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DEPARTMENT OF CIVIL ENGINEERING
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SOIL INVESTIGATION REPORT

NAME OF WORK : **<u>REVISED</u> RECOMMENDATION OF FOUNDATION FOR THE PROPOSED RECONSTRUCTION OF DILAPIDATED SLUM TENEMENTS (S+6 Floors) AT CHINDADRIPET TENEMENTAL SCHEME IN CORPORATION DIVISION 62, ZONE V OF GREATER CHENNAI CORPORATION.**

CLIENT : **The Executive Engineer**
Division – IV,
Tamil Nadu Slum Clearance Board,
T.P.Chatram (Opp. K6 Police Station),
Chennai – 600 010.

Reference : The Executive Engineer, TNSCB, Chennai, Lr. No. 561/AE(P)/Dn-IV/2021 , Dated 23.06.2021

JOB No : SM&FE 206 / Consultancy / 2021

DATE : 18th February 2023

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REVISED RECOMMENDATION OF FOUNDATION FOR THE PROPOSED RECONSTRUCTION OF DILAPIDATED SLUM TENEMENTS (S+6 Floors) AT CHINDADRIPET TENEMENTAL SCHEME IN CORPORATION DIVISION 62, ZONE V OF GREATER CHENNAI CORPORATION.

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1. INTRODUCTION

The Tamil Nadu Slum Clearance Board (TNSCB), Division – IV, T.P. Chatram, Chennai – 600 010 has proposed to reconstruct dilapidated slum Tenements (S + 6 Floors) at Chindadripet tenemental scheme in Corporation Division 62, zone V of Greater Chennai Corporation. The officials of TNSCB, Division – IV, T.P. Chatram, Chennai – 600 010 have approached the Head, Division of Soil Mechanics and Foundation Engineering, Department of Civil Engineering, College of Engineering, Guindy (CEG), Anna University**,** Chennai - 25 to carryout soil investigation in the proposed site and to recommend the most suitable foundation system for the proposed reconstruction of dilapidated slum Tenements (S+6 Floors) at Chindadripet tenemental scheme in Corporation Division 62, zone V of Greater Chennai Corporation. Accordingly, the work was taken up and field investigation was carried out during 16th August 2021 to 21st August 2021 by M/s VRR Engineering Consultancy, Chennai under the supervision of Faculty members of Division of Soil Mechanics and Foundation

Engineering, Department of Civil Engineering, Anna University**,** Chennai, Executive Engineer, Asst. Executive Engineer and Assistant Engineer of TNSCB, Division – IV, T.P. Chatram, Chennai – 600 010. This report comprises the details of soil investigation, analysis of field and laboratory test results on soil and recommendation of suitable foundation system.

2. SITE CONDITION AND EXPERIMENTAL PROGRAMME

The proposed site is located at Chindadripet in Corporation Division 62, zone V of Greater Chennai Corporation. The site is a plain terrain. The total number of borehole locations has been decided as '3', as agreed by the Officials of Executive Engineer of TNSCB, Division – IV, T.P. Chatram, Chennai and the Professor cum Project Co-ordinator, Division of Soil Mechanics and Foundation Engineering, Department of Civil Engineering, Anna University, Chennai, such that these locations are coming well within the proposed construction area. The nature of field tests includes standard penetration tests, disturbed soil sampling through split spoon sampler, identification of different soil layers, retrieving of rock core samples, location of ground water table, complete logging of the borehole etc,. Laboratory investigation consists of classification tests such as grain size distribution, Atterberg limits, specific gravity and free swell index of soil samples.

The boreholes were advanced from the existing ground level using rotary boring technique supplemented by bentonite mud circulation. Mud circulation was used to stabilize the sides and bottom of the boreholes and then to bring the soil cuts to the surface. Bentonite slurry would also help to minimize the disturbance of the soil at the bottom of the borehole while drilling operation is in progress. In general, rotary boring technique with bentonite mud circulation is found most suitable to make exploratory boreholes of diameter 150 mm (IS 1892 : 1979). During boring operation, borehole was always kept full with the drilling mud so as to prevent any disturbance to the soil within the test zone (Plate 1 of Annexure – 1).

Standard penetration tests were conducted at every 1.0 m interval up to 6.0 m depth and thereafter 1.5 m interval in all the borehole locations. These SPT tests were carried out using Winch and Auto-trip free fall device for which the expected energy level is approximately 60% to 70%. The 'N' value resulting from this procedure may be considered as N_{60}. Disturbed soil samples collected through the split spoon sampler

were preserved and transported to the soil testing laboratory for detailed identification tests. During the progress of soil investigation at the proposed site, the site was monitored by the Professor of Division of Soil Mechanics and Foundation Engineering, Department of Civil Engineering, CEG Campus, Anna University, Chennai – 25.

All field and laboratory tests were conducted as per the Indian Standard Testing procedure (SP 36 Part I: 1987 & Part II: 1988). All the field test results recorded in the bore logs are illustrated in figures A-1 to A-3. The field 'N' values at different depths and samples collected at these depths are mentioned in the bore logs. Laboratory test results (index and engineering properties) of soil samples collected through split spoon sampler are summarized in table A-1 to table A-3 of this report.

3. REVIEW OF FIELD AND LABORATORY TEST RESULTS OF SOIL PROFILE

Figures 1 show the variation of SPT 'N' value of different soil layers with respect to depth in BH 1 to BH 3 of the proposed site. It could be seen from figure 1 that the variations of SPT 'N' values are almost uniform in all the three bore holes, indicating the homogeneity of soil layer (Plate 2 of Annexure – 1).

3.1 Summary of Soil Profile in BH 1 to BH 3 Locations

1. Debris was found in top 1.0 m depth in BH 3 bore-hole location.
2. Brown Sand / Silty Sand was observed from top 1.0 m to 15.0 m depth in BH 1 location, 1.0 m to 10.5 m depth in BH 2 location, 2.5 m to 10.5 m depth in BH 3 locations with SPT 'N' value varying from 9 to >100.
3. In between these Silty Sand layers, Silty Clay was encountered in 13.5 m depth in BH 1 location, 10.5 m depth in BH 2 location and from 10.5 m to 12.0 m depth in BH 3 location, 12.0 m depth in BH 4 location and form 10.5 m to 12.0 m depth in BH 5 location with SPT 'N' value varying from 10 to 46.
4. Greyish Brown weathered sediment layer was observed in 19.5 m depth in all three bore-hole locations SPT 'N' values of >100.
5. Brownish Grey Weathered Gneiss Rock layer was found from 19.5 m to 24.0 m in BH 1 location, from 19.5 m to 22.5 m depth in BH 2 location and from 21.5 m to 22.5 m depth in BH 3 location.
6. The ground water table was observed from 2.2 m to 2.6 m depth at the time of In-situ Soil Investigation work.

Thus, it is evident that the soil profile is homogeneous with reference to relative density / consistency in the proposed site as reflected from BH 1 to BH 3 locations (Figure 1).

4.0 SHEAR STRENGTH PROPERTIES AND ELASTICITY MODULUS VALUES 'Es' OF SOIL SAMPLES

The Geotechnical design parameters required to determine the bearing capacity and settlement of foundation system are arrived by analyzing the Field Bore-Log profile and Laboratory test results and listed in table A-1 to table A-3. The 'E_s' values are computed based on Bowles 1997 correlation.

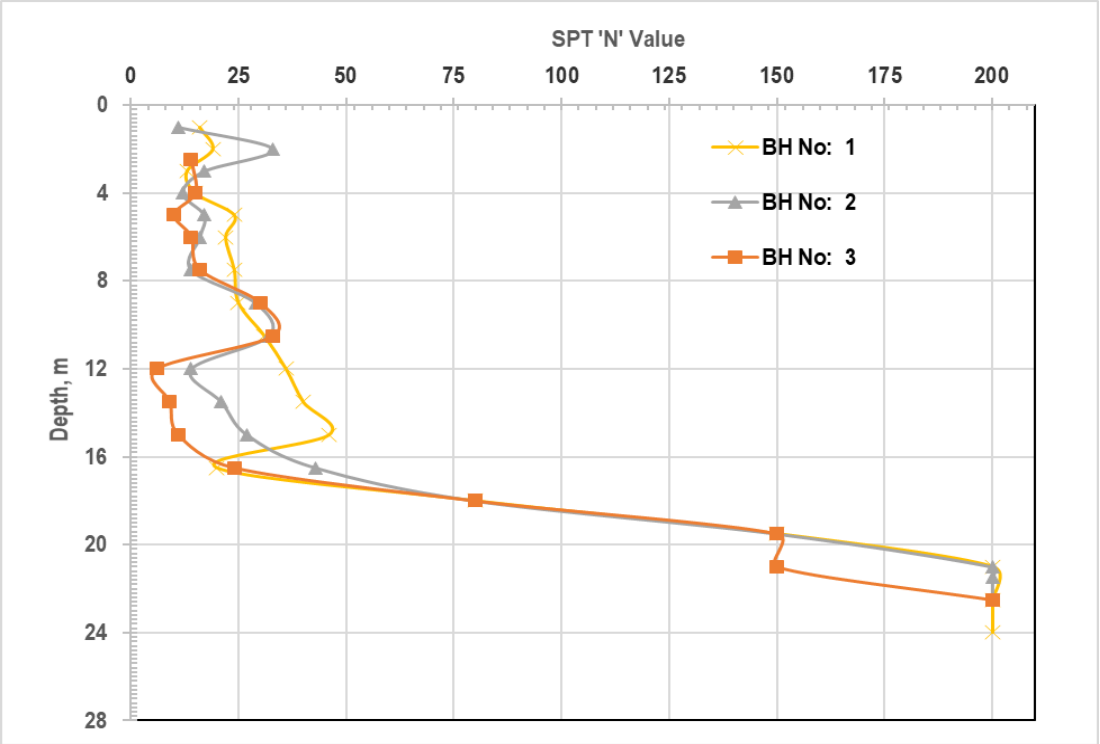

Figure (1) Variation of SPT 'N' value of different soil layers with respect to depth in Different Borehole Locations of the Site

5.0 COMPUTATION OF BEARING CAPACITY AND SETTLEMENT

Based on the observation made in the boreholes 1, 2 & 3 an attempt is made to arrive the safe bearing capacity and allowable settlement of the foundation soil. The depth of foundation is taken as 3.0 m and size of foundation as 12.26 m x 56.75 m to compute safe bearing capacity. The SPT 'N' value, Correlated Elastic Modulus 'E_s' value (Bowles 1997) and shear strength parameters and engineering properties of soil layers which are required to determine bearing capacity and settlement were taken from Table 1 to Table 3. Safe bearing capacity and settlement computations were made for the three bore-hole data. The least value of safe bearing capacity is recommended for the proposed site. The Safe Bearing Capacity is computed using Bureau of Indian Standard IS 6403-1981 equation. The elastic settlement of foundation is arrived based on IS

8009 (Part I) 1976 Method using the Elastic Modulus values of soil layers for the proposed site. The ground water table depth is taken as ground surface to compute safe bearing capacity and settlement of foundation.

5.1 Safe Bearing Capacity

For the determination of Safe Bearing Capacity using IS 6403-1981 equation, the average 'N' value and shear strength parameters below foundation level upto the influence depth of 1B is considered (Varghese 2005) for a depth of foundation 3.0 m and size of foundation as 12.26 m x 56.75 m. The safe bearing capacity thus computed is shown in Table 1. In general, the bearing capacity is a function of size of foundation for a given in-situ shear strength values. Accordingly, higher the width of foundation higher would be the bearing capacity. However, it is very important that bearing capacity should also satisfy the allowable settlement criteria. As seen from table 1, the safe bearing capacity keeps varying from 306 kN/m^2 to 1274 kN/m^2 for BH 1 to BH 3 locations at 3.0 m depth for 12.26 x 56.75 m foundation size.

TABLE 1 Net Safe Bearing Capacity of the proposed Site (Depth of Foundation is 3.0 m)

Borehole Locations	Size of Foundation	Design Shear Strength Parameters		Net Safe Bearing Capacity (kN/m^2) IS 6403-1981 Equation
		'c' (kN/m^2)	Φ in Degrees	
BH 1	12.26 m x 56.75 m	0.00	35.80	1274.00
BH 2		27.90	24.70	438.00
BH 3		16.20	23.90	306.00

5.2 Settlement Calculations for Foundation Soil

One of the important aspects of any foundation systems is to satisfy the settlement criteria apart from bearing capacity criteria. The total settlement of foundation is becoming very critical, especially if the foundation is located on clays, because the clay layer is expected to undergo excessive consolidation settlement over a period of time under sustained loadings which of-course depends on the state of clay (initial water content / void ratio), whereas in the case of loose sand layer, elastic or immediate settlement plays a crucial role. In the proposed site, the soil profile below foundation depth is predominantly Silty Sand and Silty Clay layer. Hence, elastic settlement and consolidation settlement were computed for 12.26 m x 56.75 m

foundation upto the influence depth of "2B" below the foundation depth. The computed settlements are varying between 26.78 mm to 56.41 mm for 12.26 m x 56.75 m size foundation (Table 2). ***The allowable settlement as per IS 1904 Table I 1986 is limited to 50 mm for individual footing and 100 mm for raft foundation.***

TABLE 2 Settlement calculations for the proposed Site (Depth of Foundation is 3.0 m)

Borehole Locations	Size of Foundation (m)	Pressure (kN/m^2)	Elastic Settlement (mm)	Consolidation Settlement of Clay layer (mm)	Total Settlement (mm)
BH 1	12.26 m x 56.75 m	160	26.78	-	26.78
BH 2			32.32	4.19	36.51
BH 3			46.60	9.81	56.41

6.0 COMPUTATION OF SAFE PILE CARRYING CAPACITY

Attempts are also made to suggest pile foundation for varying pile diameter. For computing the load carrying capacity of pile, Indian Standard IS 2911 (Part 1/Sec. 2) 2010 method and Meyerhof 1959 formula (Based on SPT 'N' Value) are used. The diameters of piles are assumed as 450 mm, 500 mm, 600 mm, 700 mm and 900 mm and the length of the pile is taken as 21.0 m to 23.0 m. Safe pile carrying capacity computations were made for all three-borehole data. The Indian Standard IS 2911 (2010) specifies that the base resistance should not exceed 1000 to 1100 t/m^2 for bored cast-in-situ piles and 1500 t/m^2 for precast driven piles.

For calculating the skin friction along the pile length of 21.0 m to 23.0 m, the design 'N' values and shear strength parameters for the respective depths were used. The soil layers in top 3 m depth may induce settlement of surrounding soil while pile driving which in turn may cause negative skin friction. Hence, the safe frictional resistance is computed by neglecting these layer's frictional capacity and the negative skin friction value was suitably deducted in the computation of safe bearing capacity of piles. The safe end bearing resistance and safe skin frictional resistance are together added for different pile diameter and the total safe load carrying capacity of pile thus computed is shown in Table 1. The calculations of pile carrying capacity by static formula (IS 2911: 2010) and Meyerhof formula (1959) are presented in Annexure 3. The factor of safety of 2.5 has been used for determining safe end bearing and also frictional capacity of bored cast-in-situ piles.

TABLE 3 Safe Load carrying capacity of Bored Cast-In-Situ Pile of 21.0 to 23.0 m Length for varying Diameter

Borehole Location	Pile capacity for Bored Cast-In-Situ Piles, (kN) IS 2911 Part-I 2010 Static Formula									
Diameter of Pile (mm)	Based on Shear Strength Parameters ('c' and 'Φ')					Based on SPT 'N' Values				
	450	500	600	700	900	450	500	600	700	900
BH 1	1139	1344	1802	2322	3551	1027	1220	1652	2148	3327
BH 2	1152	1359	1819	2342	3576	1040	1235	1670	2168	3353
BH 3	1166	1374	1838	2364	3605	1043	1237	1673	2172	3358

The uplift capacity of a pile is given by sum of the frictional resistance and the weight of the pile (buoyant or total as relevant) as per Section 6.3.2 of IS 2911 (Part 1/Sec. 2) 2010. As per codal provisions, the recommended factor of safety is 3.0 in the absence of any pull-out test results and 2.0 with pullout test results. Uplift capacity can be obtained from static formula by ignoring end-bearing, but adding weight of the pile (buoyant or total as relevant). The safe uplift capacities of pile for varying diameter are given in Table 2.

TABLE 4 Safe Uplift Capacity of 21.0 to 23.0 m Length Pile for varying Diameter (IS 2911 (Part 1/Sec. 2) 2010

Borehole Location	Safe Uplift Capacity (kN) IS 2911 (Part 1/Sec. 2) 2010				
Diameter of Pile (mm)	450	500	600	700	900
BH 1	497	563	700	846	1162
BH 2	510	577	718	866	1188
BH 3	530	600	747	903	1242

7. CONCLUSIONS AND RECOMMENDATIONS

Based on the discussions made in sections 3, 4, 5 and 6, the following recommendations are furnished for the reconstruction of dilapidated slum Tenements (S+6 Floors) at Chindadripet tenemental scheme in Corporation Division 62, zone V of Greater Chennai Corporation.

Option – 1 (Shallow Foundation – Raft)

1) It is recommended to provide **RAFT FOUNDATION.**

2) The recommended depth of Raft Foundation is 3.0 m from the lowest borehole level of the site.

3) The recommended safe bearing capacity at 3.0 m from the existing borehole level of the site is 160 kN/m^2. The permissible settlement for Raft Foundation is 100 mm.

4) The computed Settlement of sub-soil for are varying between 26.78 mm to 56.41 mm for 12.26 m x 56.75 m size foundation. The computed settlement value at 3.0 depth is lower than the permissible settlement values of 100 mm as per Table I of IS 1904.

5) It is recommended to provide suitable supporting system to excavate soil up to 3.0 m depth to avoid collapse of soil mass.

6) Dewatering shall be adopted if water seepage encountered while excavating 3.0 m depth soil mass.

7) The TDS and chemical content of ground water may be checked and ensured that they are not exceeding the permissible limits prior to the use of same for construction activities.

Option – 2 (Pile Foundation)

1) If any difficulties are encountered while excavating 3.0 m depth in the sandy soil, even though dewatering & supporting system are adopted at site, because of high seepage of water, constrains encountered while excavating huge area at site, it is recommended to provide pile foundation for the proposed site.

2) The recommended type of pile foundation is ***"Bored Cast-In-Situ Pile"***

3) The recommended safe vertical and lateral pile carrying capacity of the 21.0 m to 23.0 m length of 'bored cast in-situ pile' for varying diameter is shown in Table 3. The required number of piles may be varied with respect to the varying column loads.

4) The bored cast in-situ pile shall be terminated at 21.0 m to 23.0 m in Brownish Grey Weathered Gneiss Stratum.

5) With regard to execution of bored cast-in-situ pile, procedure outlined in IS 2911 Part 1 Section 2: 2010 may be referred and scrupulously followed.

6) Pile load test shall be conducted to ensure the designed pile carrying capacity. The minimum grade of concrete for pile foundation shall be M 30 to M 40.

TABLE 5 Safe Load carrying capacity and Lateral Load Capacity of Bored Cast-In-Situ Pile for varying diameter and for a length of 21.0 to 23.0 m from the existing ground level (Borehole level)

Diameter of Pile (mm)	Recommended Safe Load carrying capacity of Bored Cast-In-Situ Piles, (kN)	Recommended Lateral Load Capacity for 5 mm deflection, (kN)	Depth of fixity from bore-hole level (m)
450	1000	87.20	3.36
500	1100	103.70	3.65
600	1500	138.10	4.23
700	2000	177.30	4.78
900	3000	264.30	5.85

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FIELD BORE LOG PROFILE

Project : Reconstruction of Dilapidated Slum Tenements (S+6 Floors) at Chindadripet Scheme in Corporation Division 62, Zone V of Greater Chennai Corporation								
BH NO		BH 1		DATE OF START				16-08-2021
SITE		Chinthadripet		DATE OF COMPLETION				17-08-2021
DIA OF BORING		100 / 150 mm		GROUND WATER LEVEL (m)				2.5
TYPE OF BORING		Rotary - Autotrip SPT		RL with respect to Bed Level (m)				-
Depth below EGL(m)	**Soil / Rock Profile**	**Description / Classification of Soil and Rock / Weathering Grade of Rock as per IS 4464**		**Standard Penetration Test (SPT) / UDS / Core Drilling**				**Relative Density or Consistency of Soil / Strength of Rock**
				15	30	45	N	
1.0		Brown Sand (SP)		5	7	9	16	Medium Dense
2.0		Brown Sand (SP)		8	9	10	19	Medium Dense
3.0		Brown Sand (SP)		6	5	8	13	Medium Dense
4.0		Brown Sand (SP)		5	8	7	15	Medium Dense
5.0		Brown Sand (SP)		8	11	13	24	Medium Dense
6.0		Brown Sand (SP)		8	12	10	22	Medium Dense
7.5		Brown Sand (SP)		10	13	11	24	Medium Dense
9.0		Greyish Brown Sand (SP)		10	11	14	25	Medium Dense
10.5		Greyish Brown Sand (SP)		12	18	13	31	Dense
12.0		Greyish Sand (SP)		14	20	16	36	Dense
13.5		Greyish Silty Sand (SM-SP)		13	18	22	40	Dense
15.0		Greyish Silty Sand (SM-SP)		14	21	25	46	Dense
16.5		Greyish Silty / Clayey Sand With Lime Particles (SC)		6	5	15	20	Medium Dense
18.0		Greyish Silty Sand With Lime Particles (SM-SP)		$50_{(8\ cm)}$ Rebound			>100	Very Dense
19.5		Brown Weathered Sediments (Grade VI)		$25_{(0\ cm)}$ Rebound			>100	Hard / Very Weak
21.0		Greyish Weathered Gneiss (Grade V)		$20_{(0\ cm)}$ Rebound; TCR=10%; RQD=0%			>100	Weak
22.5		Greyish Weathered Gneiss (Grade V)		$20_{(0\ cm)}$ Rebound; TCR=40%; RQD=8%			>100	Weak
24.0		Greyish Weathered Gneiss (Grade IV)		$20_{(0\ cm)}$ Rebound; TCR=28.66%; RQD=13.33%			>100	Moderately Strong
Bore hole has been terminated at 24.0 m from the existing ground level (EGL). Nx Size Core Barrel with Diamond Cutter was used to drill from 19.5 m to 24.0 m depth Rock Stratum.								

Figure A-1

FIELD BORE LOG PROFILE

Project : Reconstruction of Dilapidated Slum Tenements (S+6 Floors) at Chindadripet Scheme in Corporation Division 62, Zone V of Greater Chennai Corporation

BH NO	BH 2	DATE OF START	18-08-2021
SITE	Chinthadripet	DATE OF COMPLETION	19-08-2021
DIA OF BORING	100 / 150 mm	GROUND WATER LEVEL (m)	2.2
TYPE OF BORING	Rotary - Autotrip SPT	RL with respect to Bed Level (m)	-

Depth below EGL(m)	Soil / Rock Profile	Description / Classification of Soil and Rock / Weathering Grade of Rock as per IS 4464	Standard Penetration Test (SPT) / UDS / Core Drilling				Relative Density or Consistency of Soil / Strength of Rock
			15	30	45	N	
1.00		Brown Sand (SP)	4	3	8	11	Medium Dense
2.00		Brown Sand (SP)	23	17	16	33	Dense
3.00		Brown Sand (SP)	7	8	9	17	Medium Dense
4.00		Brown Sand (SP)	6	6	6	12	Medium Dense
5.00		Greyish Brown Sand (SP)	7	9	8	17	Medium Dense
6.00		Greyish Brown Sand (SP)	5	7	9	16	Medium Dense
7.50		Greyish Brown Sand (SP)	4	5	9	14	Medium Dense
9.00		Greyish Brown Sand (SP)	7	10	19	29	Medium Dense
10.50		Greyish Brown Sand (SP)	9	10	22	32	Dense
12.00		Blackish Grey Silty Clay (CH)	4	5	9	14	Stiff
13.50		Blackish Grey Silty Clay (CH)	6	9	12	21	Very Stiff
15.00		Brownish Grey Silty / Clayey Sand (SC)	8	12	15	27	Medium Dense
16.50		Greyish Silty Sand (SM-SP)	13	19	24	43	Dense
18.00		Brown Sand (SP) - Residual Soil	$50_{(6\ cm)}$ Rebound			>100	Very Dense
19.50		Greyish Brown Weathered Sediments (Grade VI)	$30_{(0\ cm)}$ Rebound			>100	Hard / Very Weak
21.00		Brownish Grey Weathered Gneiss (Grade V)	$20_{(0\ cm)}$ Rebound; TCR=17.33%; RQD=0%			>100	Weak
21.50		Brownish Grey Weathered Gneiss (Grade V)	$20_{(0\ cm)}$ Rebound; TCR=48%; RQD=0%			>100	Weak
22.50		Brownish Grey Weathered Gneiss (Grade V)	$20_{(0\ cm)}$ Rebound; TCR=36%; RQD=0%			>100	Weak

Bore hole has been terminated at 22.5 m from the existing ground level (EGL). Nx Size Core Barrel with Diamond Cutter was used to drill from 19.5 m to 22.5 m depth Rock Stratum.

Figure A-2

FIELD BORE LOG PROFILE

Project : Reconstruction of Dilapidated Slum Tenements (S+6 Floors) at Chindadripet Scheme in Corporation Division 62, Zone V of Greater Chennai Corporation								
BH NO	BH 3		DATE OF START				20-08-2021	
SITE	Chinthadripet		DATE OF COMPLETION				21-08-2021	
DIA OF BORING	100 / 150 mm		GROUND WATER LEVEL (m)				2.6	
TYPE OF BORING	Rotary - Autotrip SPT		RL with respect to Bed Level (m)				-	
Depth below EGL(m)	Soil / Rock Profile	Description / Classification of Soil and Rock / Weathering Grade of Rock as per IS 4464	Standard Penetration Test (SPT) / UDS / Core Drilling				Relative Density or Consistency of Soil / Strength of Rock	
			15	30	45	N		
1.5		Debris	-	-	-	-	-	
2.5		Brown Sand (SP)	6	6	8	14	Medium Dense	
4.0		Brown Sand (SP)	7	6	9	15	Medium Dense	
5.0		Brown Sand (SP)	6	5	5	10	Loose	
6.0		Greyish Brown Sand (SP)	6	6	8	14	Medium Dense	
7.5		Greyish Brown Sand (SP)	5	6	10	16	Medium Dense	
9.0		Brown Sand (SP)	9	16	14	30	Medium Dense	
10.5		Greyish Brown Sand (SP)	12	15	18	33	Hard	
12.0		Blackish Grey Silty Clay (CH)	3	2	4	6	Medium Stiff	
13.5		Blackish Grey Silty Clay (CH)	4	4	5	9	Loose	
15.0		Blackish Grey Silty / Clayey Sand (SC)	3	4	7	11	Medium Dense	
16.5		Greyish Brown Silty / Clayey Sand (SC)	10	11	13	24	Medium Dense	
18.0		Brown Sand (SP)	$50_{(5\ cm)}$ Rebound			>100	Very Dense	
19.5		Brown Weathered Sediments (Grade VI)	$30_{(0\ cm)}$ Rebound			>100	Hard / Very Weak	
21.0		Brown Weathered Sediments (Grade VI)	$25_{(0\ cm)}$ Rebound			>100	Hard / Very Weak	
22.5		Brownish Grey Weathered Gneiss (Grade V)	$20_{(0\ cm)}$ Rebound; TCR=18.66%; RQD=0%			>100	Hard / Weak	
Bore hole has been terminated at 22.5 m from the existing ground level (EGL). Nx Size Core Barrel with Diamond Cutter was used to drill from 21.0 m to 22.5 m depth Rock Stratum.								

Figure A-3

Table A-1

Project : Reconstruction of Dilapidated Slum Tenements (S+6 Floors) at Chindadripet Scheme in Corporation Division 62, Zone V of Greater Chennai Corporation

BH No:	1	Ground Water Table Depth (m):	2.5

LABORATORY TEST RESULTS

Depth (m)	SPT 'N' Value	Description / Classification of Soil and Rock / Weathering Grade of Rock as per IS 4464	Index Properties						Specific Gravity	Grain Size Analysis (%)						Direct Shear / Terzaghi and Peck (1974) - Shear Strength Parameters	
			Natural Moisture Content, %	Bulk Density (kN/m^3)	Liquid Limit, %	Plastic Limit, %	Plasticity Index, %	Free Swell Index		Gravel	Coarse Sand	Medium Sand	Fine Sand	Fines		Cohesion (c), kN/m^2	Angle of Friction (Φ) in Degrees
														Silt	Clay		
1.0	16	Brown Sand (SP)	20	18.5	NP	NP	NP	NP	2.64	0	2	59	33	6		0	31
2.0	19	Brown Sand (SP)	18	19.1	NP	NP	NP	NP	2.63	0	0	44	48	8		0	32
3.0	13	Brown Sand (SP)	19	17.7	NP	NP	NP	NP	2.64	0	6	51	37	6		0	29
4.0	15	Brown Sand (SP)	17	18.2	NP	NP	NP	NP	2.63	0	4	59	33	4		0	30
5.0	24	Brown Sand (SP)	18	22.0	NP	NP	NP	NP	2.64	0	0	71	27	2		0	35
6.0	22	Brown Sand (SP)	18	19.6	NP	NP	NP	NP	2.63	0	1	65	31	3		0	34
7.5	24	Brown Sand (SP)	17	20.0	NP	NP	NP	NP	2.63	0	8	58	30	4		0	35
9.0	25	Greyish Brown Sand (SP)	17	20.1	NP	NP	NP	NP	2.64	0	5	61	29	5		0	35
10.5	31	Greyish Brown Sand (SP)	20	21.0	NP	NP	NP	NP	2.64	0	0	55	36	9		0	38
12.0	36	Greyish Sand (SP)	20	21.6	NP	NP	NP	NP	2.63	0	0	30	62	8		0	40
13.5	40	Greyish Silty Sand (SM-SP)	16	22.0	NP	NP	NP	NP	2.66	0	5	57	23	15		0	41
15.0	46	Greyish Silty Sand (SM-SP)	13	22.0	NP	NP	NP	NP	2.66	0	4	57	21	18		0	42
16.5	20	Greyish Silty / Clayey Sand With Lime Particles (SC)	17	22.0	34	18	16	50	2.65	0	5	26	32	37		30	29
18.0	>100	Greyish Silty Sand With Lime Particles (SM-SP)	11	22.0	NP	NP	NP	NP	2.66	0	12	41	26	21		0	42
					Porosity of Rock (%)					Strength of Rock							
										UCS, kN/m^2			I_s, kN/m^2				
19.5	>100	Brown Weathered Sediments (Grade VI)	-	22.0	-				2.67	-			-			0	44
21.0	>100	Greyish Weathered Gneiss (Grade V)	1.54	24.1	2.62				2.68	-			1120			0	45
22.5	>100	Greyish Weathered Gneiss (Grade V)	1.52	24.2	2.52				2.68	24350			1420			0	45
24.0	>100	Greyish Weathered Gneiss (Grade IV)	1.42	24.2	2.47				2.68	28410			1515			0	45

Table A-2

Project : Reconstruction of Dilapidated Slum Tenements (S+6 Floors) at Chindadripet Scheme in Corporation Division 62, Zone V of Greater Chennai Corporation

BH No:	2	Ground Water Table Depth (m):	2.2

LABORATORY TEST RESULTS

Depth (m)	SPT 'N' Value	Description / Classification of Soil and Rock / Weathering Grade of Rock as per IS 4464	Index Properties						Specific Gravity	Grain Size Analysis (%)						Direct Shear / Terzaghi and Peck (1974) - Shear Strength Parameters	
			Natural Moisture Content, %	Bulk Density (kN/m^3)	Liquid Limit, %	Plastic Limit, %	Plasticity Index, %	Free Swell Index		Gravel	Coarse Sand	Medium Sand	Fine Sand	Fines		Cohesion (c), kN/m^2	Angle of Friction (Φ) in Degrees
														Silt	Clay		
1.0	11	Brown Sand (SP)	15	17.2	NP	NP	NP	NP	2.63	0	3	40	50	7		0	28
2.0	33	Brown Sand (SP)	17	21.2	NP	NP	NP	NP	2.63	0	12	27	52	9		0	39
3.0	17	Brown Sand (SP)	17	18.7	NP	NP	NP	NP	2.64	0	14	42	38	6		0	31
4.0	12	Brown Sand (SP)	19	17.5	NP	NP	NP	NP	2.64	0	1	44	50	5		0	28
5.0	17	Greyish Brown Sand (SP)	20	22.0	NP	NP	NP	NP	2.63	0	0	51	44	5		0	31
6.0	16	Greyish Brown Sand (SP)	17	18.5	NP	NP	NP	NP	2.64	0	3	60	34	3		0	31
7.5	14	Greyish Brown Sand (SP)	20	18.0	NP	NP	NP	NP	2.64	0	0	70	27	3		0	30
9.0	29	Greyish Brown Sand (SP)	16	20.7	NP	NP	NP	NP	2.63	0	6	56	33	5		0	37
10.5	32	Greyish Brown Sand (SP)	20	21.1	NP	NP	NP	NP	2.63	0	2	65	27	6		0	38
12.0	14	Blackish Grey Silty Clay (CH)	55	18.0	65	28	37	70	2.59	0	0	11	10	79		88	0
13.5	21	Blackish Grey Silty Clay (CH)	46	19.5	61	27	34	70	2.60	0	0	15	13	72		131	0
15.0	27	Brownish Grey Silty / Clayey Sand (SC)	14	22.0	49	17	32	65	2.65	0	0	44	31	25		50	32
16.5	43	Greyish Silty Sand (SM-SP)	13	22.0	NP	NP	NP	NP	2.63	0	3	40	37	20		0	40
18.0	>100	Brown Sand (SP)	14	22.0	NP	NP	NP	NP	2.64	0	4	74	21	1		0	42
					Porosity of Rock (%)					Strength of Rock							
										UCS, kN/m^2			I_s, kN/m^2				
19.50	>100	Greyish Brown Weathered Sediments (Grade VI)	-	22.0	-				2.67	-			-			0	44
21.00	>100	Brownish Grey Weathered Gneiss (Grade V)	1.64	23.8	2.65				2.68	-			1055			0	45
21.50	>100	Brownish Grey Weathered Gneiss (Grade V)	1.58	24.1	2.62				2.68	-			1170			0	45
22.50	>100	Brownish Grey Weathered Gneiss (Grade V)	1.55	24.1	2.58				2.68	-			1290			0	45

Table A-3

Project : Reconstruction of Dilapidated Slum Tenements (S+6 Floors) at Chindadripet Scheme in Corporation Division 62, Zone V of Greater Chennai Corporation

BH No:	3	Ground Water Table Depth (m):	2.6

LABORATORY TEST RESULTS

Depth (m)	SPT 'N' Value	Description / Classification of Soil and Rock / Weathering Grade of Rock as per IS 4464	Index Properties						Specific Gravity	Grain Size Analysis (%)						Direct Shear / Terzaghi and Peck (1974) - Shear Strength Parameters	
			Natural Moisture Content, %	Bulk Density (kN/m^3)	Liquid Limit, %	Plastic Limit, %	Plasticity Index, %	Free Swell Index		Gravel	Coarse Sand	Medium Sand	Fine Sand	Fines		Cohesion (c), kN/m^2	Angle of Friction (Φ) in Degrees
														Silt	Clay		
2.5	14	Brown Sand (SP)	20	18.0	NP	NP	NP	NP	2.64	0	0	30	63	7		0	30
4.0	15	Brown Sand (SP)	18	18.2	NP	NP	NP	NP	2.64	0	5	46	45	4		0	30
5.0	10	Brown Sand (SP)	19	16.9	NP	NP	NP	NP	2.63	0	1	50	44	5		0	27
6.0	14	Greyish Brown Sand (SP)	18	22.0	NP	NP	NP	NP	2.63	0	3	55	37	5		0	30
7.5	16	Greyish Brown Sand (SP)	16	18.5	NP	NP	NP	NP	2.64	0	3	68	25	4		0	31
9.0	30	Brown Sand (SP)	17	20.9	NP	NP	NP	NP	2.63	0	2	66	30	2		0	37
10.5	33	Greyish Brown Sand (SP)	17	21.2	NP	NP	NP	NP	2.63	0	2	66	30	2		0	39
12.0	6	Blackish Grey Silty Clay (CH)	61	15.3	84	33	51	129	2.60	0	1	8	5	86		38	0
13.5	9	Blackish Grey Silty Clay (CH)	70	16.5	99	41	58	124	2.61	0	0	1	1	98		56	0
15.0	11	Blackish Grey Silty / Clayey Sand (SC)	35	17.2	54	24	30	75	2.65	0	3	37	20	40		30	25
16.5	24	Greyish Brown Silty / Clayey Sand (SC)	18	22.0	46	18	28	70	2.65	0	0	46	28	26		50	32
18.0	>100	Brown Sand (SP)	9	22.0	NP	NP	NP	NP	2.63	12	18	58	12	0		0	42
					Porosity of Rock (%)					Strength of Rock							
										UCS, kN/m^2		I_s, kN/m^2					
19.5	>100	Brown Weathered Sediments (Grade VI)	-	22.0	-				2.67	-		-				0	44
21.0	>100	Brown Weathered Sediments (Grade VI)	-	22.0	-				2.67	-		-				0	44
22.5	>100	Brownish Grey Weathered Gneiss (Grade V)	1.64	23.4	2.65				2.68	-		1240				0	45

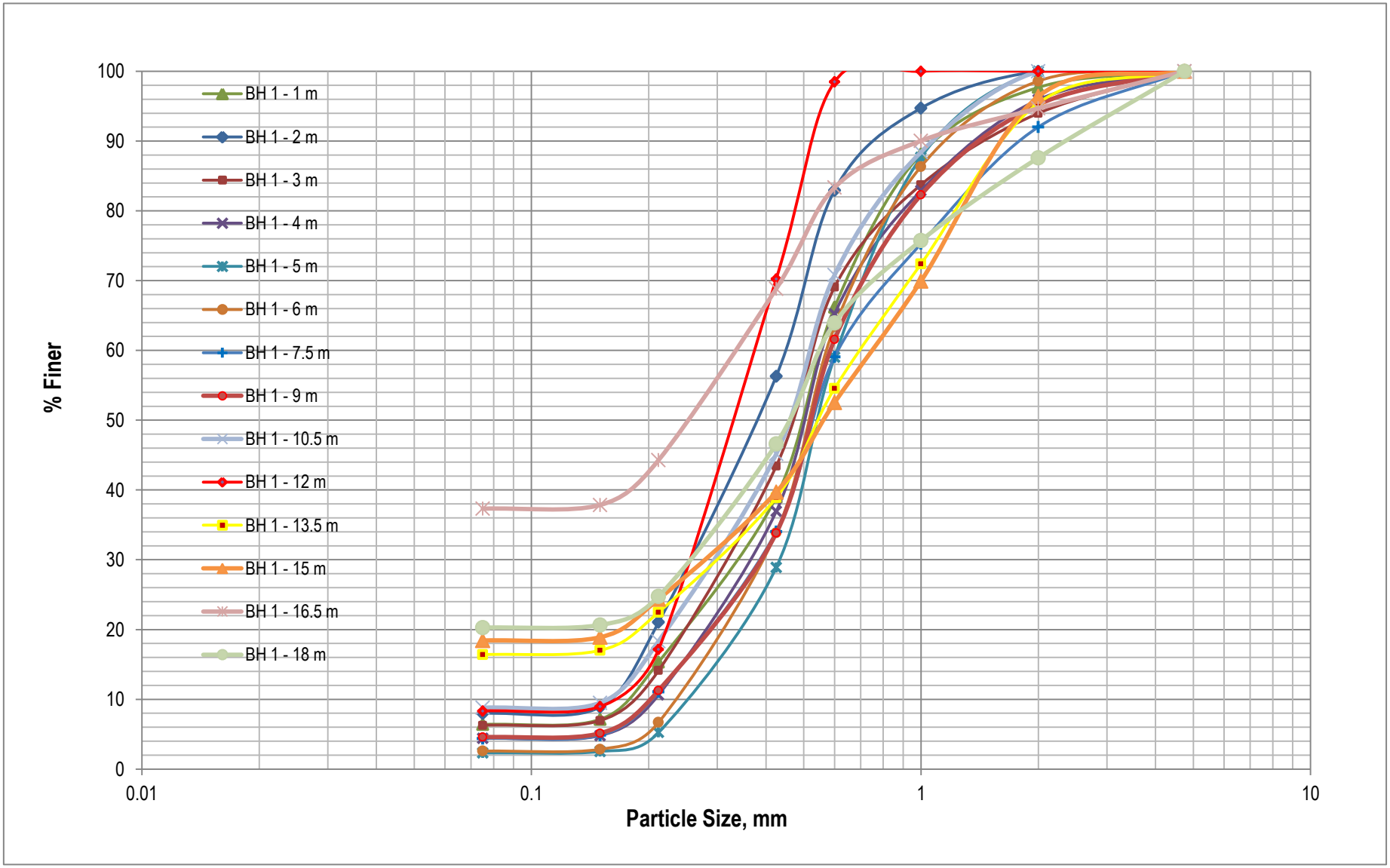


Figure C- 1 Grain Size Distribution of Soil Samples collected in BH 1 Location

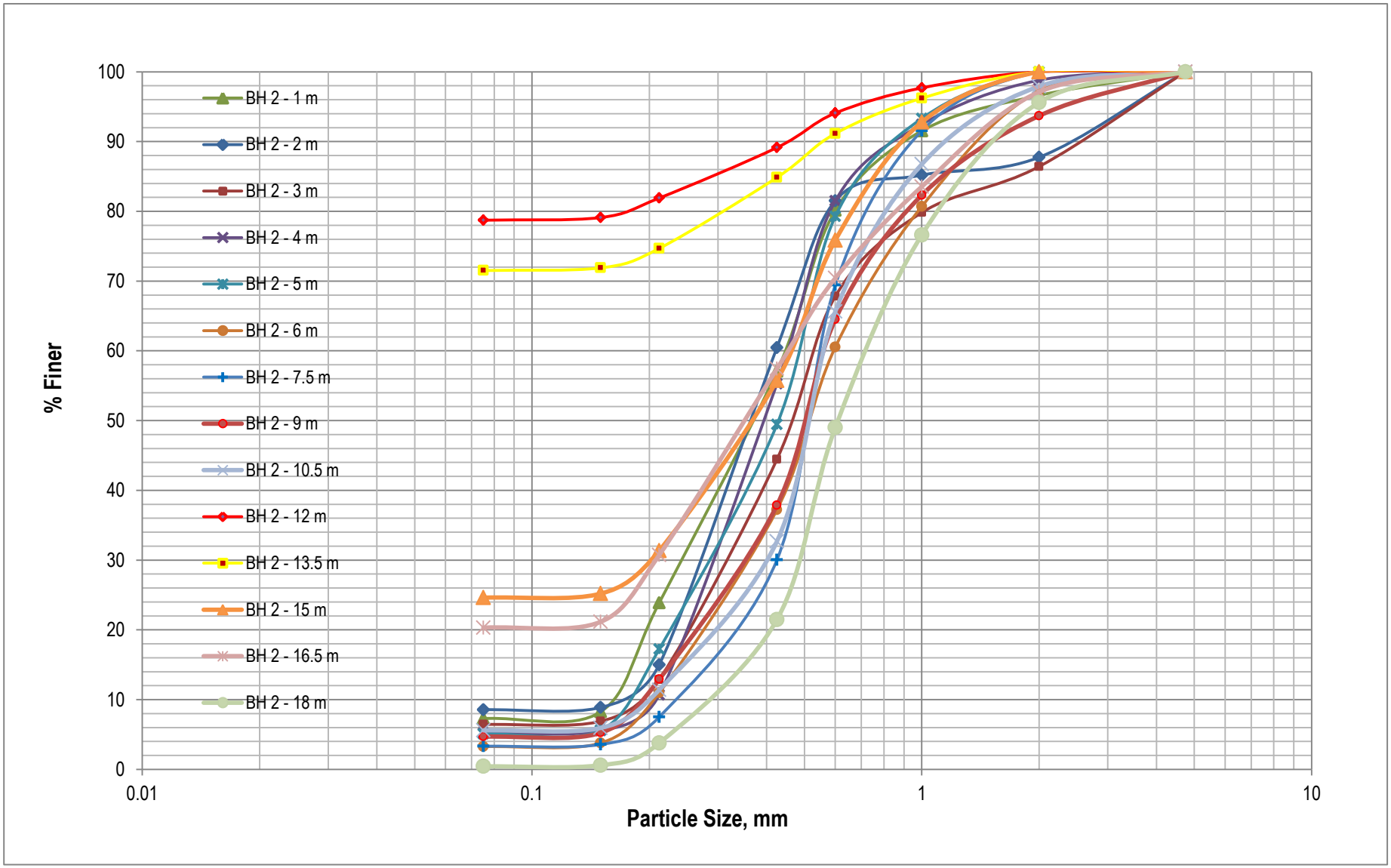


Figure C-2 Grain Size Distribution of Soil Samples collected in BH 2 Location

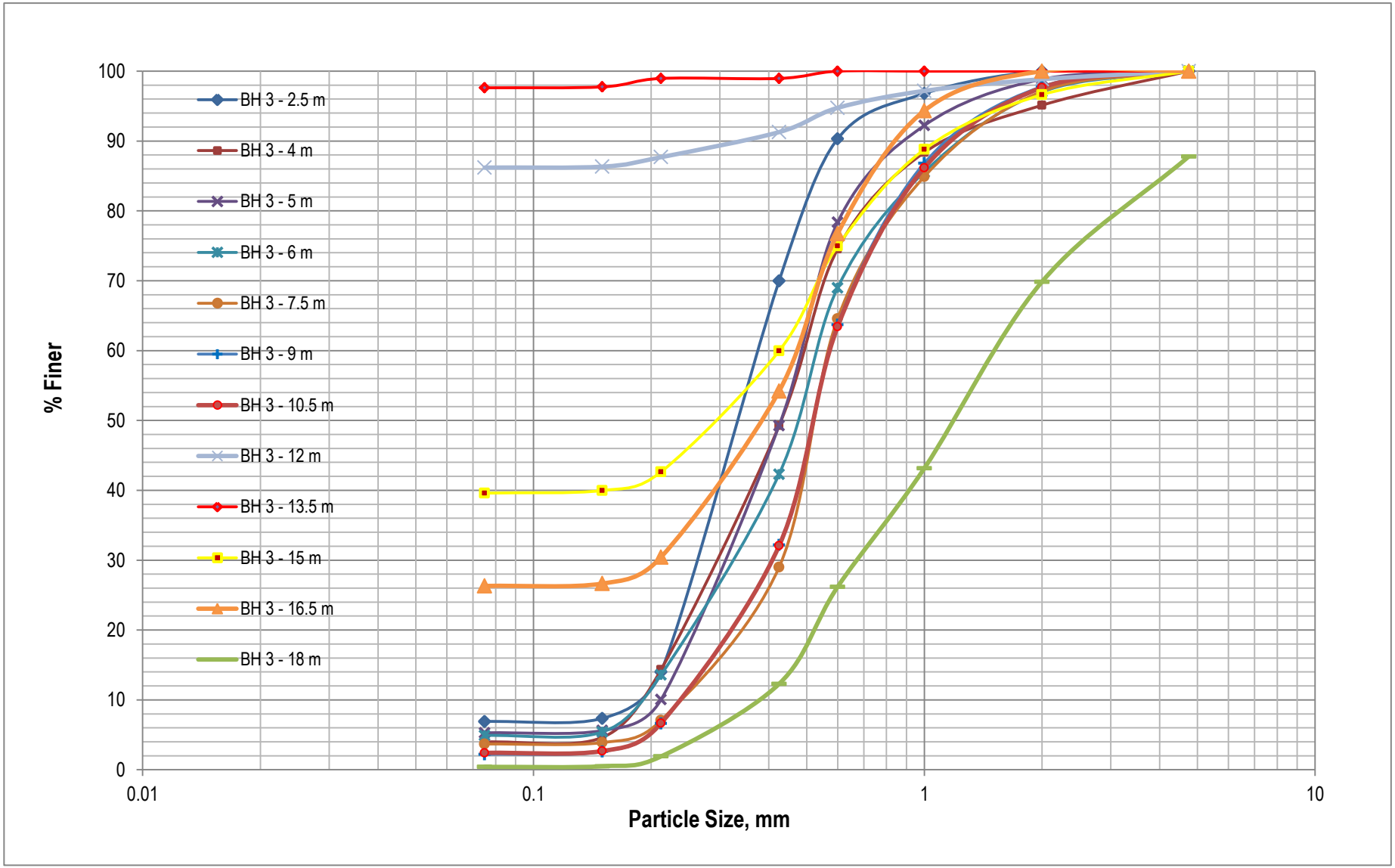


Figure C-3 Grain Size Distribution of Soil Samples collected in BH 3 Location

Annexure – 1

Site Photographs

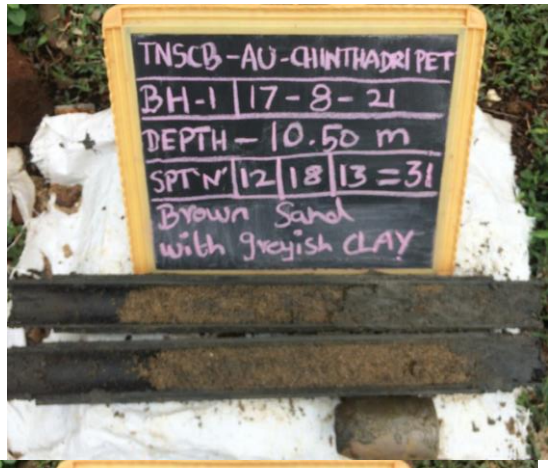
Plate 1 SPT test is in progress at the Reconstruction of Dilapidated Slum Tenements (S+6 Floors) at Chindadripet Scheme in Corporation Division 62, Zone V of Greater Chennai Corporation.

Plate 2 View of Soil / Rock Samples collected in 3 borehole locations of the proposed site

Plate 3 Professor of Division of Soil Mechanics and Foundation Engineering, College of Engineering Guindy, Anna University, Chennai – 600 025 and Official of TNSCB, T.P. Chatram, Chennai – 600 010, inspected the Soil Investigation work at the Reconstruction of Dilapidated Slum Tenements (S+6 Floors) at Chindadripet Scheme in Corporation Division 62, Zone V of Greater Chennai Corporation.

Annexure – 2 View of Soil Samples collected in BH 1 to BH 3 Locations of the Proposed Reconstruction of Dilapidated Slum Tenements (S+6 Floors) at Chindadripet Scheme in Corporation Division 62, Zone V of Greater Chennai Corporation

Plate – 1 Soil Sample Collected by conducting SPT in BH-01 Location


TNSCB-AU-CHINTHADRI PET
BH-1 | 17-8-21
DEPTH - 10.50 m
SPT 'N' | 12 | 18 | 13 = 31
Brown Sand
with Greyish CLAY


TNSCB-AU-CHINTHADRI PET
BH-1 | 17-8-21
DEPTH - 12.00 m
SPT 'N' | 14 | 20 | 16 = 36
Grey Silty SAND


TNSCB-AU-CHINTHADRI PET
BH-1 | 17-8-21
DEPTH - 13.50 m
SPT 'N' | 13 | 18 | 22 = 40
Grey SAND


TNSCB-AU-CHINTHADRI PET
BH-1 | 17-8-21
DEPTH - 15.00 m
SPT 'N' | 14 | 21 | 25 = 46
Grey SAND

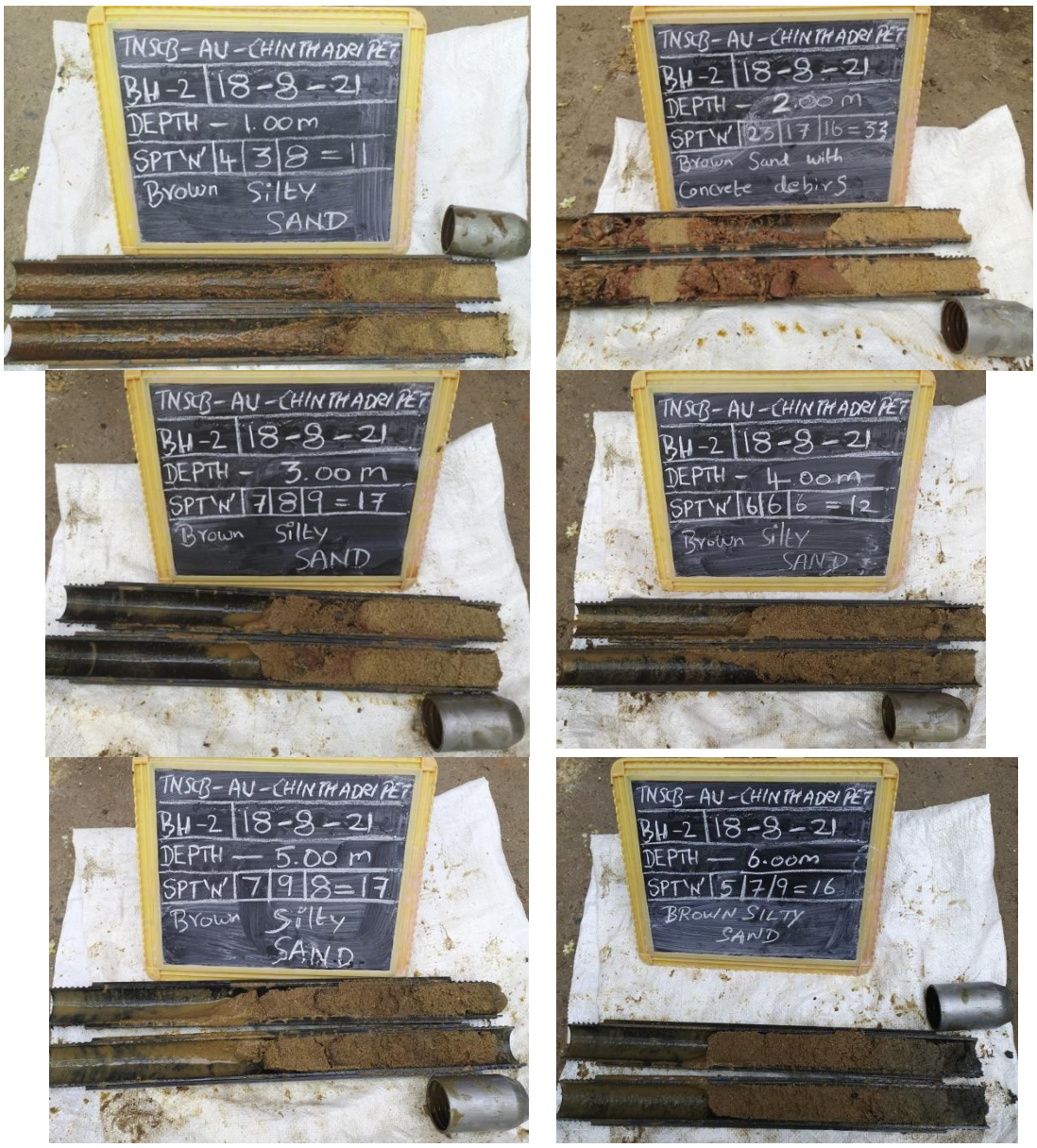

TNSCB-AU-CHINTHADRI PET
BH-1 | 17-8-21
DEPTH - 16.50 m
SPT 'N' | 6 | 5 | 15 = 20
Greenish Grey
Silty SAND

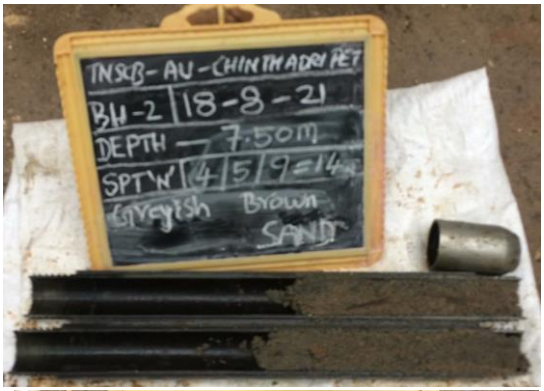

TNSCB-AU-CHINTHADRI PET
BH-1 | 17-8-21
DEPTH - 18.00 m
SPT 'N' | 8cm 50Rb > 100
Brown Weathered
Sediments


TNSCB-AU-CHINTHADRI PET
BH-1 | 17-8-21
DEPTH - 19.50m
'N' 0CM >100 TCR-0%
25 Rb
Weathered Rock


TNSCB-AU-CHINTHADRI PET
BH-1 | 17-8-21
DEPTH - 21.00 m
'N' > 100, TCR-10% RQD-0%
GREYISH WEATHERED
ROCK

Plate – 2 Soil Sample Collected by conducting SPT in BH-02 Location




TNSCB-AU-CHINTHADRIPET
BH-2 | 18-8-21
DEPTH — 7.50m
SPT'N' | 4 | 5 | 9 = 14
Greyish Brown
SAND

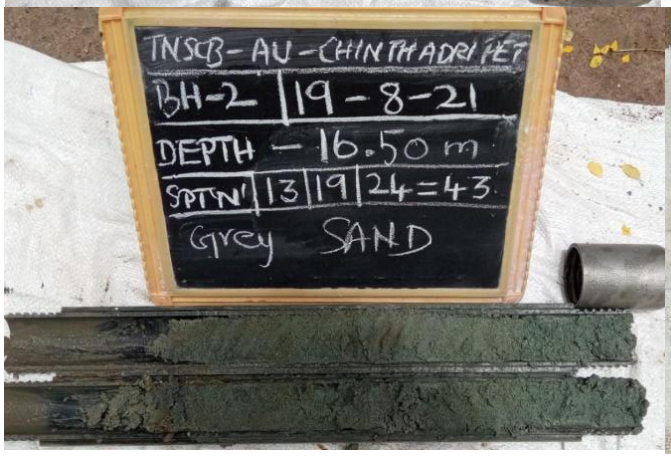

TNSCB-AU-CHINTHADRIPET
BH-2 | 18-8-21
DEPTH — 9.00 m
SPT'N' | 7 | 10 | 19 = 29
Brownish grey
SAND


TNSCB-AU-CHINTHADRIPET
BH-2 | 18-8-21
DEPTH — 10.50 m
SPT'N' | 9 | 10 | 22 = 32
Brownish Grey
SAND


TNSCB-AU-CHINTHADRIPET
BH-2 | 19-8-21
DEPTH — 12.00 m
SPT'N' | 4 | 5 | 9 = 14
Grey Sandy
CLAY


TNSCB-AU-CHINTHADRIPET
BH-2 | 19-8-21
DEPTH - 13.50 m
SPT'N' | 6 | 9 | 12 = 21
Grey Sandy
CLAY


TNSCB-AU-CHINTHADRIPET
BH-2 | 19-8-21
DEPTH - 15.00m
SPT'N' | 8 | 12 | 15 = 27
Greyish brown
Silty SAND


TNSCB-AU-CHINTHADRIPET
BH-2 | 19-8-21
DEPTH - 16.50 m
SPT'N' | 13 | 19 | 24 = 43
Grey SAND


TNSCB-AU-CHINTHADRIPET
BH-2 | 19-8-21
DEPTH - 18.00m
SPT'N' | 6cm 50 Rb > 100
Brown Weathered
Rock

Plate – 3 Soil Sample Collected by conducting SPT in BH-03 Location


TNSCB-AU-CHINTHADRIPET
BH-3 | 21-8-21
DEPTH - 7.50m
SPT'N' | 5 | 6 | 10=16
Brown SAND

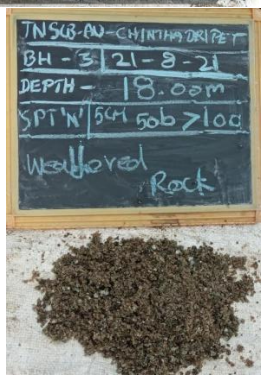

TNSCB-AU-CHINTHADRIPET
BH-3 | 21-8-21
DEPTH - 9.00m
SPT'N' | 9 | 16 | 14=30
Brown SAND


TNSCB-AU-CHINTHADRIPET
BH-3 | 21-8-21
DEPTH - 10.50m
SPT'N' | 12 | 15 | 18=33
Brown SAND


TNSCB-AU-CHINTHADRIPET
BH-3 | 21-8-21
DEPTH - 13.50m
SPT'N' | 4 | 4 | 5=9
Grey Silty CLAY

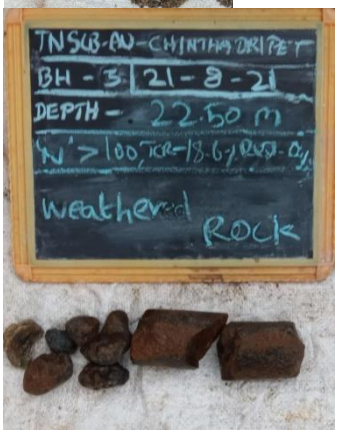

TNSCB-AU-CHINTHADRIPET
BH-3 | 21-8-21
DEPTH - 15.00m
SPT'N' | 3 | 4 | 7=11
Grey Sandy CLAY


TNSCB-AU-CHINTHADRIPET
BH-3 | 21-8-21
DEPTH - 16.50m
SPT'N' | 10 | 11 | 13=24
Grey SAND


TNSCB-AU-CHINTHADRIPET
BH-3 | 21-8-21
DEPTH - 18.00m
SPT'N' | 50cm 50b >100
Weathered Rock


TNSCB-AU-CHINTHADRIPET
BH-3 | 21-8-21
DEPTH - 19.50m
Weathered ROCK


TNSCB-AU-CHINTHADRIPET
BH-3 | 21-8-21
DEPTH - 21.00m
SPT'N' | 0 cm 25Rb >100
Weathered ROCK


TNSCB-AU-CHINTHADRIPET
BH-3 | 21-8-21
DEPTH - 22.50m
Weathered ROCK

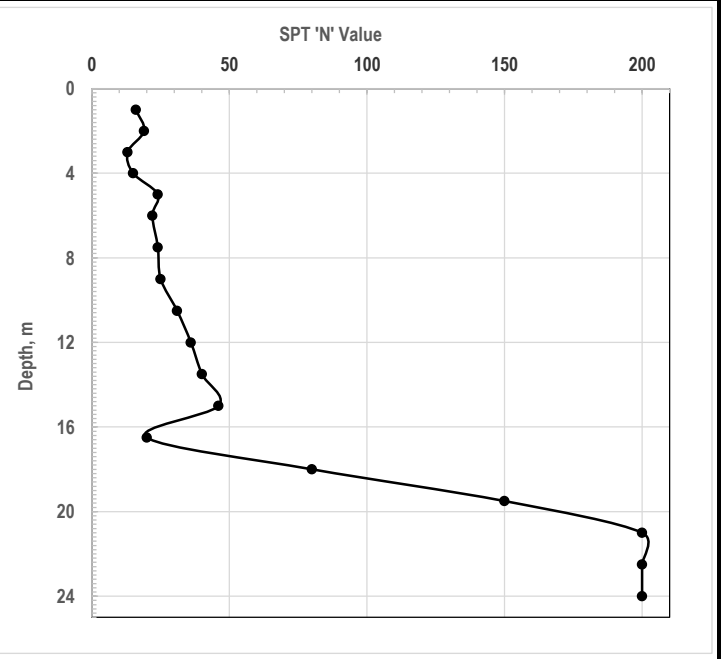
Appendix - A
GEOTECHNICAL DESIGN PARAMETERS

GEOTECHNICAL DESIGN PARAMETERS OF DIFFERENT LAYERS BELOW GROUND LEVEL

PROJECT: Reconstruction of Dilapidated Slum Tenements (S+6 Floors) at Chindadripet Scheme in Corporation Division 62, Zone V of Greater Chennai Corporation

BH No:	1				GWT (m):	2.5	
Depth below GL (m)	In-situ SPT 'N' Value	Description / Classification of Soil and Rock / Weathering Grade of Rock as per IS 4464	Design 'N' Value	Bulk Density, kN/m^3	Modulus of Elasticity (E_s), kN/m^2	Design Shear Strength Parameters	
						Shear Strength (c_u), kN/m^2	Angle of Friction (Φ) in Degrees
1.00	16	Brown Sand (SP)	16	18.5	46400	0	31
2.00	19	Brown Sand (SP)	19	19.1	55100	0	32
3.00	13	Brown Sand (SP)	13	17.7	37700	0	29
4.00	15	Brown Sand (SP)	15	18.2	43500	0	30
5.00	24	Brown Sand (SP)	24	22.0	69600	0	35
6.00	22	Brown Sand (SP)	22	19.6	63800	0	34
7.50	24	Brown Sand (SP)	24	20.0	69600	0	35
9.00	25	Greyish Brown Sand (SP)	25	20.1	72500	0	35
10.50	31	Greyish Brown Sand (SP)	31	21.0	89900	0	38
12.00	36	Greyish Sand (SP)	36	21.6	104400	0	40
13.50	40	Greyish Silty Sand (SM-SP)	40	22.0	116000	0	41
15.00	46	Greyish Silty Sand (SM-SP)	46	22.0	133400	0	42
16.50	20	Greyish Silty / Clayey Sand With Lime Particles (SC)	20	22.0	58000	30	29
18.00	>100	Greyish Silty Sand With Lime Particles (SM-SP)	80	22.0	232000	0	42
19.50	>100	Brown Weathered Sediments (Grade VI)	150	22.0	435000	0	44
21.00	>100	Greyish Weathered Gneiss (Grade V)	200	24.1	1412538	0	45
22.50	>100	Greyish Weathered Gneiss (Grade V)	200	24.2	2511886	0	45
24.00	>100	Greyish Weathered Gneiss (Grade IV)	200	24.2	2511886	0	45

Variation of SPT 'N' Value with respect to Depth

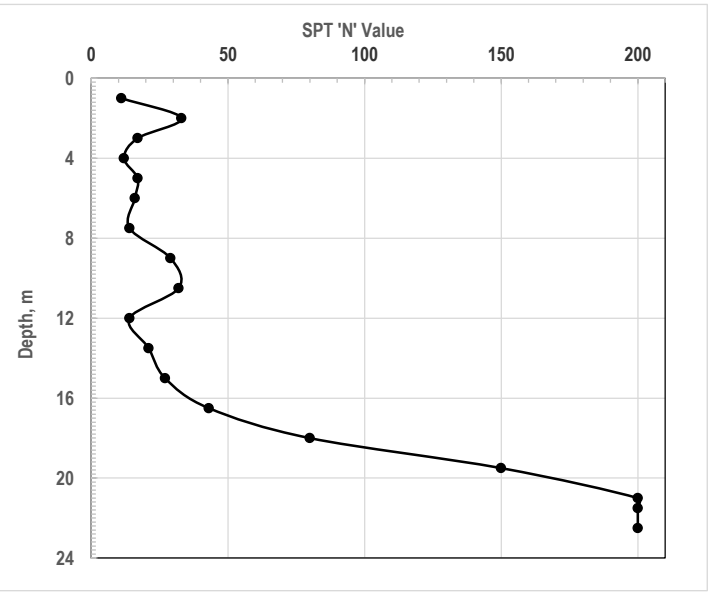


GEOTECHNICAL DESIGN PARAMETERS OF DIFFERENT LAYERS BELOW GROUND LEVEL

PROJECT: Reconstruction of Dilapidated Slum Tenements (S+6 Floors) at Chindadripet Scheme in Corporation Division 62, Zone V of Greater Chennai Corporation

BH No:	2				GWT (m):	2.2	
Depth below GL (m)	In-situ SPT 'N' Value	Description / Classification of Soil and Rock / Weathering Grade of Rock as per IS 4464	Design 'N' Value	Bulk Density, kN/m^3	Modulus of Elasticity (E_s), kN/m^2	Design Shear Strength Parameters	
						Shear Strength (c_u), kN/m^2	Angle of Friction (Φ) in Degrees
1.00	11	Brown Sand (SP)	11	17.2	31900	0	28
2.00	33	Brown Sand (SP)	33	21.2	95700	0	39
3.00	17	Brown Sand (SP)	17	18.7	49300	0	31
4.00	12	Brown Sand (SP)	12	17.5	34800	0	28
5.00	17	Greyish Brown Sand (SP)	17	22.0	49300	0	31
6.00	16	Greyish Brown Sand (SP)	16	18.5	46400	0	31
7.50	14	Greyish Brown Sand (SP)	14	18.0	40600	0	30
9.00	29	Greyish Brown Sand (SP)	29	20.7	84100	0	37
10.50	32	Greyish Brown Sand (SP)	32	21.1	92800	0	38
12.00	14	Blackish Grey Silty Clay (CH)	14	18.0	44000	88	0
13.50	21	Blackish Grey Silty Clay (CH)	21	19.5	65500	131	0
15.00	27	Brownish Grey Silty / Clayey Sand (SC)	27	22.0	78300	50	32
16.50	43	Greyish Silty Sand (SM-SP)	43	22.0	124700	0	40
18.00	>100	Brown Sand (SP)	80	22.0	232000	0	42
19.50	>100	Greyish Brown Weathered Sediments (Grade VI)	150	22.0	435000	0	44
21.00	>100	Brownish Grey Weathered Gneiss (Grade V)	200	23.8	1412538	0	45
21.50	>100	Brownish Grey Weathered Gneiss (Grade V)	200	24.1	1412538	0	45
22.50	>100	Brownish Grey Weathered Gneiss (Grade V)	200	24.1	1412538	0	45

Variation of SPT 'N' Value with respect to Depth

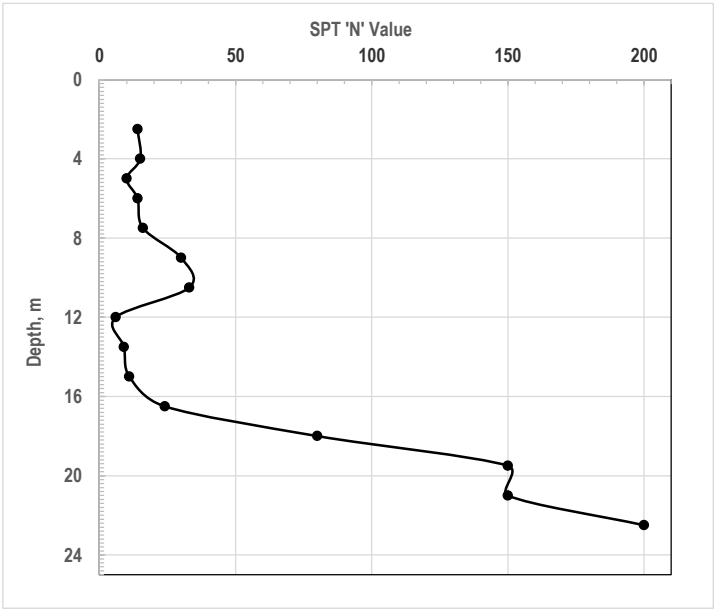


GEOTECHNICAL DESIGN PARAMETERS OF DIFFERENT LAYERS BELOW GROUND LEVEL

PROJECT: Reconstruction of Dilapidated Slum Tenements (S+6 Floors) at Chindadripet Scheme in Corporation Division 62, Zone V of Greater Chennai Corporation

BH No:	3				GWT (m):	2.6	
Depth below GL (m)	In-situ SPT 'N' Value	Description / Classification of Soil and Rock / Weathering Grade of Rock as per IS 4464	Design 'N' Value	Bulk Density, kN/m^3	Modulus of Elasticity (E_s), kN/m^2	Design Shear Strength Parameters	
						Shear Strength (c_u), kN/m^2	Angle of Friction (Φ) in Degrees
2.50	14	Brown Sand (SP)	14	18.0	40600	0	30
4.00	15	Brown Sand (SP)	15	18.2	43500	0	30
5.00	10	Brown Sand (SP)	10	16.9	29000	0	27
6.00	14	Greyish Brown Sand (SP)	14	22.0	40600	0	30
7.50	16	Greyish Brown Sand (SP)	16	18.5	46400	0	31
9.00	30	Brown Sand (SP)	30	20.9	87000	0	37
10.50	33	Greyish Brown Sand (SP)	33	21.2	95700	0	39
12.00	6	Blackish Grey Silty Clay (CH)	6	15.3	19000	38	0
13.50	9	Blackish Grey Silty Clay (CH)	9	16.5	28000	56	0
15.00	11	Blackish Grey Silty / Clayey Sand (SC)	11	17.2	31900	30	25
16.50	24	Greyish Brown Silty / Clayey Sand (SC)	24	22.0	69600	50	32
18.00	>100	Brown Sand (SP)	80	22.0	232000	0	42
19.50	>100	Brown Weathered Sediments (Grade VI)	150	22.0	435000	0	44
21.00	>100	Brown Weathered Sediments (Grade VI)	150	22.0	435000	0	44
22.50	>100	Brownish Grey Weathered Gneiss (Grade V)	200	23.4	1412538	0	45

Variation of SPT 'N' Value with respect to Depth



Appendix - B

SBC AND SETTLEMENT CALCULATIONS

APPENDIX - B - SBC and Settlement Calculations

DETERMINATION OF BEARING CAPACITY USING IS 6403 – 1981 EQUATION

$$q_u = c\, N_c\, s_c\, d_c\, i_c + q_0\, N_q\, s_q\, d_q\, i_q + 0.5\, B\, \gamma_1\, N_\gamma\, s_\gamma\, d_\gamma\, i_\gamma\, W'$$

Where,

q_u - Ultimate Bearing Capacity, kN/m^2

B - Width of foundation, m

c - Undraind cohesion value below foundation, kN/m^2

q_0 - Effective overburden pressure at foundation level (γ_0 D), kN/m^2

γ_0 - Effective unit weight of soil above foundation level

γ_1 - Effective unit weight of soil below foundation level

N_c, N_q, N_γ - Bearing Capacity Factors

s_c, s_q, s_γ - Shape factors

d_c, d_q, d_γ - Depth factors

i_c, i_q, i_γ - Inclination factors

W' - Water table correction factor

Computation of Average Shear Strength Parameters 1 B below Foundation Level

$c_{av} = (c_1H_1 + c_2H_2 + c_3H_3 + c_4H_4)/ (H_1 + H_2 + H_3 + H_4)$

$\tan \varphi_{av} = (\tan \varphi_1H_1 + \tan \varphi_2H_2 + \tan \varphi_3H_3 + \tan \varphi_4H_4)/ (H_1 + H_2 + H_3 + H_4)$

Elastic / Immediate Settlement computation as per IS 8009 (Part I)

9.2.3.2 The immediate settlement beneath the centre or corner of a flexible loaded area is given by:

$$S_i = pB \frac{(1 - \mu^2)}{E} I \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (11)$$

where

μ = Poisson's ratio = 0·5 for clay, and

I = Influence factor [depends on length (L) to breadth (B) ratio of the footing].

Values of E shall be determined from the stress strain curve obtained from triaxial consolidated undrained test. The consolidation pressure adopted in triaxial consolidation test should be equal to the effective pressure at the depth from which the sample has been taken. The values of I may be determined from Fig. 11 for clay layers with various H_t/B ratio and from Table 2 for clay layers of semi-infinite extent.

TABLE 2 VALUES OF I FOR CLAY LAYERS OF SEMI-INFINITE EXTENT

Shape	Influence Factor (I)		
	Centre	Corner	Average
(1)	(2)	(3)	(4)
Circle	1·00	0·64 (edge)	0·85
Square	1·12	0·56	0·95
Rectangle:			
L/B = 1·5	1·36	0·68	1·20
2	1·53	0·77	1·31
5	2·10	1·05	1·83
10	2·52	1·26	2·25
100	3·38	1·69	2·96

APPENDIX - B - SBC and Settlement Calculations

Bowles, J. (1997). Foundation Analysis and Design. 5th Ed., The McGraw-Hill Companies, Inc., New York, 308.

TABLE 5-6

Equations for stress-strain modulus E_s by several test methods

E_s in kPa for SPT and units of q_c for CPT; divide kPa by 50 to obtain ksf. The N values should be estimated as N_{55} and not N_{70}. Refer also to Tables 2-7 and 2-8.

Soil	SPT	CPT
Sand (normally consolidated)	$E_s = 500(N + 15)$ $= 7000\sqrt{N}$ $= 6000N$ — — —	$E_s = (2 \text{ to } 4)q_u$ $= 8000\sqrt{q_c}$ — — — $E_s = 1.2(3D_r^2 + 2)q_c$
	‡$E_s = (15\,000 \text{ to } 22\,000) \cdot \ln N$	*$E_s = (1 + D_r^2)q_c$
Sand (saturated)	$E_s = 250(N + 15)$	$E_s = Fq_c$ $e = 1.0 \quad F = 3.5$ $e = 0.6 \quad F = 7.0$
Sands, all (norm. consol.)	¶$E_s = (2600 \text{ to } 2900)N$	
Sand (overconsolidated)	†$E_s = 40\,000 + 1050N$ $E_{s(\text{OCR})} \approx E_{s,\text{nc}}\sqrt{\text{OCR}}$	$E_s = (6 \text{ to } 30)q_c$
Gravelly sand	$E_s = 1200(N + 6)$ $= 600(N + 6) \quad N \le 15$ $= 600(N + 6) + 2000 \quad N > 15$	
Clayey sand	$E_s = 320(N + 15)$	$E_s = (3 \text{ to } 6)q_c$
Silts, sandy silt, or clayey silt	$E_s = 300(N + 6)$	$E_s = (1 \text{ to } 2)q_c$
	If $q_c < 2500$ kPa use $\quad$ $E_s' = 2.5q_c$ $2500 < q_c < 5000$ use $\quad E_s' = 4q_c + 5000$ where E_s' = constrained modulus $= \dfrac{E_s(1-\mu)}{(1+\mu)(1-2\mu)} = \dfrac{1}{m_v}$	$
Soft clay or clayey silt		$E_s = (3 \text{ to } 8)q_c$

*Vesić (1970).

†Author's equation from plot of D'Appolonia et al. (1970).

‡USSR (may not be standard blow count N).

¶Japanese Design Standards (lower value for structures).

$Senneset et al. (1988)

General sources: First European Conference on Standard Penetration Testing (1974), vol. 2.1, pp. 150–151; *CGJ*, November 1983, pp. 726–737; *Use of In Situ Tests in Geotechnical Engineering*, ASCE (1986), p. 1173; Mitchell and Gardner (1975); *Penetration Testing (Second European Conference)* (1982), vol. 1, p. 160; 11th ICSMFE (1985), vol. 2, pp. 462, 765; vol. 4, p. 2185; *International Symposium on Penetration Testing* (1988), 2 vols.

TABLE 5-6

Equations for stress-strain modulus E_s by several test methods (*continued*)

E_s in kPa for SPT and units of q_c for CPT; divide kPa by 50 to obtain ksf. The N values should be estimated as N_{55} and not N_{70}. Refer also to Tables 2-7 and 2-8.

Soil		
Use the undrained shear strength s_u in units of s_u		
Clay and silt	$I_P > 30$ or *organic*	$E_s = (100 \text{ to } 500)s_u$
Silty or sandy clay	$I_P < 30$ or *stiff*	$E_s = (500 \text{ to } 1500)s_u$ Again, $E_{s,\text{OCR}} \approx E_{s\,\text{nc}}\sqrt{\text{OCR}}$ Use smaller s_u-coefficient for highly plastic clay.

Of general application in clays is

$$E_s = Ks_u \qquad \text{(units of } s_u\text{)} \tag{a}$$

where K is defined as

$$K = 4200 - 142.54I_P + 1.73I_P^2 - 0.007\,1I_P^3 \tag{b}$$

and I_P = plasticity index in **percent.** Use $20\% \le I_P \le 100\%$ and round K to the nearest multiple of 10.

Another equation of general application is

$$E_s = 9400 - 8900I_P + 11\,600I_c - 8800S \qquad \text{(kPa)} \tag{c}$$

I_P, I_c, S = previously defined above and/or in Chap. 2

Appendix - B (1) - SBC Calculations

SBC at 3.0 m Depth in Different Borehole Locations **IS 6403 - 1981 Equation**

Borehole Location	=	**BH 1**	**BH 2**	**BH 3**
Length of foundation (L), m	=	**56.75**	**56.75**	**56.75**
Width of foundation (B), m	=	**12.26**	**12.26**	**12.26**
Depth of foundation (D), m	=	**3.00**	**3.00**	**3.00**
Angle of Internal Friction (φ) in Degrees	=	35.80	24.70	23.90
Undraind cohesion value below foundation (c), kN/m^2	=	0.00	27.90	16.20
Ground Water Table Depth (GWT), m	=	0.00	0.00	0.00
Effective unit weight of soil above foundation level (γ_0), kN/m^3	=	8.50	7.20	8.00
Effective overburden pressure at foundation level (q_0), (γ_0 x D), kN/m^2	=	25.50	21.60	24.00
Effective unit weight of soil below foundation level (γ_1), kN/m^3	=	10.40	9.40	8.50
Bearing Capacity Factor (N_c)	=	49.65	20.28	19.18
Bearing Capacity Factor (N_q)	=	36.81	10.33	9.50
Bearing Capacity Factor (N_γ)	=	54.54	10.42	9.31
Shape factor (s_c)	=	1.04	1.04	1.04
Shape factor (s_q)	=	1.04	1.04	1.04
Shape factor (s_γ)	=	0.91	0.91	0.91
Depth factor (d_c)	=	1.10	1.08	1.08
Depth factor (d_q)	=	1.05	1.04	1.04
Depth factor (d_γ)	=	1.05	1.04	1.04
Inclination factor (i_c)	=	1.00	1.00	1.00
Inclination factor (i_q)	=	1.00	1.00	1.00
Inclination factor (i_γ)	=	1.00	1.00	1.00
Water table correction factor (W')	=	0.50	0.50	0.50
Net Ulitmate Bearing Capacity (q_{nu}), kN/m^2	=	**3821**	**1313**	**918**
Factor of Safety	=	**3.00**	**3.00**	**3.00**
Net Safe Bearing Capacity ($q_{n.safe}$), kN/m^2	=	**1274**	**438**	**306**

Settlement Analysis of Foundation for 12.26 m x 56.75 m Foundation at 3.0 m Depth in BH 1 Location

Length of foundation (L), m	=	**56.75**
Width of foundation (B), m	=	**12.26**
Depth of foundation (D), m	=	**3.00**
L/B Ratio	=	4.63
Avergae Influence Factor as per Table 2 of 8009 (Part-I)	=	1.766
Stress at the Level of Foundation, (q), kN/m^2	=	160.00
Depth correction factor as per Fig. 12 of 8009 (Part-I)	=	0.97
Rigidity factor as per Sec.9.5.2 of 8009 (Part-I)	=	0.80
$\sum q \times B \times ((1-\mu^2) / E_s) \times I_f$ at corner of footing in 'm'	=	0.00488492
Average Settlement of Foundation (mm)	=	**26.78**

Depth (m)	Soil / Rock Type	'μ' Value	'E_s' Value (kN/m^2)	Depth Below Footing 'z' (m)	H_t (m)	H_t/B	'I_f' (Fig. 11-IS 8009-Part I) at Corner	q x B x ((1-μ^2) / E_s) x I_f
1.00	Brown Sand (SP)	0.35000	46400	-	-	-	-	-
2.00	Brown Sand (SP)	0.35000	55100	-	-	-	-	-
3.00	Brown Sand (SP)	0.35000	37700	0.50	1.00	0.07837	0.01200	0.00057024
4.00	Brown Sand (SP)	0.35000	43500	1.50	1.00	0.07267	0.01100	0.00048853
5.00	Brown Sand (SP)	0.35000	69600	2.50	1.00	0.06775	0.01000	0.00029774
6.00	Brown Sand (SP)	0.35000	63800	3.75	1.50	0.09369	0.01400	0.00049325
7.50	Brown Sand (SP)	0.35000	69600	5.25	1.50	0.08567	0.01300	0.00045918
9.00	Greyish Brown Sand (SP)	0.35000	72500	6.75	1.50	0.07891	0.01200	0.00044177
10.50	Greyish Brown Sand (SP)	0.35000	89900	8.25	1.50	0.07314	0.01100	0.00035234
12.00	Greyish Sand (SP)	0.35000	104400	9.75	1.50	0.06815	0.01000	0.00029600
13.50	Greyish Silty Sand (SM-SP)	0.35000	116000	11.25	1.50	0.06380	0.01000	0.00028455
15.00	Greyish Silty Sand (SM-SP)	0.35000	133400	12.75	1.50	0.05998	0.00900	0.00023690
16.50	Greyish Silty / Clayey Sand With Lime Particles (SC)	0.35000	58000	14.25	1.50	0.05658	0.00800	0.00051338
18.00	Greyish Silty Sand With Lime Particles (SM-SP)	0.35000	232000	17.25	4.50	0.15249	0.02300	0.00041075
22.50	Greyish Weathered Gneiss (Grade V)	0.40000	2511886	20.25	1.50	0.04614	0.00700	0.00001218
24.00	Greyish Weathered Gneiss (Grade IV)	0.40000	2511886	22.76	3.52	0.10051	0.01500	0.00002811
				Total (2B)=	**24.52**			**0.00488492**

Settlement Analysis of Foundation for 12.26 m x 56.75 m Foundation at 3.0 m Depth in BH 2 Location

Length of foundation (L), m	=	**56.75**
Width of foundation (B), m	=	**12.26**
Depth of foundation (D), m	=	**3.00**
L/B Ratio	=	4.63
Avergae Influence Factor as per Table 2 of 8009 (Part-I)	=	1.766
Stress at the Level of Foundation, (q), kN/m^2	=	160.00
Depth correction factor as per Fig. 12 of 8009 (Part-I)	=	0.97
Rigidity factor as per Sec.9.5.2 of 8009 (Part-I)	=	0.80
$\sum q \times B \times ((1-\mu^2) / E_s) \times I_f$ at corner of footing in 'm'	=	0.00589553
Average Settlement of Foundation (mm)	=	**32.32**

Depth (m)	Soil / Rock Type	'μ' Value	'E_s' Value (kN/m^2)	Depth Below Footing 'z' (m)	H_t (m)	H_t/B	'I_f' (Fig. 11-IS 8009-Part I) at Corner	q x B x ((1-μ^2) / E_s) x I_f
1.00	Brown Sand (SP)	0.35000	31900	-	-	-	-	-
2.00	Brown Sand (SP)	0.35000	95700	-	-	-	-	-
3.00	Brown Sand (SP)	0.35000	49300	0.50	1.00	0.07837	0.01200	0.00043607
4.00	Brown Sand (SP)	0.35000	34800	1.50	1.00	0.07267	0.01100	0.00061066
5.00	Greyish Brown Sand (SP)	0.35000	49300	2.50	1.00	0.06775	0.01000	0.00042035
6.00	Greyish Brown Sand (SP)	0.35000	46400	3.75	1.50	0.09369	0.01400	0.00067822
7.50	Greyish Brown Sand (SP)	0.35000	40600	5.25	1.50	0.08567	0.01300	0.00078717
9.00	Greyish Brown Sand (SP)	0.35000	84100	6.75	1.50	0.07891	0.01200	0.00038083
10.50	Greyish Brown Sand (SP)	0.35000	92800	8.25	1.50	0.07314	0.01100	0.00034133
12.00	Blackish Grey Silty Clay (CH)	0.30000	44000	9.75	1.50	0.06815	0.01000	0.00072833
13.50	Blackish Grey Silty Clay (CH)	0.30000	65500	11.25	1.50	0.06380	0.01000	0.00052260
15.00	Brownish Grey Silty / Clayey Sand (SC)	0.35000	78300	12.75	1.50	0.05998	0.00900	0.00040361
16.50	Greyish Silty Sand (SM-SP)	0.35000	124700	14.25	1.50	0.05658	0.00800	0.00023878
18.00	Brown Sand (SP)	0.35000	232000	15.75	1.50	0.05355	0.00800	0.00013561
19.50	Greyish Brown Weathered Sediments (Grade VI)	0.40000	435000	18.00	3.00	0.09914	0.01500	0.00014024
22.50	Brownish Grey Weathered Gneiss (Grade V)	0.40000	1412538	22.01	5.02	0.14648	0.02200	0.00007174
				Total (2B)=	**24.52**			**0.00589553**

Consolidation Settlement Analysis of 12.26 m x 56.75 m Foundation at 3.0 m Depth for BH 2 Location

Raft Size (m)= 12.26 x 56.75 Depth of Footing (m) = 3.0

Pressure at Bottom of Footing = 160.00 kN/m^2

Depth (m)	Soil Type	SPT 'N' Value	'Es' Value (kN/m^2)	Depth Below Footing 'z' (m)	Change in Area (m$^{2)}$	Change in Pressure 'Δσ' (kPa)	m_v (m^2/kN)	H (m)	Consolidation Settlement, S_c (mm)
1.0	Brown Sand (SP)	11	31900	-	-	-	-	-	-
2.0	Brown Sand (SP)	33	95700	-	-	-	-	-	-
3.0	Brown Sand (SP)	17	49300	0.5	730.51	152.39	0.000020	1.00	-
4.0	Brown Sand (SP)	12	34800	1.50	801.5200	138.89	0.000029	1.00	-
5.0	Greyish Brown Sand (SP)	17	49300	2.50	874.5300	127.29	0.000020	1.00	-
6.0	Greyish Brown Sand (SP)	16	46400	3.75	968.605	114.93	0.000022	1.50	-
7.5	Greyish Brown Sand (SP)	14	40600	5.25	1085.62	102.54	0.000025	1.50	-
9.0	Greyish Brown Sand (SP)	29	84100	6.75	1207.135	92.22	0.000012	1.50	-
10.5	Greyish Brown Sand (SP)	32	92800	8.25	1333.15	83.50	0.000011	1.50	-
12.0	Blackish Grey Silty Clay (CH)	14	44000	9.75	1463.665	76.06	0.000023	1.50	2.6239
13.5	Blackish Grey Silty Clay (CH)	21	65500	11.25	1598.68	69.63	0.000015	1.50	1.5667
15.0	Brownish Grey Silty / Clayey Sand (SC)	27	78300	12.75	1738.195	64.04	0.000013	1.50	-
16.5	Greyish Silty Sand (SM-SP)	43	124700	14.25	1882.21	59.14	0.000008	1.50	-
18.0	Brown Sand (SP)	80	232000	15.75	2030.725	54.82	0.000004	1.50	-
19.5	Greyish Brown Weathered Sediments (Grade VI)	150	435000	18.00	2261.935	49.21	0.000002	3.00	-
22.5	Brownish Grey Weathered Gneiss (Grade V)	200	1412538	22.01	2699.1052	41.24	0.000001	5.02	-
							Total (2B)=	**24.52**	**4.19**

Total Settlement of Footing (Elatic + Consolidation) as per IS 8009 Part I 1976 Method is 36.51 mm which is lower than allowable settlemet of 100 mm for Raft Foundation as per IS 1904 - 1986

Settlement Analysis of Foundation for 12.26 m x 56.75 m Foundation at 3.0 m Depth in BH 3 Location

Length of foundation (L), m	=	**56.75**
Width of foundation (B), m	=	**12.26**
Depth of foundation (D), m	=	**3.00**
L/B Ratio	=	4.63
Avergae Influence Factor as per Table 2 of 8009 (Part-I)	=	1.766
Stress at the Level of Foundation, (q), kN/m^2	=	160.00
Depth correction factor as per Fig. 12 of 8009 (Part-I)	=	0.97
Rigidity factor as per Sec.9.5.2 of 8009 (Part-I)	=	0.80
$\sum q \times B \times ((1-\mu^2) / E_s) \times I_f$ at corner of footing in 'm'	=	0.00850189
Average Settlement of Foundation (mm)	=	**46.60**

Depth (m)	Soil / Rock Type	'μ' Value	'E_s' Value (kN/m^2)	Depth Below Footing 'z' (m)	H_t (m)	H_t/B	'I_f' (Fig. 11-IS 8009-Part I) at Corner	q x B x ((1-μ^2) / E_s) x I_f
2.50	Brown Sand (SP)	0.35000	40600	1.00	1.00	0.07541	0.01100	0.00050440
4.00	Brown Sand (SP)	0.35000	43500	1.50	1.00	0.07267	0.01100	0.00048853
5.00	Brown Sand (SP)	0.35000	29000	2.50	1.00	0.06775	0.01000	0.00071459
6.00	Greyish Brown Sand (SP)	0.35000	40600	3.75	1.50	0.09369	0.01400	0.00077510
7.50	Greyish Brown Sand (SP)	0.35000	46400	5.25	1.50	0.08567	0.01300	0.00068878
9.00	Brown Sand (SP)	0.35000	87000	6.75	1.50	0.07891	0.01200	0.00036814
10.50	Greyish Brown Sand (SP)	0.35000	95700	8.25	1.50	0.07314	0.01100	0.00033099
12.00	Blackish Grey Silty Clay (CH)	0.30000	19000	9.75	1.50	0.06815	0.01000	0.00168666
13.50	Blackish Grey Silty Clay (CH)	0.35000	28000	11.25	1.50	0.06380	0.01000	0.00117886
15.00	Blackish Grey Silty / Clayey Sand (SC)	0.35000	31900	12.75	1.50	0.05998	0.00900	0.00099068
16.50	Greyish Brown Silty / Clayey Sand (SC)	0.35000	69600	14.25	1.50	0.05658	0.00800	0.00042782
18.00	Brown Sand (SP)	0.35000	232000	15.75	1.50	0.05355	0.00800	0.00013561
19.50	Brown Weathered Sediments (Grade VI)	0.40000	435000	17.25	1.50	0.05083	0.00800	0.00007294
21.00	Brown Weathered Sediments (Grade VI)	0.40000	435000	18.75	1.50	0.04837	0.00700	0.00006707
22.50	Brownish Grey Weathered Gneiss (Grade V)	0.40000	1412538	22.01	5.02	0.14648	0.02200	0.00007174
				Total (2B)=	**24.52**			**0.00850189**

Consolidation Settlement Analysis of 12.26 m x 56.75 m Foundation at 3.0 m Depth for BH 3 Location

Raft Size (m)= 12.26 x 56.75 Depth of Footing (m) = 3.0

Pressure at Bottom of Footing = 160.00 kN/m^2

Depth (m)	Soil Type	SPT 'N' Value	'Es' Value (kN/m^2)	Depth Below Footing 'z' (m)	Change in Area (m$^{2)}$	Change in Pressure 'Δσ' (kPa)	m_v (m^2/kN)	H (m)	Consolidation Settlement, S_c (mm)
2.5	Brown Sand (SP)	14	40600	0.5	730.51	152.39	0.000025	1.00	-
4.0	Brown Sand (SP)	15	43500	1.50	801.52	138.89	0.000023	1.00	-
5.0	Brown Sand (SP)	10	29000	2.50	874.5300	127.29	0.000034	1.00	-
6.0	Greyish Brown Sand (SP)	14	40600	3.75	968.6050	114.93	0.000025	1.50	-
7.5	Greyish Brown Sand (SP)	16	46400	5.25	1085.6200	102.54	0.000022	1.50	-
9.0	Brown Sand (SP)	30	87000	6.75	1207.135	92.22	0.000011	1.50	-
10.5	Greyish Brown Sand (SP)	33	95700	8.25	1333.15	83.50	0.000010	1.50	-
12.0	Blackish Grey Silty Clay (CH)	6	19000	9.75	1463.665	76.06	0.000053	1.50	6.0465
13.5	Blackish Grey Silty Clay (CH)	9	28000	11.25	1598.68	69.63	0.000036	1.50	3.7602
15.0	Blackish Grey Silty / Clayey Sand (SC)	11	31900	12.75	1738.195	64.04	0.000031	1.50	-
16.5	Greyish Brown Silty / Clayey Sand (SC)	24	69600	14.25	1882.21	59.14	0.000014	1.50	-
18.0	Brown Sand (SP)	80	232000	15.75	2030.725	54.82	0.000004	1.50	-
19.5	Brown Weathered Sediments (Grade VI)	150	435000	17.25	2183.74	50.98	0.000002	1.50	-
21.0	Brown Weathered Sediments (Grade VI)	150	435000	18.75	2341.255	47.55	0.000002	1.50	-
22.5	Brownish Grey Weathered Gneiss (Grade V)	200	1412538	22.01	2699.1052	41.24	0.000001	5.02	-
							Total (2B)=	**24.52**	**9.81**

Total Settlement of Footing (Elatic + Consolidation) as per IS 8009 Part I 1976 Method is 56.41 mm which is lower than allowable settlemet of 100 mm for Raft Foundation as per IS 1904 - 1986

LOAD-CARRYING CAPACITY OF PILES — STATIC ANALYSIS - IS 2911 : 2010

PILES IN GRANULAR SOILS

The ultimate load capacity (Q_u) of piles, in kN, in granular soils is given by the following formula:

$$Q_u = A_p(\tfrac{1}{2} D\gamma N_\gamma + P_D N_q) + \sum_{i=1}^{n} K_i P_{Di} \tan\delta_i A_{si}$$

The first term gives end-bearing resistance and the second term gives skin friction resistance.

where

A_p = cross-sectional area of pile tip, in m^2;

D = diameter of pile shaft, in m;

γ = effective unit weight of the soil at pile tip, in kN/m^3;

N_γ and N_q = bearing capacity factors depending upon the angle of internal friction, ϕ at pile tip;

P_D = effective overburden pressure at pile tip, in kN/m^2 (*see* Note 5);

$\sum_{i=1}^{n}$ = summation for layers 1 to n in which pile is installed and which contribute to positive skin friction;

K_i = coefficient of earth pressure applicable for the ith layer (*see* Note 3);

P_{Di} = effective overburden pressure for the ith layer, in kN/m^2;

δ_i = angle of wall friction between pile and soil for the ith layer; and

A_{si} = surface area of pile shaft in the ith layer, in m^2.

NOTES

1 N_γ factor can be taken for general shear failure according to IS 6403.

2 N_q factor will depend on the nature of soil, type of pile, the L/B ratio and its method of construction. The values applicable for bored piles are given in Fig. 1 **of IS 2911 : 2010 Part I**

3 K_i, the earth pressure coefficient depends on the nature of soil strata, type of pile, spacing of pile and its method of construction. For driven piles in loose to dense sand with ϕ varying between 30° and 40°, K_i values in the range of 1 to 1.5 may be used.

4 δ, the angle of wall friction may be taken equal to the friction angle of the soil around the pile stem.

5 In working out pile capacity by static formula, the maximum effective overburden at the pile tip should correspond to the critical depth, which may be taken as 15 times the diameter of the pile shaft for $\phi \leq 30°$ and increasing to 20 times for $\phi \geq 40°$.

6 For piles passing through cohesive strata and terminating in a granular stratum, a penetration of at least twice the diameter of the pile shaft should be given into the granular stratum.

PILES IN COHESIVE SOILS

The ultimate load capacity (Q_u) of piles, in kN, in cohesive soils is given by the following formula:

$$Q_u = A_p N_c c_p + \sum_{i=1}^{n} \alpha_i c_i A_{si}$$

The first term gives the end-bearing resistance and the second term gives the skin friction resistance.

where

A_p = cross-sectional area of pile tip, in m^2;

N_c = bearing capacity factor, may be taken as 9;

c_p = average cohesion at pile tip, in kN/m^2;

$\sum_{i=1}^{n}$ = summation for layers 1 to n in which the pile is installed and which contribute to positive skin friction;

α_i = adhesion factor for the ith layer depending on the consistency of soil, (*see* Note);

c_i = average cohesion for the ith layer, in kN/m^2; and

A_{si} = surface area of pile shaft in the ith layer, in m^2.

B-3.3 Ultimate skin friction resistance can be approximated to local side friction (f_s), in kN/m^2, obtained from static cone resistance as given in Table 1.

Table 1 Side Friction for Different Types of Soil

Sl No.	Type of Soil	Local Side Friction, f_s kN/m^2
(1)	(2)	(3)
i)	q_c less than 1 000 kN/m^2	$q_c/30 < f_s < q_c/10$
ii)	Clay	$q_c/25 < f_s < 2q_c/25$
iii)	Silty clay and silty sand	$q_c/100 < f_s < q_c/25$
iv)	Sand	$q_c/100 < f_s < q_c/50$
v)	Coarse sand and gravel	$q_c/100 < f_s < q_c/150$

q_c = cone resistance, in kN/m^2.

USE OF STATIC CONE PENETRATION DATA

When full static cone penetration data are available for the entire depth, the following correlation may be used as a guide for the determination of ultimate load capacity of a pile.

0.6

Ultimate end bearing resistance (q_u), in kN/m^2, may be obtained as:

$$q_u = \frac{\frac{q_{c0} + q_{c1}}{2} + q_{c2}}{2}$$

where

q_{c0} = average static cone resistance over a depth of 2D below the pile tip, in kN/m^2;

q_{c1} = minimum static cone resistance over the same 2D below the pile tip, in kN/m^2;

q_{c2} = average of the envelope of minimum static cone resistance values over the length of pile of 8D above the pile tip, in kN/m^2; and

D = diameter of pile shaft.

NOTE — The value of adhesion factor, α_i depends on the undrained shear strength of the clay and may be obtained from Fig. 2.of IS 2911 : 2010 Part I

Table 2 Co-relation Between N and q_c for Different Types of Soil

Sl No.	Type of Soil	q_c/N
(1)	(2)	(3)
i)	Clay	150-200
ii)	Silts, sandy silts and slightly cohesive silt-sand mixtures	200-250
iii)	Clean fine to medium sand and slightly silty sand	300-400
iv)	Coarse sand and sands with little gravel	500-600
v)	Sandy gravel and gravel	800-1 000

Appendix - C (DETERMINATION OF PILE CARRYING CAPACITY AS PER IS 2911:2010)

PILE CARRYING CAPACITY BASED ON SHEAR STRENGTH PARAMETERS ('c' and 'Φ') (IS 2911: 2010)

$$Q_u = A_p (cN_c + P_D N_q + 0.5\gamma D N_\gamma) + \Sigma A_{si}(\alpha_i c_i + K P_{Di} \tan\Phi)$$

Where,

Q_u	-	Ultimate Pile Capacity, kN
A_p	-	Cross Sectional Area of Pile, m^2
c_i	-	Cohesion value of soil at pile base, kN/m^2
P_D	-	Effective overburden pressure at pile base , kN/m^2
γ	-	Unit weight of soil, kN/m^3
D	-	Diameter of pile, m
A_{si}	-	Surface Area of Pile at respective soil layers, m^2
α_i	-	Adhesion factor
c	-	Cohesion value of soil at respective soil layers, kN/m^2
K_i	-	Co-efficient of earth pressure at respective soil layers
P_{Di}	-	Effective overburden pressure at respective soil layers, kN/m^2
Φ	-	Friction angle, degrees
N_c, N_q, N_γ	-	Bearing capacity factors based on IS 2911: 2010 and IS 6403 -1981

PILE CARRYING CAPACITY OF SOCKETED PILES BY COLE AND STROUD APPROACH (1977) - IS 2911 : 2010

$$Q_a = c_{u1} N_c \cdot \frac{\pi B^2}{4F_s} + \alpha\, c_{u2} \cdot \frac{\pi B L}{F_s}$$

where

c_{u1} = shear strength of rock below the base of the pile, in kN/m^2 (*see* Fig. 3);

Type of Soil	Limiting Frictional Resistance (t/m^2)
Sand	6
Silt	6
Clay	7

N_c = bearing capacity factor taken as 9;

F_s = factor of safety usually taken as 3;

α = 0.9 (recommended value);

c_{u2} = average shear strength of rock in the socketed length of pile, in kN/m^2 (*see* Fig 3);

B = minimum width of pile shaft (diameter in case of circular piles), in m; and

L = socket length of pile, in m.

Limiting End Bearing Resistance (t/m^2) as per IS 2911	
Bored Piles	**Driven Piles**
1000 - 1100	1500

Appendix - C (DETERMINATION OF PILE CARRYING CAPACITY AS PER IS 2911:2010)

DETERMINATION OF PILE CARRYING CAPACITY AS PER IS 2911 : 2010

Borehole Location **BH 1**

Length of Pile (L), m	=	21.00	m		From Existing Borehole Level		
Angle of Internal Friction (φ) in Degrees	=	45.00					
Undraind cohesion value at PileTip (c_p), kN/m^2	=	0.00	kN/m^2				
Submerged Unit Weight at PileTip (Υ_p), kN/m^2	=	14.10	kN/m^2				
Ground Water Table Depth (GWT), m	=	0.00	m		Submerged Condition		
Bearing Capacity Factor (N_c)	=	9.00					
Bearing Capacity Factor (N_q)	=	350.00			Taken from Figure 1 of IS 2911:2010 Part 1 Sec.2		
Bearing Capacity Factor (N_γ)	=	271.75					
Factor of Safety (FS)	=	2.50					
Diameter of Pile (D), mm	=	450	500	600	700	900	
Critical Depth of Pile (20 x D), m	=	9	10	12	14	18	
Effective overburden pressure at Pile Tip (P_D), kN/m^2	=	77.68	93.50	110.45	128.15	182.15	
End Bearing Resisrtnce of Pile (q_p), kN/m^2 using 'c' and 'φ'	=	28048.37	33682.91	39806.99	46193.57	65476.74	
End Bearing Resisrtnce of Pile (q_p), kN/m^2 using 'N' values	=	80000.00	80000.00	80000.00	80000.00	80000.00	
Limiting End Bearing Resisrtnce of Pile (q_p), kN/m^2	=	10000.00	10000.00	10000.00	10000.00	10000.00	
Ultimate End Bearing Capacity of Pile ($Q_{p\text{-}ult}$), kN using 'c' and 'φ' values	=	1590.43	1963.50	2827.43	3848.45	6361.73	
Ultimate End Bearing Capacity of Pile ($Q_{p\text{-}ult}$), kN using 'N' values	=	1590.43	1963.50	2827.43	3848.45	6361.73	
Safe End Bearing Capacity of Pile ($Q_{p\text{-}safe}$), kN using 'c' and 'φ' values	=	636.17	785.40	1130.97	1539.38	2544.69	
Safe End Bearing Capacity of Pile ($Q_{p\text{-}safe}$), kN using 'N' values	=	636.17	785.40	1130.97	1539.38	2544.69	
Ultimate Frictional Capacity of Pile ($Q_{f\text{-}ult}$), kN using 'c' and 'φ' values	=	1337.22	1485.80	1782.97	2080.13	2674.45	
Ultimate Frictional Capacity of Pile ($Q_{f\text{-}ult}$), kN using 'N' values	=	1260.56	1400.63	1680.75	1960.88	2521.13	
Negetive Skin Fricton of Pile (Q_{nf}), kN using 'c' and 'φ' values	=	31.95	35.50	42.60	49.70	63.89	
Negetive Skin Friction of Pile (Q_{nf}), kN using 'N' values	=	113.10	125.66	150.80	175.93	226.19	
Safe Frictional Capacity of Pile ($Q_{f\text{-}safe}$), kN using 'c' and 'φ' values	=	502.94	558.82	670.59	782.35	1005.88	
Safe Frictional Capacity of Pile ($Q_{f\text{-}safe}$), kN using 'N' values	=	391.13	434.59	521.50	608.42	782.26	
Self Weight of Pile (W), kN	=	83.50	103.08	148.44	202.04	333.99	
Safe Pile Carrying Capacity of Pile (Q_{safe}), kN ('c' and 'φ')	=	1139	1344	1802	2322	3551	
Safe Pile Carrying Capacity of Pile (Q_{safe}), kN ('N' values)	=	1027	1220	1652	2148	3327	
Recommended Safe Pile Carrying Capacity of Pile (Q_{safe}), kN	**=**	**1083**	**1282**	**1727**	**2235**	**3439**	
Safe Uplift Capacity of Pile (Q_{up}), kN using 'c' and 'φ' values	**=**	**497**	**563**	**700**	**846**	**1162**	

Appendix - C (DETERMINATION OF PILE CARRYING CAPACITY AS PER IS 2911:2010)

Depth (m)	Soil Description	H_i (m)	'c' kN/m^2	'φ'	'Y' kN/m^3	'Y$_{sub}$' kN/m^3	P_{Di} (kN/m^2)	'α$_i$'	'K$_i$'	N' Value
1.00	Brown Sand (SP)	1.00	0	31	18.50	8.50	4.25	0.00	1.00	16
2.00	Brown Sand (SP)	1.00	0	32	19.10	9.10	13.05	0.00	1.00	19
3.00	Brown Sand (SP)	1.00	0	29	17.70	7.70	21.45	0.00	1.00	13
4.00	Brown Sand (SP)	1.00	0	30	18.20	8.20	29.40	0.00	1.00	15
5.00	Brown Sand (SP)	1.00	0	35	22.00	12.00	39.50	0.00	1.00	24
6.00	Brown Sand (SP)	1.00	0	34	19.60	9.60	50.30	0.00	1.00	22
7.50	Brown Sand (SP)	1.50	0	35	20.00	10.00	62.60	0.00	1.00	24
9.00	Greyish Brown Sand (SP)	1.50	0	35	20.10	10.10	77.68	0.00	1.00	25
10.50	Greyish Brown Sand (SP)	1.50	0	38	21.00	11.00	93.50	0.00	1.00	31
12.00	Greyish Sand (SP)	1.50	0	40	21.60	11.60	110.45	0.00	1.00	36
13.50	Greyish Silty Sand (SM-SP)	1.50	0	41	22.00	12.00	128.15	0.00	1.00	40
15.00	Greyish Silty Sand (SM-SP)	1.50	0	42	22.00	12.00	146.15	0.00	1.00	46
16.50	Greyish Silty / Clayey Sand With Lime Particles (SC)	1.50	30	29	22.00	12.00	164.15	0.30	1.00	20
18.00	Greyish Silty Sand With Lime Particles (SM-SP)	1.50	0	42	22.00	12.00	182.15	0.00	1.00	80
19.50	Brown Weathered Sediments (Grade VI)	1.50	0	44	22.00	12.00	200.15	0.00	1.00	150
21.00	Greyish Weathered Gneiss (Grade V)	1.50	0	45	24.10	14.10	219.73	0.00	1.00	200
22.50	Greyish Weathered Gneiss (Grade V)	1.50	0	45	24.20	14.20	240.95	0.00	1.00	200
24.00	Greyish Weathered Gneiss (Grade IV)	1.50	0	45	24.20	14.20	262.25	0.00	1.00	200

Appendix - C (DETERMINATION OF PILE CARRYING CAPACITY AS PER IS 2911:2010)

		Ultimate Frictional Capacity, kN using 'c' and 'φ' values						Ultimate Frictional Capacity, kN using 'N' values					
Depth (m)	Soil Description	q_s (kN/m^2)	450 mm	500 mm	600 mm	700 mm	900 mm	q_s (kN/m^2)	450 mm	500 mm	600 mm	700 mm	900 mm
1.00	Brown Sand (SP)	2.55	3.61	4.01	4.81	5.62	7.22	26.67	37.70	41.89	50.27	58.64	75.40
2.00	Brown Sand (SP)	8.15	11.53	12.81	15.37	17.93	23.06	31.67	44.77	49.74	59.69	69.64	89.54
3.00	Brown Sand (SP)	11.89	16.81	18.68	22.41	26.15	33.62	21.67	30.63	34.03	40.84	47.65	61.26
4.00	Brown Sand (SP)	16.97	24.00	26.66	32.00	37.33	47.99	25.00	35.34	39.27	47.12	54.98	70.69
5.00	Brown Sand (SP)	27.66	39.10	43.45	52.13	60.82	78.20	40.00	56.55	62.83	75.40	87.96	113.10
6.00	Brown Sand (SP)	33.93	47.96	53.29	63.95	74.61	95.93	36.67	51.84	57.60	69.12	80.63	103.67
7.50	Brown Sand (SP)	43.83	92.95	103.28	123.93	144.59	185.90	40.00	84.82	94.25	113.10	131.95	169.65
9.00	Greyish Brown Sand (SP)	54.39	115.34	128.15	153.78	179.41	230.67	41.67	88.36	98.17	117.81	137.44	176.71
10.50	Greyish Brown Sand (SP)	73.05	127.23	141.37	169.65	197.92	254.47	51.67	109.56	121.74	146.08	170.43	219.13
12.00	Greyish Sand (SP)	92.68	127.23	141.37	169.65	197.92	254.47	60.00	127.23	141.37	169.65	197.92	254.47
13.50	Greyish Silty Sand (SM-SP)	111.40	127.23	141.37	169.65	197.92	254.47	66.67	127.23	141.37	169.65	197.92	254.47
15.00	Greyish Silty Sand (SM-SP)	131.59	127.23	141.37	169.65	197.92	254.47	76.67	127.23	141.37	169.65	197.92	254.47
16.50	(SC)	99.99	127.23	141.37	169.65	197.92	254.47	33.33	70.69	78.54	94.25	109.96	141.37
18.00	Greyish Silty Sand With Lime Particles (SM-SP)	164.01	127.23	141.37	169.65	197.92	254.47	133.33	127.23	141.37	169.65	197.92	254.47
19.50	Brown Weathered Sediments (Grade VI)	193.28	127.23	141.37	169.65	197.92	254.47	250.00	127.23	141.37	169.65	197.92	254.47
21.00	Greyish Weathered Gneiss (Grade V)	219.73	127.23	141.37	169.65	197.92	254.47	333.33	127.23	141.37	169.65	197.92	254.47
22.50	Greyish Weathered Gneiss (Grade V)	240.95	127.23	141.37	169.65	197.92	254.47	333.33	127.23	141.37	169.65	197.92	254.47
24.00	Greyish Weathered Gneiss (Grade IV)	262.25	127.23	141.37	169.65	197.92	254.47	333.33	127.23	141.37	169.65	197.92	254.47

DETERMINATION OF PILE CARRYING CAPACITY AS PER IS 2911 : 2010

Borehole Location **BH 2**

Length of Pile (L), m	=	21.00	m		From Existing Borehole Level		
Angle of Internal Friction (φ) in Degrees	=	45.00					
Undraind cohesion value at PileTip (c_p), kN/m^2	=	0.00	kN/m^2				
Submerged Unit Weight at PileTip (Υ_p), kN/m^2	=	14.10	kN/m^2				
Ground Water Table Depth (GWT), m	=	0.00	m		Submerged Condition		
Bearing Capacity Factor (N_c)	=	9.00					
Bearing Capacity Factor (N_q)	=	350.00			Taken from Figure 1 of IS 2911:2010 Part 1 Sec.2		
Bearing Capacity Factor (N_γ)	=	271.75					
Factor of Safety (FS)	=	2.50					
Diameter of Pile (D), mm	=	450	500	600	700	900	
Critical Depth of Pile (20 x D), m	=	9	10	12	14	18	
Effective overburden pressure at Pile Tip (P_D), kN/m^2	=	75.13	91.48	105.80	118.93	171.05	
End Bearing Resisrtnce of Pile (q_p), kN/m^2 using 'c' and 'φ'	=	27155.87	32974.16	38179.49	42964.82	61591.74	
End Bearing Resisrtnce of Pile (q_p), kN/m^2 using 'N' values	=	80000.00	80000.00	80000.00	80000.00	80000.00	
Limiting End Bearing Resisrtnce of Pile (q_p), kN/m^2	=	10000.00	10000.00	10000.00	10000.00	10000.00	
Ultimate End Bearing Capacity of Pile ($Q_{p\text{-}ult}$), kN using 'c' and 'φ' values	=	1590.43	1963.50	2827.43	3848.45	6361.73	
Ultimate End Bearing Capacity of Pile ($Q_{p\text{-}ult}$), kN using 'N' values	=	1590.43	1963.50	2827.43	3848.45	6361.73	
Safe End Bearing Capacity of Pile ($Q_{p\text{-}safe}$), kN using 'c' and 'φ' values	=	636.17	785.40	1130.97	1539.38	2544.69	
Safe End Bearing Capacity of Pile ($Q_{p\text{-}safe}$), kN using 'N' values	=	636.17	785.40	1130.97	1539.38	2544.69	
Ultimate Frictional Capacity of Pile ($Q_{f\text{-}ult}$), kN using 'c' and 'φ' values	=	1332.93	1481.03	1777.23	2073.44	2665.85	
Ultimate Frictional Capacity of Pile ($Q_{f\text{-}ult}$), kN using 'N' values	=	1269.99	1411.10	1693.32	1975.54	2539.98	
Negetive Skin Fricton of Pile (Q_{nf}), kN using 'c' and 'φ' values	=	17.36	19.29	23.15	27.00	34.72	
Negetive Skin Friction of Pile (Q_{nf}), kN using 'N' values	=	103.67	115.19	138.23	161.27	207.35	
Safe Frictional Capacity of Pile ($Q_{f\text{-}safe}$), kN using 'c' and 'φ' values	=	515.81	573.12	687.75	802.37	1031.62	
Safe Frictional Capacity of Pile ($Q_{f\text{-}safe}$), kN using 'N' values	=	404.32	449.25	539.10	628.95	808.65	
Self Weight of Pile (W), kN	=	83.50	103.08	148.44	202.04	333.99	
Safe Pile Carrying Capacity of Pile (Q_{safe}), kN ('c' and 'φ')	=	1152	1359	1819	2342	3576	
Safe Pile Carrying Capacity of Pile (Q_{safe}), kN ('N' values)	=	1040	1235	1670	2168	3353	
Recommended Safe Pile Carrying Capacity of Pile (Q_{safe}), kN	**=**	**1096**	**1297**	**1744**	**2255**	**3465**	
Safe Uplift Capacity of Pile (Q_{up}), kN using 'c' and 'φ' values	**=**	**510**	**577**	**718**	**866**	**1188**	

Appendix - C (DETERMINATION OF PILE CARRYING CAPACITY AS PER IS 2911:2010)

Depth (m)	Soil Description	H_i (m)	'c' kN/m^2	'φ'	'Y' kN/m^3	'Y$_{sub}$' kN/m^3	P_{Di} (kN/m^2)	'α$_i$'	'K$_i$'	N' Value
1.00	Brown Sand (SP)	1.00	0	28	17.20	7.20	3.60	0.00	1.00	11
2.00	Brown Sand (SP)	1.00	0	39	21.20	11.20	12.80	0.00	1.00	33
3.00	Brown Sand (SP)	1.00	0	31	18.70	8.70	22.75	0.00	1.00	17
4.00	Brown Sand (SP)	1.00	0	28	17.50	7.50	30.85	0.00	1.00	12
5.00	Greyish Brown Sand (SP)	1.00	0	31	22.00	12.00	40.60	0.00	1.00	17
6.00	Greyish Brown Sand (SP)	1.00	0	31	18.50	8.50	50.85	0.00	1.00	16
7.50	Greyish Brown Sand (SP)	1.50	0	30	18.00	8.00	61.10	0.00	1.00	14
9.00	Greyish Brown Sand (SP)	1.50	0	37	20.70	10.70	75.13	0.00	1.00	29
10.50	Greyish Brown Sand (SP)	1.50	0	38	21.10	11.10	91.48	0.00	1.00	32
12.00	Blackish Grey Silty Clay (CH)	1.50	88	0	18.00	8.00	105.80	0.80	1.00	14
13.50	Blackish Grey Silty Clay (CH)	1.50	131	0	19.50	9.50	118.93	0.65	1.00	21
15.00	Brownish Grey Silty / Clayey Sand (SC)	1.50	50	32	22.00	12.00	135.05	0.30	1.00	27
16.50	Greyish Silty Sand (SM-SP)	1.50	0	40	22.00	12.00	153.05	0.00	1.00	43
18.00	Brown Sand (SP)	1.50	0	42	22.00	12.00	171.05	0.00	1.00	80
19.50	Greyish Brown Weathered Sediments (Grade VI)	1.50	0	44	22.00	12.00	189.05	0.00	1.00	150
21.00	Brownish Grey Weathered Gneiss (Grade V)	1.50	0	45	23.80	13.80	208.40	0.00	1.00	200
21.50	Brownish Grey Weathered Gneiss (Grade V)	0.50	0	45	24.10	14.10	222.28	0.00	1.00	200
22.50	Brownish Grey Weathered Gneiss (Grade V)	1.00	0	45	24.10	14.10	232.85	0.00	1.00	200

Appendix - C (DETERMINATION OF PILE CARRYING CAPACITY AS PER IS 2911:2010)

		Ultimate Frictional Capacity, kN using 'c' and 'φ' values						Ultimate Frictional Capacity, kN using 'N' values					
Depth (m)	Soil Description	q_s (kN/m^2)	450 mm	500 mm	600 mm	700 mm	900 mm	q_s (kN/m^2)	450 mm	500 mm	600 mm	700 mm	900 mm
1.00	Brown Sand (SP)	1.91	2.71	3.01	3.61	4.21	5.41	18.33	25.92	28.80	34.56	40.32	51.84
2.00	Brown Sand (SP)	10.37	14.65	16.28	19.54	22.79	29.31	55.00	77.75	86.39	103.67	120.95	155.51
3.00	Brown Sand (SP)	13.67	19.32	21.47	25.77	30.06	38.65	28.33	40.06	44.51	53.41	62.31	80.11
4.00	Brown Sand (SP)	16.40	23.19	25.77	30.92	36.07	46.38	20.00	28.27	31.42	37.70	43.98	56.55
5.00	Greyish Brown Sand (SP)	24.39	34.49	38.32	45.98	53.65	68.98	28.33	40.06	44.51	53.41	62.31	80.11
6.00	Greyish Brown Sand (SP)	30.55	43.19	47.99	57.59	67.19	86.39	26.67	37.70	41.89	50.27	58.64	75.40
7.50	Greyish Brown Sand (SP)	35.28	74.81	83.12	99.74	116.36	149.61	23.33	49.48	54.98	65.97	76.97	98.96
9.00	Greyish Brown Sand (SP)	56.61	120.05	133.39	160.06	186.74	240.09	48.33	102.49	113.88	136.66	159.44	204.99
10.50	Greyish Brown Sand (SP)	71.47	127.23	141.37	169.65	197.92	254.47	53.33	113.10	125.66	150.80	175.93	226.19
12.00	Blackish Grey Silty Clay (CH)	70.40	127.23	141.37	169.65	197.92	254.47	70.00	127.23	141.37	169.65	197.92	254.47
13.50	Blackish Grey Silty Clay (CH)	85.15	127.23	141.37	169.65	197.92	254.47	105.00	127.23	141.37	169.65	197.92	254.47
15.00	Brownish Grey Silty / Clayey Sand (SC)	99.39	127.23	141.37	169.65	197.92	254.47	45.00	95.43	106.03	127.23	148.44	190.85
16.50	Greyish Silty Sand (SM-SP)	128.42	127.23	141.37	169.65	197.92	254.47	71.67	127.23	141.37	169.65	197.92	254.47
18.00	Brown Sand (SP)	154.01	127.23	141.37	169.65	197.92	254.47	133.33	127.23	141.37	169.65	197.92	254.47
19.50	Greyish Brown Weathered Sediments (Grade VI)	182.56	127.23	141.37	169.65	197.92	254.47	250.00	127.23	141.37	169.65	197.92	254.47
21.00	Brownish Grey Weathered Gneiss (Grade V)	208.40	127.23	141.37	169.65	197.92	254.47	333.33	127.23	141.37	169.65	197.92	254.47
21.50	Brownish Grey Weathered Gneiss (Grade V)	222.28	42.41	47.12	56.55	65.97	84.82	333.33	42.41	47.12	56.55	65.97	84.82
22.50	Brownish Grey Weathered Gneiss (Grade V)	232.85	84.82	94.25	113.10	131.95	169.65	333.33	84.82	94.25	113.10	131.95	169.65

DETERMINATION OF PILE CARRYING CAPACITY AS PER IS 2911 : 2010

Borehole Location **BH 3**

Length of Pile (L), m	=	23.00	m	From Existing Borehole Level			
Angle of Internal Friction (φ) in Degrees	=	45.00					
Undraind cohesion value at PileTip (c_p), kN/m^2	=	0.00	kN/m^2				
Submerged Unit Weight at PileTip (Υ_p), kN/m^2	=	13.40	kN/m^2				
Ground Water Table Depth (GWT), m	=	0.00	m	Submerged Condition			
Bearing Capacity Factor (N_c)	=	9.00					
Bearing Capacity Factor (N_q)	=	350.00		Taken from Figure 1 of IS 2911:2010 Part 1 Sec.2			
Bearing Capacity Factor (N_γ)	=	271.75					
Factor of Safety (FS)	=	2.50					
Diameter of Pile (D), mm	=	450	500	600	700	900	
Critical Depth of Pile (20 x D), m	=	9	10	12	14	18	
Effective overburden pressure at Pile Tip (P_D), kN/m^2	=	101.08	109.93	120.20	134.60	188.60	
End Bearing Resisrtnce of Pile (q_p), kN/m^2 using 'c' and 'φ'	=	36195.57	39384.10	43162.43	48384.50	67648.64	
End Bearing Resisrtnce of Pile (q_p), kN/m^2 using 'N' values	=	80000.00	80000.00	80000.00	80000.00	80000.00	
Limiting End Bearing Resisrtnce of Pile (q_p), kN/m^2	=	10000.00	10000.00	10000.00	10000.00	10000.00	
Ultimate End Bearing Capacity of Pile ($Q_{p\text{-}ult}$), kN using 'c' and 'φ' values	=	1590.43	1963.50	2827.43	3848.45	6361.73	
Ultimate End Bearing Capacity of Pile ($Q_{p\text{-}ult}$), kN using 'N' values	=	1590.43	1963.50	2827.43	3848.45	6361.73	
Safe End Bearing Capacity of Pile ($Q_{p\text{-}safe}$), kN using 'c' and 'φ' values	=	636.17	785.40	1130.97	1539.38	2544.69	
Safe End Bearing Capacity of Pile ($Q_{p\text{-}safe}$), kN using 'N' values	=	636.17	785.40	1130.97	1539.38	2544.69	
Ultimate Frictional Capacity of Pile ($Q_{f\text{-}ult}$), kN using 'c' and 'φ' values	=	1375.79	1528.66	1834.39	2140.12	2751.59	
Ultimate Frictional Capacity of Pile ($Q_{f\text{-}ult}$), kN using 'N' values	=	1222.86	1358.74	1630.49	1902.23	2445.73	
Negetive Skin Fricton of Pile (Q_{nf}), kN using 'c' and 'φ' values	=	20.41	22.67	27.21	31.74	40.81	
Negetive Skin Friction of Pile (Q_{nf}), kN using 'N' values	=	82.47	91.63	109.96	128.28	164.93	
Safe Frictional Capacity of Pile ($Q_{f\text{-}safe}$), kN using 'c' and 'φ' values	=	529.91	588.79	706.55	824.31	1059.82	
Safe Frictional Capacity of Pile ($Q_{f\text{-}safe}$), kN using 'N' values	=	406.68	451.87	542.24	632.61	813.36	
Self Weight of Pile (W), kN	=	91.45	112.90	162.58	221.29	365.80	
Safe Pile Carrying Capacity of Pile (Q_{safe}), kN ('c' and 'φ')	=	1166	1374	1838	2364	3605	
Safe Pile Carrying Capacity of Pile (Q_{safe}), kN ('N' values)	=	1043	1237	1673	2172	3358	
Recommended Safe Pile Carrying Capacity of Pile (Q_{safe}), kN	**=**	**1104**	**1306**	**1755**	**2268**	**3481**	
Safe Uplift Capacity of Pile (Q_{up}), kN using 'c' and 'φ' values	**=**	**530**	**600**	**747**	**903**	**1242**	

Appendix - C (DETERMINATION OF PILE CARRYING CAPACITY AS PER IS 2911:2010)

Depth (m)	Soil Description	H_i (m)	'c' kN/m^2	'φ'	'Y' kN/m^3	'Y$_{sub}$' kN/m^3	P_{Di} (kN/m^2)	'α$_i$'	'K$_i$'	N' Value
2.50	Brown Sand (SP)	2.50	0	30	18.00	8.00	10.00	0.00	1.00	14
4.00	Brown Sand (SP)	1.50	0	30	18.20	8.20	26.15	0.00	1.00	15
5.00	Brown Sand (SP)	1.00	0	27	16.90	6.90	35.75	0.00	1.00	10
6.00	Greyish Brown Sand (SP)	1.00	0	30	22.00	12.00	45.20	0.00	1.00	14
7.50	Greyish Brown Sand (SP)	1.50	0	31	18.50	8.50	57.58	0.00	1.00	16
9.00	Brown Sand (SP)	1.50	0	37	20.90	10.90	72.13	0.00	1.00	30
10.50	Greyish Brown Sand (SP)	1.50	0	39	21.20	11.20	88.70	0.00	1.00	33
12.00	Blackish Grey Silty Clay (CH)	1.50	38	0	15.30	5.30	101.08	0.80	1.00	6
13.50	Blackish Grey Silty Clay (CH)	1.50	56	0	16.50	6.50	109.93	0.80	1.00	9
15.00	Blackish Grey Silty / Clayey Sand (SC)	1.50	30	25	17.20	7.20	120.20	0.30	1.00	11
16.50	Greyish Brown Silty / Clayey Sand (SC)	1.50	50	32	22.00	12.00	134.60	0.30	1.00	24
18.00	Brown Sand (SP)	1.50	0	42	22.00	12.00	152.60	0.00	1.00	80
19.50	Brown Weathered Sediments (Grade VI)	1.50	0	44	22.00	12.00	170.60	0.00	1.00	150
21.00	Brown Weathered Sediments (Grade VI)	1.50	0	44	22.00	12.00	188.60	0.00	1.00	150
22.50	Brownish Grey Weathered Gneiss (Grade V)	2.00	0	45	23.40	13.40	211.00	0.00	1.00	200

Appendix - C (DETERMINATION OF PILE CARRYING CAPACITY AS PER IS 2911:2010)

Depth (m)	Soil Description	Ultimate Frictional Capacity, kN using 'c' and 'φ' values						Ultimate Frictional Capacity, kN using 'N' values					
		q_s (kN/m^2)	450 mm	500 mm	600 mm	700 mm	900 mm	q_s (kN/m^2)	450 mm	500 mm	600 mm	700 mm	900 mm
2.50	Brown Sand (SP)	5.77	20.41	22.67	27.21	31.74	40.81	23.33	82.47	91.63	109.96	128.28	164.93
4.00	Brown Sand (SP)	15.10	32.02	35.57	42.69	49.80	64.03	25.00	53.01	58.90	70.69	82.47	106.03
5.00	Brown Sand (SP)	18.22	25.75	28.61	34.34	40.06	51.50	16.67	23.56	26.18	31.42	36.65	47.12
6.00	Greyish Brown Sand (SP)	26.10	36.89	40.99	49.19	57.39	73.79	23.33	32.99	36.65	43.98	51.31	65.97
7.50	Greyish Brown Sand (SP)	34.59	73.36	81.51	97.81	114.12	146.72	26.67	56.55	62.83	75.40	87.96	113.10
9.00	Brown Sand (SP)	54.35	115.25	128.06	153.67	179.28	230.51	50.00	106.03	117.81	141.37	164.93	212.06
10.50	Greyish Brown Sand (SP)	71.83	127.23	141.37	169.65	197.92	254.47	55.00	116.63	129.59	155.51	181.43	233.26
12.00	Blackish Grey Silty Clay (CH)	30.40	64.47	71.63	85.95	100.28	128.93	30.00	63.62	70.69	84.82	98.96	127.23
13.50	Blackish Grey Silty Clay (CH)	44.80	95.00	105.56	126.67	147.78	190.00	45.00	95.43	106.03	127.23	148.44	190.85
15.00	Blackish Grey Silty / Clayey Sand (SC)	65.05	127.23	141.37	169.65	197.92	254.47	18.33	38.88	43.20	51.84	60.48	77.75
16.50	Greyish Brown Silty / Clayey Sand (SC)	99.11	127.23	141.37	169.65	197.92	254.47	40.00	84.82	94.25	113.10	131.95	169.65
18.00	Brown Sand (SP)	137.40	127.23	141.37	169.65	197.92	254.47	133.33	127.23	141.37	169.65	197.92	254.47
19.50	Brown Weathered Sediments (Grade VI)	164.75	127.23	141.37	169.65	197.92	254.47	250.00	127.23	141.37	169.65	197.92	254.47
21.00	Brown Weathered Sediments (Grade VI)	182.13	127.23	141.37	169.65	197.92	254.47	250.00	127.23	141.37	169.65	197.92	254.47
22.50	Brownish Grey Weathered Gneiss (Grade V)	211.00	169.65	188.50	226.19	263.89	339.29	333.33	169.65	188.50	226.19	263.89	339.29

Appendix - C (DETERMINATION OF PILE CARRYING CAPACITY AS PER IS 2911:2010)

DETERMINATION OF LATERAL PILE CARRYING CAPACITY AS PER IS 2911 : 2010

Length of Pile (L), m	=	**23.00**	**m**	**From Existing Borehole Level**			
Type of Fixity	=	**Fixed Head by Pile Cap**					
Cantilever Length above Ground Level (e), m	=	**0.00**	**m**	**Point of appilcation of Lateral Load (Assumed)**			
Allowable Deflection as per IS 2911 Part 4 : 1985, Page No. 10 in mm	=	**5.00**	**mm**				
Modulus of Subgrade Reaction of Soil (η_h)	=	3200.00	kN/m^3	**From Table 3 of IS 2911 Part 1 Sec. 2**			
Grade of Concrete	=	**30.00**	**N/mm^2**	**M 30**			
Young's Modulus of Pile Materia (E), kN/m^2	=	27386127.88	kN/m^2				
Diametr of Pile (D), mm	=	450	500	600	700	900	
Moment of Inertia of Pile Section (I), m^4	=	0.00201	0.00307	0.00636	0.01179	0.03221	
Stiffness Factor, (T)	=	1.77	1.92	2.22	2.52	3.08	
Criteria for Behaviour of Pile as per Table 5 of IS 2911 Part I Sec. 2	=	Long Pile	Long Pile	Long Pile	Long Pile	Long Pile	
(e/R)	=	0.00	0.00	0.00	0.00	0.00	
(Z_f/T) from Fig.4 of IS 2911 Part 1 Sec.2	=	1.90	1.90	1.90	1.90	1.90	
Depth of Fixity (Z_f), m	=	3.36	3.65	4.23	4.78	5.85	
Allowable Deflection as per IS 2911 Part 4 : 1985, Page No. 10 in mm	=	5.00	5.00	5.00	5.00	5.00	
Lateral Load Capacity of Pile (H), kN	=	**87.20**	**103.70**	**138.10**	**177.30**	**264.30**	

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