its address at KH No.7/9, Ground floor, Nangloi, Jat Harsukh BLK, Prem nagar, Delhi- 110041 by the BSES Rajdhani Power Limited with its address at 1st Floor; C-Block, BSES Bhawan, Nehru Place Delhi, -110019. The report presents the details of field investigation carried out in the month of January 2025 and the results are obtained from various fields and laboratory tests based on computation. Foundation analysis has been done and recommendation has been made as regards to suitable type of foundations to be provided for the proposed structure.

2.0 SCOPE OF WORK

a) Mobilization and demobilization of all relevant men and machinery including all T&P required for carrying out soil investigation work as per direction of Engineer-in-charge.
b) Drilling 1 Nos. Bore holes up to the depth of 15 or refusal whichever is earlier below the ground surface by shell and auger method.
c) Conducting Standard Penetration Test at 1.50m regular interval as per Indian Standard Specification.
d) Collection of disturbed and undisturbed soil samples from the bore holes at regular interval of 3.0m or change of strata.
e) Carrying out lab test to find physical properties of sub soil strata.
f) Recording of water table level in the bore hole after completion of bore hole.
g) Preparation and submission of report incorporating all the data obtained from the field and laboratory tests.
h) Evaluation of SBC based on shear & settlement Criteria.
i) The field testing for bore holes has been done on 29/01/2025

3.0 LOCATION OF BORE HOLES

One nos. of bore holes are drilled at the proposed site. All the test locations are given by the client.

4.0 FIELD INVESTIGATION

4.1 Grain size distribution of soil at various depths has been carried out and grain size distribution curve is drawn. The soil type and shear parameters as obtained in the various bore-hole are given in the table below:

Bore Hole (BH) No.	Subsoil Layers	Soil Type	Shear Parameters	
			Cohesion c in Kg/cm^2	Action of friction (in Degree)
BH-1	Layer-1 (0.0m to 10.5m)	Silty Sand with Gravel	0.022	20^0
	Layer-2 (10.5m to 15.0m)	Soft Disintegrated Rock	-	-

4.2 Subsurface Exploration

Subsurface Exploration was carried out in 1 no. of bore hole at site using rotary drilling. The depth of bore- hole was taken from the existing ground surface.

4.3 Boring

The bore holes of 150 mm dia. were drilled by using rotary drilling method to collect soil sample up to the specified depth.

4.5 Standard Penetration Test (SPT)

Standard penetration tests as per IS: 2131-1981 was conducted at the bore hole, each at 1.5m interval or change of strata. The tests were performed by using a standard split spoon sampler attached to 'A' rod placed at the test level in the bore hole. The sampler was driven to a depth of 45cm by means of a standard hammer weighing 63.5 Kg. falling freely through a vertical height of 75 cm. Blows required for each 15 cm penetration (Total penetration 45cm) were recorded and the number of blows for last 30cm penetration of the sampler was taken as N values. Blows for first 15 cm penetration of the sampler in each test, were discarded owing to the possible disturbance of the strata during auguring operations. The observed and the corrected N SPT values (IS: 2131-1981) are given with graphical representation on and soil profile.

5.0 GROUND WATER TABLE

Water table was not encountered in the bore hole.

6.0 LABORATORY TESTS

A visual and discrete examination of all the soil samples collected was carried out for deciding the number and type of tests as well as the number of samples to be tested from each bore hole. Based on the strata met at site the following tests were conducted on samples to classify them and to evaluate their index and Engineering properties

a) Grain size distribution
b) Bulk density and Moisture content
c) Direct Shear Test
d) Triaxial Tests
e) Liquid limits and plastic limits
f) Specific Gravity
g) Chemical analysis of soil and water for chloride and sulphate content.
h) Electrical resistivity test.

a) Grain Size Distribution

Grain size distribution of the soil is determined by sieving the soil sample in a set of IS sieves: 4.75mm, 2.36mm, 0.825mm, 0.6mm, 0.425mm, 0.30mm, 0.150mm, 0.075mm size. Grain Size Analysis curve has been plotted and attached in the appendices of this report for the soil samples collected from various depths of bore-holes.

b) Bulk Density And Natural Moisture Content

Undisturbed samples were collected from the boreholes in thin wall steel sample tubes by taking the dimensions and weight of these sample tubes, the bulk density of the soil is determined. Moisture content of the soil has been calculated by Oven Drying Method.

c) Direct Shear Test

A direct shear test is a laboratory or field test used by geotechnical engineers to measure the shear strength properties of soil or rock material, or of discontinuities in soil or rock masses. The test is performed on specimens from undisturbed soil sample. A specimen is placed in a shear box which has two stacked rings to hold the sample; the contact between the two rings is at approximately the mid-height of the sample. A confining stress is applied vertically to the specimen, and the upper ring is pulled laterally until the sample fails, or through a specified strain. The load applied and the strain induced is recorded at frequent intervals to determine a stress-strain curve for each confining stress. Several specimens are tested at varying confining stresses to determine the shear strength parameters, the soil cohesion (c) and the angle of internal friction (commonly friction angle) (ϕ). The results of the tests on each specimen are plotted on a graph with the peak (or residual) stress on the x-axis and the confining stress on the y-axis. The y-intercept of the curve which fits the test results is the cohesion, and the slope of the line or curve is the friction angle.

d) Triaxial Test

In this test undisturbed soil specimen is subjected to 3 compressive stresses at right angle to one another, horizontally coffining constantly and the vertical stress is gradually increased until each specimen failsto evaluate cohesion and angle of shearing resistance. Triaxial shear tests have been performed by subjecting the cohesive-soil samples to major principal stresses in increase steps. The test specimen is allowed to consolidate under a number of successive increments of vertical pressure, each pressure increment being maintained constant until the deformation ceases, generally in 24 hours. The successive pressure employed are 0.10, 0.20, 0.40, 0.60, 0.80, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0 and 5.0 kg/cm2. Thus, these stress increments are progressively carried-out until the failure of the specimen. The dial gauge readings for measuring the deformation are taken after the application of the pressure increment at the following total elapsed time of 0.25, 1.0, 4.0, 9.0, 16.0, 25.0, 36.0, 49.0, 64.0, 0.81 and 100 minutes until the consolidation is completed.

e) Atterberg Limits

Atterberg Limits in the form of liquid limit, plastic limit and shrinkage limit are determined for the soil to establish its consistency. In the case of cohesion less soil, plastic limit is first determined and if it cannot be determined the soil sample is reported to be non-plastic.

f) Specific Gravity

Specific Gravity of the soil has been determined by Specific Gravity Bottle.

g) Chemical analysis of soil and water for chloride and sulphate content.

i. Heat the clean evaporating dish to 180℃ for 1 hour. Cool in the desiccator, weigh and store in the desiccator until ready for use.

ii. Filter a portion of the sample through any of the filters mentioned in 4.1, Select volume of the sample which has residue between 25 and 250 mg. preferably between 100 to 200 mg. This volume may be estimated from values of specific conductance. To obtain a measurable residue. Successive aliquots of filtered sample may be added to the sample dish,

iii. Pipette this volume to a weighed evaporating dish placed on a-steam-bath. Evaporation may also be performed in a drying oven. The temperature shall be lowered to approximately 98℃ to prevent boiling and splattering of the sample. After complete evaporation of water from the residue. Transfer the dish to an oven at 103-105℃ or 179·181℃ and dry to constant mass, that is, till the difference in the successive weighings is less than 0-5 mg. Drying for a long duration (usually 1 to 2 hours) is done to eliminate necessity of checking for constant mass. The time for drying to constant mass with a given type of sample when a number of samples of nearlv same type are to be analysed has to be determined by trial.

iv. Weigh the dish as soon as it has cooled avoiding residue to stay for long time as some residues are hygroscopic and may absorb water from desiccant that is not absolutely dry.

h) Electrical resistivity test

The purpose of electrical resistivity survey is to determine the subsurface resistivity distribution by making measurements on the ground surface. From these measurements the true resistivity of the subsurface can be estimated against corrosion. The ground resistivity is related to various geological parameters, such as, the mineral and fluid Content, porosity and degree of water saturation in rock. Electrical resistivity surveys have been used for many decades in hydrogeological, mining and geotechnical investigations. More recently, it has been used for environmental surveys. It has the following other purposes:

a) To rapidly explore the subsurface conditions in order to locate ground water, thickness of overburden, depth to different rock types and stratigraphic features.
b) To delineate weak formations, faults and dykes, if any, and to identify location of steeply dipping contacts between different rock types and earth material.
c) To delineate zones of seepage and identify its source around various structures of river valley projects.
d) Assessment of groundwater potential, quality and determination of aquifer characteristics.
e) To correlate data from resistivity survey with those obtained from borehole and trial pit logs.

For earthing of electrical conductors.

Range of Soil Resistivity (ohm-metres)	(Class of Soil)
Less than 25	Severely corrosive
25-50	Moderately corrosive
50-100	Mildly corrosive
Above 100	Very mildly corrosive

7.0 STRENGTH CHARACTERISTICS OF SOIL

The strength of a material is defined as the greatest stress it can sustain. If the stress exceeds strength, failure occurs. Strength analysis can be performed for tensile, compressive and shear stresses. Since soil mass has very little or negligible tensile strength, hence tensile strength analysis is rarely performed. Normally the geometry of most geotechnical problems is such that the soil mass is in compression, but do not fail in compression. Although the introduction of large compressive stresses may result in soil failure, the soil is actually failing in shear, not in compression. Therefore, nearly all geotechnical strength analysis is performed for shear stresses. The shear strength of a soil in any direction is the maximum shear stress that can be applied to the soil in that direction. It can also be defined as the resistance to deformation by continuous shear displacement of soil particles.

The shear strength of soil is basically made up of the following components:

(i) Frictional component:

It is mainly due to interlocking of soil particles and the friction between them.

(ii) Cohesion component:

It is due to mutual attraction that exists between the fine particles of some soils. The shear strength of cohesive soil results both from friction as well as cohesion whereas for cohesion-less soil it results from friction alone.

The shear strength equation was first proposed by French engineer Coulomb. He expressed the shear strength's' as a linear function of total normal stress 'σ' on the potential surface of sliding

$s = c + \sigma \tan(\phi)$

Where s = shear strength

To assess the strength characteristics of soil at the proposed site 1 nos. of bore hole were drilled up to the depth mentioned in the bore log data. This Bore hole was advanced by Shell and Auger method up to the depth specified below the ground surface. While advancing the bore holes SPT tests were conducted at regular intervals of 1.5m depth and representative samples were collected and analyzed for soil classification. Water table was not encountered in the bore. The SPT values obtained have been corrected for overburden pressure. These corrected values have been plotted against depth and are shown in the respective bore log. It has been seen from the plots that the SPT values varying from 31 to 100> has been achieved for various bore holes and at various depth as shown in bore log plot between SPT value and depth. Direct Shear Tests were conducted on undisturbed soil samples collected at regular intervals of 3.0m for evaluating the shear parameters. The results are shown in the bore log.

8.0 DESIGN CRITERIA

Any foundation (shallow footing) is to be safe against possible failure against

a) Excessive shear Failure (the bearing pressure should be within the permissible limits)

b) Excessive settlement

The settlement depends not only on the type of soil below the foundation but also on the type of foundation, material used for construction and functionality of the structure.

9.0 DESIGN METHODOLOGY FOR SOIL

9.1 Raft/Isolated foundation

Since the structure to be constructed on this site is G+2 and one story for future in extension structure Raft foundation has been analyzed, at a depth of 2.0m below EGL and isolated foundation has been analyzed, at a depth of 2.0m & 2.5 below EGL as required by the client on limited soil sample. An allowable settlement of 75mm settlement for raft footing and allowable settlement of 50mm settlement for isolated footing has been considered as per IS: 1904 – 1986. The evaluation of SBC of foundation has been done using following two criteria

Shear Failure Criteria

The safe bearing pressure from interpolation of General & Local Shear failure criteria can be obtained, using the Equation given below

Q_{ab} =0.67C NcSc dc ic + q (Nq-1) sq dq iq + 0.5 B γ Nr Sr dr ir Rw1

Where

C = cohesion in KN/m^2

B = Width of the footing in m

dq, dγ, dc = Depth factors

Sq, Sγ, Sc = Shape factors

Iq, Iγ, Ic = Inclination factors

N'q, N'γ, N'c = Bearing capacity factor

q = Total surcharge at the base level of foundation

W' = Water table correction factor (Considered for flooding and heavy rain)

γ = Bulk unit wt. of foundation soil, in KN/m^3

a) Settlements:

i) Soil profile is given for each bore hole. The Soil profile which is likely to cause greater settlements is to be considered for calculations.

ii) The imposed load at the foundation level is likely to compress the soil up to the depth of approximately equal to 1.5B below the foundations.

iii) The settlements can be calculated using IS-8009 part-I & II.

SAMPLE CALCULATION FOR RAFT FOUNDATION
2.0M DEPTH FOR SHEAR CRITERIA

SAFE BEARING CAPACITY		
Symbol	**Description**	**Value**
C	Cohesion	**2.2 KN/m2**
ϕ	Angle of shearing resistance of soil in degrees	**20**
ϕ_m	Angle of shearing resistance of soil in degrees [$\tan^{-1}(0.67(\tan\phi))$]	13.70
G	Specific Gravity	2.66
γ_d	Dry Density of Soil	17.10
e	Void ratio [$(G\gamma_w/\gamma_d)-1$]	0.56
Interpolation of Bearing Capacity Factor		
N'c	Bearing Capacity Factor (Local Shear)	**14.60**
N'q	Bearing Capacity Factor (Local Shear)	**6.26**
N'r	Bearing Capacity Factor (Local Shear)	**5.23**
	Shape of Base	Rectangle
Sc	Shape Factor (Square)	1.10
Sq	Shape Factor (Square)	1.10
Sr	Shape Factor (Square)	0.80
D	Depth of Foundation	2
B	Width of Foundation	10
Nϕ	$\tan^2(\pi/4 + \phi/2)$	0.018
dc	Depth Factors ($1 + 0.2\ Dt/B\surd N\phi$)	1.01
ic	Inclination Factors	1
iq	Inclination Factors	1
ir	Inclination Factors	1
γ	Density at Foundation Level	17.60 KN/m3
q	Total surcharge at the base level of foundation (γ X D)	35.20 KN/m3
dq = dr	Depth Factors (1 for $\phi < 10^\circ$)	-
dq = dr	Depth Factors ($1+0.1\ Dt/B\sqrt{N\phi}$ for $\phi < 10^\circ$)	1.003
Rw_1	Reduction Factor	1
Qu	Ultimat bearing capacity of Foundation	Qu = 0.5 C Nc Sc dc ic + q (Nq-1) sq dq iq + 0.5 B γ Nr Sr dr ir Rw1
Qu	**Ultimat bearing capacity of Foundation**	**591 KN/m2**
FS	Factor of Safety	2.5
qs	**Qu/FS**	**236 KN/m2**
	Allowable Bearing Capacity of Foundation	**24 KN/m2**

SAMPLE CALCULATION FOR ISOLATED FOUNDATION 2.0M DEPTH FOR SHEAR CRITERIA

SAFE BEARING CAPACITY		
Symbol	**Description**	**Value**
C	Cohesion	**2.2 KN/m2**
ϕ	Angle of shearing resistance of soil in degrees	**20**
ϕ_m	Angle of shearing resistance of soil in degrees [$\tan^{-1}(0.67(\tan\phi))$]	13.70
G	Specific Gravity	2.66
γ_d	Dry Density of Soil	17.10
e	Void ratio [$(G\gamma_w/\gamma_d)-1$]	0.56
Interpolation of Bearing Capacity Factor		
N'c	Bearing Capacity Factor (Local Shear)	**14.60**
N'q	Bearing Capacity Factor (Local Shear)	**6.26**
N'r	Bearing Capacity Factor (Local Shear)	**5.23**
	Shape of Base	Square
Sc	Shape Factor (Square)	1.30
Sq	Shape Factor (Square)	1.20
Sr	Shape Factor (Square)	0.80
D	Depth of Foundation	2
B	Width of Foundation	2
Nϕ	$\tan^2(\pi/4 + \phi/2)$	0.018
dc	Depth Factors ($1 + 0.2\ Dt/B\sqrt{N\phi}$)	1.03
ic	Inclination Factors	1
iq	Inclination Factors	1
ir	Inclination Factors	1
γ	Density at Foundation Level	17.60 KN/m3
q	Total surcharge at the base level of foundation (γ X D)	35.20 KN/m3
dq = dr	Depth Factors (1 for $\phi < 10^\circ$)	-
dq = dr	Depth Factors ($1+0.1\ Dt/B\sqrt{N\phi}$ for $\phi < 10^\circ$)	1.013
Rw_1	Reduction Factor	1
Qu	Ultimat bearing capacity of Foundation	Qu = 0.5 C Nc Sc dc ic + q (Nq-1) sq dq iq + 0.5 B γ Nr Sr dr ir Rw1
Qu	**Ultimat bearing capacity of Foundation**	**321 KN/m2**
FS	Factor of Safety	2.5
qs	**Qu/FS**	**128 KN/m2**
	Allowable Bearing Capacity of Foundation	**13 KN/m2**

SAMPLE CALCULATION FOR RAFT FOUNDATION 2.0M DEPTH FOR SETTLEMENTS CRITERIA

SETTLEMENT CONSIDERATION AS PER IS: 8009 Part I (Fig. 9) (AT THE DEPTH OF 2.0M FROM E.G.L.)		
N_R	N Value Recorded at a depth of 2.0m	31.0
N_C	N Value Corrected at a depth of 2.0m	23.0
B	Width of Footing	10.0 m
	Permissible Settlement As Per IS: 8009 Part I(Fig. 9)	75 mm
	Settlement by applying 1kg/sqcm pressure as per IS:8009-I - 1976	18.0 mm
	Corrected settlement by applying W' (RW) for 1 kg/cm^2	18.0 mm
	Pressure allowed for 75mm settlement (75/corr. Settlement)	4.167
	Bearing Capacity of Foundation	**41.67 t/m2**
	Allowable Bearing Capacity of Foundation	**41.67 t/m2**

SAMPLE CALCULATION FOR ISOLATED FOUNDATION 2.0M DEPTH FOR SETTLEMENTS CRITERIA

SETTLEMENT CONSIDERATION AS PER IS: 8009 Part I (Fig. 9) (AT THE DEPTH OF 2.0M FROM E.G.L.)		
N_R	N Value Recorded at a depth of 2.0m	31.0
N_C	N Value Corrected at a depth of 2.0m	23.0
B	Width of Footing	2.0 m
	Permissible Settlement As Per IS: 8009 Part I(Fig. 9)	50 mm
	Settlement by applying 1kg/sqcm pressure as per IS:8009-I - 1976	16.0 mm
	Corrected settlement by applying W' (RW) for 1 kg/cm^2	16.0 mm
	Pressure allowed for 50mm settlement (50/corr. Settlement)	3.125
	Bearing Capacity of Foundation	**31.25 t/m2**
	Allowable Bearing Capacity of Foundation	**31.25 t/m2**

10.0 DISCUSSION ON SOIL PROFILE

Results of field and laboratory tests indicate that the soil strata is Silty sand with gravel up to depth of 10.5m. Below 10.5m soil strata is Soft Disintegrated Rock up to the depth of exploration (10.5>m). Bore log data of various bore holes are shown in Fig. A.

11.0 CHEMICAL ANALYSIS OF SOIL AND WATER (BIS CODE IS: 456-2000)

Will be submitted final report.

12.0 RESULTS OF ELECTRICAL RESISTIVITY TEST (IS CODE: 3043 – 1987)

Will be submitted final report.

13.0 BEARING CAPACITY

13.1 FROM SHEAR CRITERIA

RAFT/ ISOLATED FOUNDATION

Depth of Foundation (m)	Size of footing (m)	Net Allowable Bearing Capacity (T/Sq.M)
2.0	2.0X2.0	13.0
	2.5X2.5	14.0
	Raft 10 = >	24.0
2.5	2.0X2.0	15.0
	2.5X2.5	16.0

13.2 FROM SETTLEMENT CRITERIA

RAFT/ ISOLATED FOUNDATION

Depth of Foundation (m)	Size of footing (m)	Net Allowable Bearing Capacity (T/Sq.M)
2.0	2.0X2.0	31.25
	2.5X2.5	29.41
	Raft 10 = >	41.67
2.5	2.0X2.0	31.25
	2.5X2.5	29.41

14.0 RECOMMENDATIONS

RAFT/ ISOLATED FOUNDATION

Depth of Foundation (m)	Size of footing (m)	Net Allowable Bearing Capacity (T/Sq.M)
2.0	2.0X2.0	13.0
	2.5X2.5	14.0
	Raft 10 = >	24.0
2.5	2.0X2.0	15.0
	2.5X2.5	16.0

1. Modulus of Subgrade Reaction: The Modulus of soil Subgrade reaction shall be taken as 7880. Kn/m^3 at a depth of 3.0m for design of raft foundation.

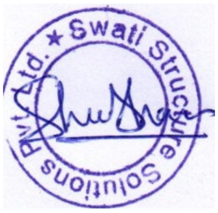
NOTE:-

1. If any loose pockets are observed during excavation for foundation, the same shall be filled with PCC 1:5:10. Foundation can subsequently be placed over this prepared surface.
2. If the profile of soil at any location defers from what is shown, the same shall be brought in notice of soil consultant before laying any foundation.

15.0 CLOSURE

We appreciate the opportunity to perform this investigation for you and have pleasure in submitting this report. Please contact us when we can be of further service to you.

For Swati Structure Solutions Pvt. Ltd



Er. Shubham Ojha