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# SOIL INVESTIGATION REPORT

**NAME OF WORK** : **RECOMMENDATION OF FOUNDATION FOR THE RECONSTRUCTION OF SLUM TENEMENTS AT NATTAN THOTTAM, TNSCB, DIVISION-VI, CHENNAI**

**CLIENT** : **The Executive Engineer**
Division - VI,
Tamil Nadu Slum Clearance Board
No. 130, R.K. Mutt Road,
Mylapore,
Chennai – 600 004

**Reference** : Your Lr. No. SCB/Dn VI/AE (P)/1/2018 Dated 23.04.2019

**JOB No** : SM&FE 145 / Consultancy / TNSCB / 2019

**DATE** : 14th August 2019

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**Professor & Head**

**Dr. V.K. STALIN, M.E., Ph.D.**
**Professor**

# RECOMMENDATION OF FOUNDATION FOR THE RECONSTRUCTION OF SLUM TENEMENTS AT NATTAN THOTTAM, TNSCB, DIVISION-VI, CHENNAI

Job. No. SM&FE 145 / Consultancy / TNSCB / 2019 Date:14.08.2019

**CLIENT:**

**The Executive Engineer**
Division - VI,
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No. 130, R.K. Mutt Road,
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## 1. INTRODUCTION

The Tamil Nadu Slum Clearance Board (TNSCB), Division – VI, Chennai – 600 004 has proposed to reconstruct the Slum Tenements for stilt+5 floors at Nattan Thottam in TNSCB, Division– VI, Chennai. The officials of TNSCB, Division – VI, Chennai – 600 004 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 reconstruction of Slum Tenements at Nattan Thottamin TNSCB, Division--VI, Chennai. Accordingly, the work was taken up and field investigation was carried out during 16th July to 26th July 2019 under the supervision of Faculty members of Division of Soil Mechanics and Foundation



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Engineering, Department of Civil Engineering, Anna University, Chennai in the presence of Executive Engineer, Asst. Executive Engineer and Assistant Engineer of TNSCB, Division – VI, Chennai – 600 004. This report comprises the details of soil investigation, analysis of field and laboratory test results on soil and recommendation of suitable foundation system.

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## 2. SITE CONDITION AND EXPERIMENTAL PROGRAMME

The proposed site is located at Nattan Thottam in TNSCB, Division – VI, Chennai – 600 004. The site is plain terrain. The Borehole locations in Google Map is shown in Figure C-1. The total number of borehole locations has been decided as 4 as agreed by the Executive Engineer of TNSCB, Division – VI, Chennai – 600 004 and the Professor & Head and Project Co-ordinator, Division of Soil Mechanics and Foundation Engineering, Department of Civil Engineering, Anna University, Chennai. 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 and assessment of geology of rock profile.

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 – 3).

Standard penetration tests were conducted at every 1.5 m interval up to 10 m depth from the existing ground level. These SPT tests were carried out using Winch and Cathead device for which the expected energy level is approximately 55% to 60%. 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



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testing laboratory for detailed identification tests. During the progress of soil investigation at the proposed site, the site was inspected and supervised by the faculty members of Department of Civil Engineering, CEG Campus, Anna University, Chennai -25 and officials of TNSCB, Kancheepuram. The Nx size core barrel with Impregnated Diamond Bit was used to drill the rock stratum to retrieve rock core samples. Ground water levels were recorded at the end of each boring.

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-4. 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 and rock samples retrieved through Nx size core barrel are summarized in table A-1 to table A-4 of this report.

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

Figures 1 to 4 show the variation of SPT 'N' value of different soil / rock layers with respect to depth in BH 1 to BH 4 of the proposed site. It could be seen from figure 5 that the variations of SPT 'N' values are almost uniform in all the four bore holes, indicating the homogeneity of soil / rock layer (Plate 2 of Annexure – 3) except 5 m to 7.5 m depth in BH 3 location. The ground water table is located at 1.38 m to 1.60 m depth during the time of investigation.

### 3.1 Summary of Soil Profile in BH 1 to BH 4 Locations

1. The soil profile logged in ten boreholes are primarily sand layer in the depth range of existing ground level to 21.0 m except BH 2 and BH 3. The 'N' values observed in these depth range is varying in between 10 to > 100.
2. Brown Silty clay (CH) layer is encountered at 3.0 m and 4.0 m depths with 'N' values of 7 and 23. In BH 3 location, Sand stone layer was encountered at 5 m to 7.5 m depth range.
3. Beyond 21.0 m to maximum termination depth of 26.0 m, the strata are Weathered Gneiss (Grade V) in all the boreholes with 'N' values > 100.

Thus, it is evident that the soil / rock profile is more or less uniform in the proposed site as reflected from BH 1 to BH 4 locations (Figure 5).



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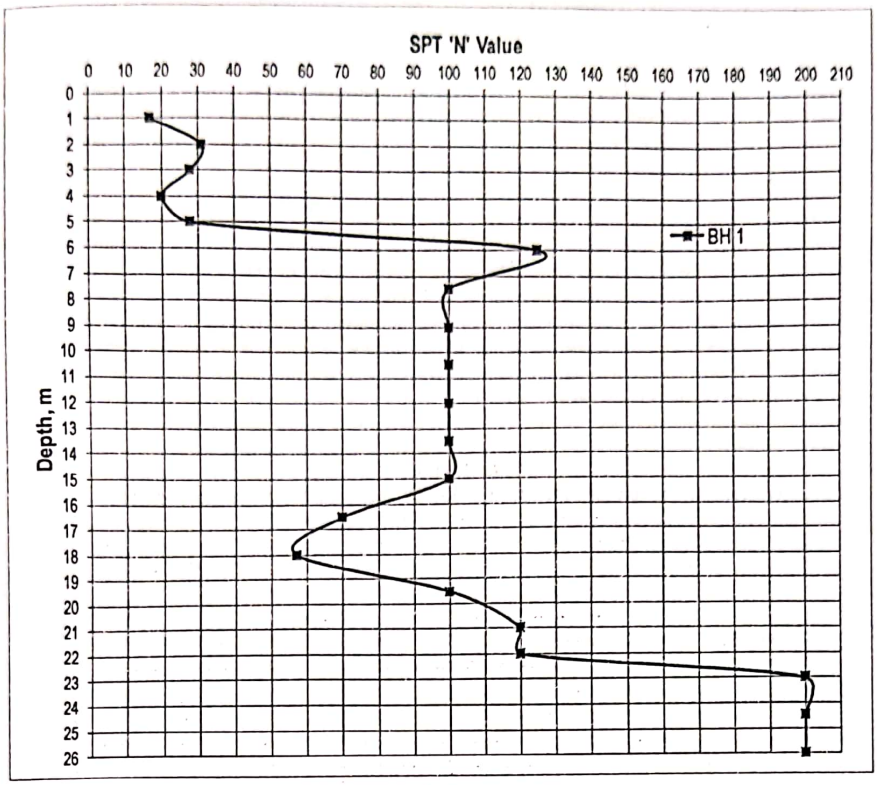
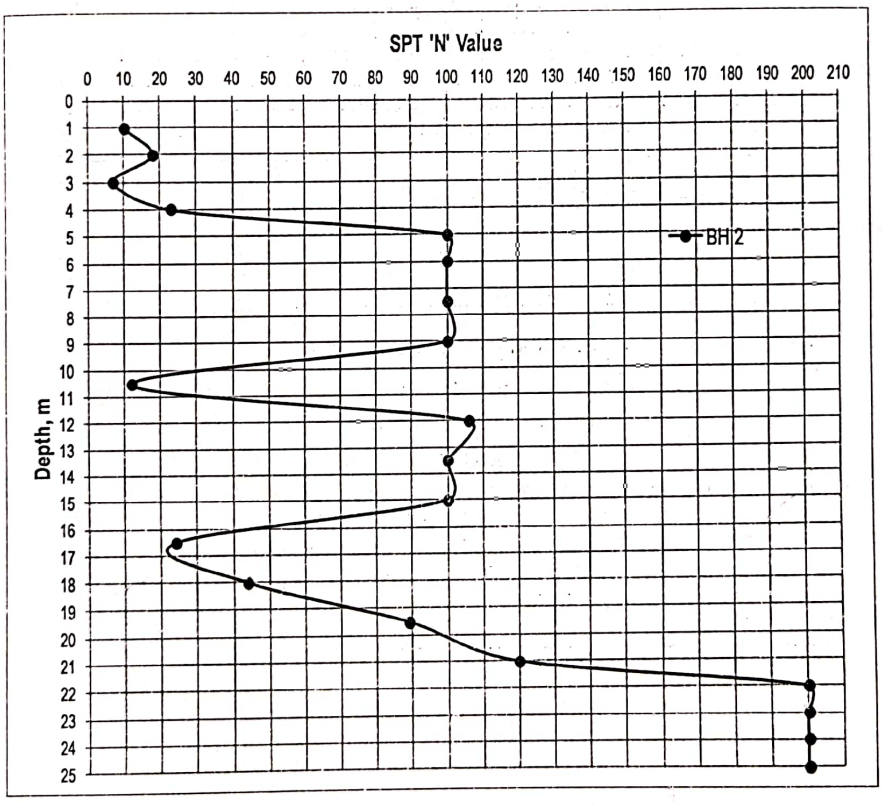



**Figure (1) Variation of SPT 'N' value of different soil / rock layers with respect to Depth in BH 1 Location**






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**Figure (2) Variation of SPT 'N' value of different soil / rock layers with respect to depth in BH 2 Location**

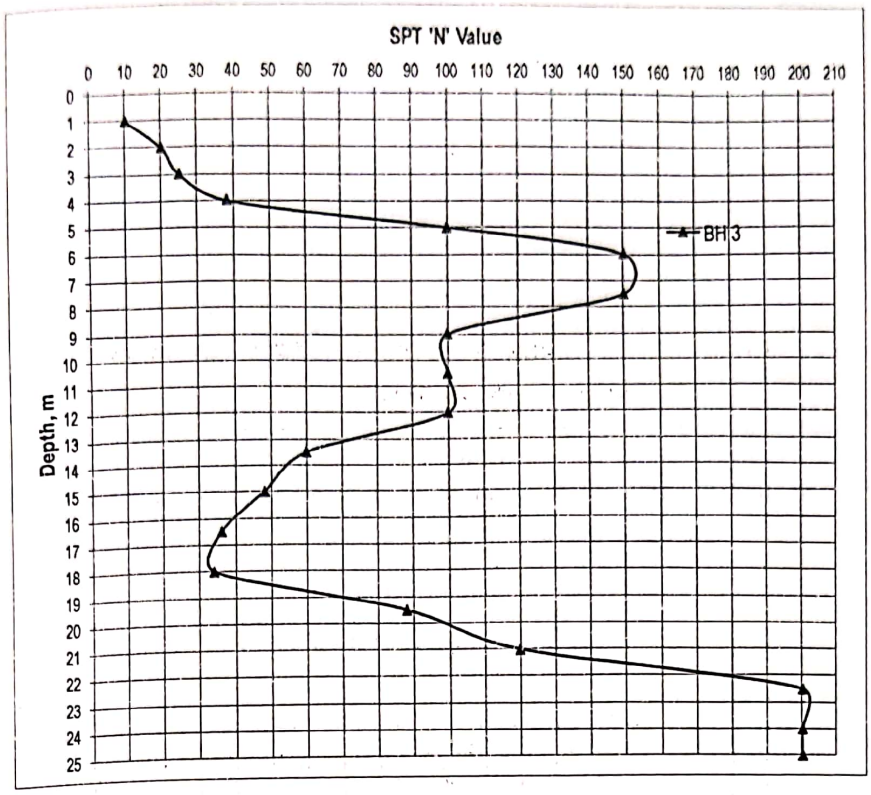
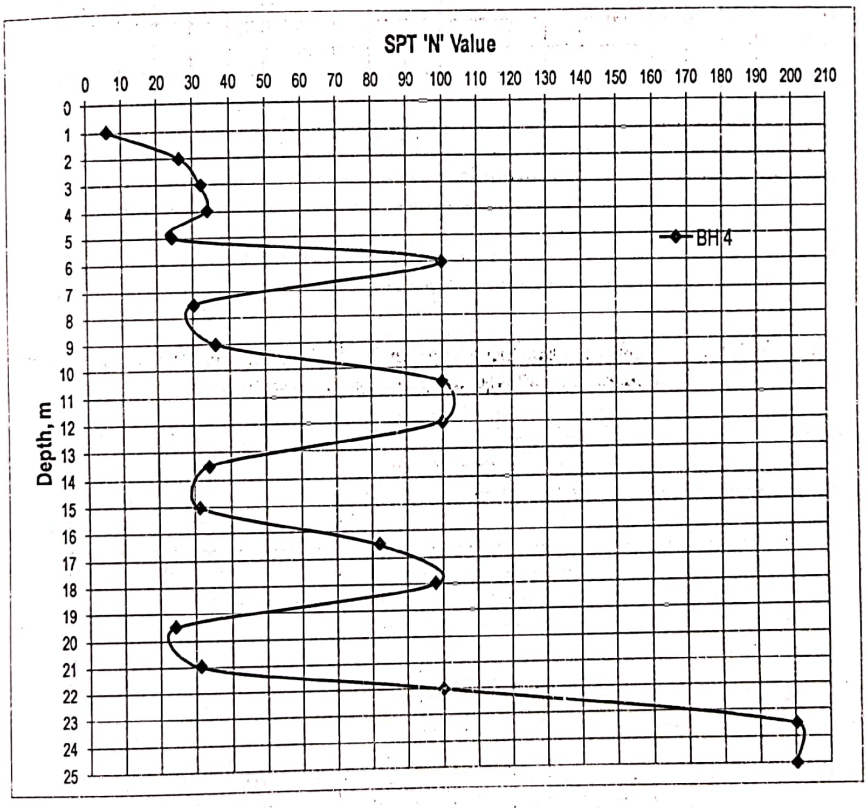



**Figure (3) Variation of SPT 'N' value of different soil / rock layers with respect to depth in BH 3 Location**






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Figure (4) Variation of SPT 'N' value of different soil / rock layers with respect to depth in BH 4 Location

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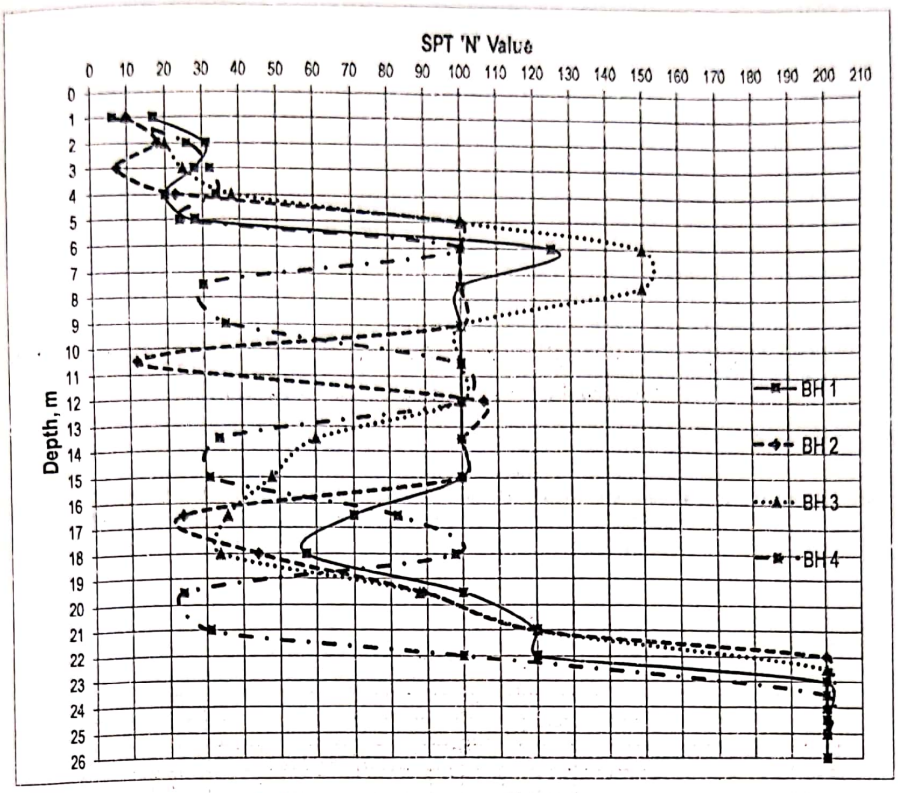



Figure (5) Variation of SPT 'N' value of different soil / rock layers with respect to depth in Different Borehole Locations of the Site

## 4.0 SHEAR STRENGTH PROPERTIES AND ELASTICITY MODULUS VALUES '$E_s$' OF SOIL / ROCK 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 - 1 to table - 5. The '$E_s$' values are computed based on Bowles 1997 correlation.

TABLE 1 SPT "N' values, Correlated '$E_s$' value and Shear Strength Parameters for BH 1 Location

| Depth (m) | SPT 'N' Value | Elastic Modulus 'Es' Value (kN/m²) | Shear Strength Parameters | |
|---|---|---|---|---|
| | | | 'c' (kN/m²) | Φ in Degrees |
| 1.00 | 17 | 16000 | 0 | 31.5 |
| 2.00 | 31 | 23000 | 0 | 38 |
| 3.00 | 28 | 21500 | 0 | 37 |
| 4.00 | 20 | 17500 | 0 | 32 |
| 5.00 | 28 | 21500 | 0 | 37 |
| 6.00 | 125 | 70000 | 0 | 44 |
| 7.50 | > 100 | 57500 | 0 | 44 |
| 9.00 | > 100 | 57500 | 0 | 43 |



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| | | | | |
|---|---|---|---|---|
| 10.50 | > 100 | 57500 | 0 | 43 |
| 12.00 | > 100 | 57500 | 0 | 44 |
| 13.50 | > 100 | 57500 | 0 | 44 |
| 15.00 | > 100 | 57500 | 0 | 43 |
| 16.50 | 70 | 42500 | 0 | 43 |
| 18.00 | 57 | 36000 | 0 | 43 |
| 19.50 | > 100 | 46000 | 0 | 40 |
| 21.00 | > 100 | 67500 | 0 | 44 |
| 22.00 | > 100 | 67500 | 0 | 44 |
| 23.00 | > 100 | 250000 | 0 | 45 |
| 24.50 | > 100 | 250000 | 0 | 45 |
| 26.00 | > 100 | 250000 | 0 | 45 |

**TABLE 2 SPT "N' values, Correlated '$E_s$' value and Shear Strength Parameters for BH 2 Location**

| Depth (m) | SPT 'N' Value | Elastic Modulus 'Es' Value (kN/m²) | Shear Strength Parameters | |
|---|---|---|---|---|
| | | | 'c' (kN/m²) | Φ in Degrees |
| 1.00 | 10 | 12500 | 0 | 26.5 |
| 2.00 | 18 | 16500 | 0 | 32 |
| 3.00 | 7 | 4160 | 44 | 0 |
| 4.00 | 23 | 12160 | 124 | 22 |
| 5.00 | > 100 | 57500 | 0 | 43 |
| 6.00 | > 100 | 57500 | 0 | 44 |
| 7.50 | > 100 | 57500 | 0 | 44 |
| 9.00 | > 100 | 57500 | 0 | 44 |
| 10.50 | 12 | 13500 | 0 | 27.5 |
| 12.00 | 106 | 60500 | 0 | 44 |
| 13.50 | > 100 | 57500 | 0 | 44 |
| 15.00 | > 100 | 57500 | 0 | 44 |
| 16.50 | 24 | 19500 | 0 | 35 |
| 18.00 | 44 | 29500 | 0 | 40 |
| 19.50 | 89 | 52000 | 0 | 42 |
| 21.00 | > 100 | 67500 | 0 | 44 |
| 22.00 | > 100 | 250000 | 0 | 45 |
| 23.00 | > 100 | 250000 | 0 | 45 |
| 24.00 | > 100 | 250000 | 0 | 45 |
| 25.00 | > 100 | 250000 | 0 | 45 |

**TABLE 3 SPT "N' values, Correlated '$E_s$' value and Shear Strength Parameters for BH 3 Location**

| Depth (m) | SPT 'N' Value | Elastic Modulus 'Es' Value (kN/m²) | Shear Strength Parameters | |
|---|---|---|---|---|
| | | | 'c' (kN/m²) | Φ in Degrees |
| 1.00 | 10 | 10000 | 0 | 26 |
| 2.00 | 20 | 17500 | 0 | 33 |
| 3.00 | 25 | 20000 | 0 | 35.5 |
| 4.00 | 38 | 26500 | 0 | 41 |
| 5.00 | > 100 | 57500 | 0 | 44 |



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| | | | | |
|---|---|---|---|---|
| 6.00 | > 100 | 197500 | 0 | 45 |
| 7.50 | > 100 | 197500 | 0 | 45 |
| 9.00 | > 100 | 57500 | 0 | 44 |
| 10.50 | > 100 | 57500 | 0 | 44 |
| 12.00 | > 100 | 57500 | 0 | 44 |
| 13.50 | 60 | 37500 | 0 | 43 |
| 15.00 | 48 | 31500 | 0 | 42 |
| 16.50 | 36 | 25500 | 0 | 40 |
| 18.00 | 34 | 24500 | 0 | 39.5 |
| 19.50 | 88 | 51500 | 0 | 43 |
| 21.00 | > 100 | 67500 | 0 | 44 |
| 22.50 | > 100 | 250000 | 0 | 45 |
| 24.00 | > 100 | 250000 | 0 | 45 |
| 25.00 | > 100 | 250000 | 0 | 45 |

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**TABLE 4 SPT "N' values, Correlated 'Es' value and Shear Strength Parameters for BH 4 Location**

| Depth (m) | SPT 'N' Value | Elastic Modulus 'Es' Value (kN/m²) | Shear Strength Parameters | |
|---|---|---|---|---|
| | | | 'c' (kN/m²) | Φ in Degrees |
| 1.00 | 6 | 6720 | 0 | 24 |
| 2.00 | 26 | 20500 | 0 | 36 |
| 3.00 | 32 | 23500 | 0 | 38.5 |
| 4.00 | 34 | 24500 | 0 | 39.5 |
| 5.00 | 24 | 19500 | 0 | 35 |
| 6.00 | > 100 | 57500 | 0 | 44 |
| 7.50 | 30 | 22500 | 0 | 37.5 |
| 9.00 | 36 | 25500 | 0 | 40 |
| 10.50 | > 100 | 57500 | 0 | 44 |
| 12.00 | > 100 | 57500 | 0 | 44 |
| 13.50 | 34 | 24500 | 0 | 39.5 |
| 15.00 | 31 | 23000 | 0 | 38 |
| 16.50 | 82 | 48500 | 0 | 42 |
| 18.00 | 98 | 56500 | 0 | 44 |
| 19.50 | 24 | 9600 | 150 | 0 |
| 21.00 | 31 | 11840 | 194 | 0 |
| 22.00 | > 100 | 57500 | 0 | 44 |
| 23.50 | > 100 | 250000 | 0 | 45 |
| 25.00 | > 100 | 250000 | 0 | 45 |

## 5.0 COMPUTATION OF BEARING CAPACITY AND SETTLEMENT

Based on the observation made in the boreholes 1 to 4, an attempt is made to arrive the safe bearing capacity, safe bearing pressure and allowable settlement of the foundation soil. The depth of foundation is taken as 2.5 m and width of foundation as 2.5 m to compute safe bearing capacity. The SPT 'N' value, Correlated Elastic Modulus 'Es' value (Bowles 1997) and shear strength parameters and engineering properties of



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soil layers which are required to determine bearing capacity and settlement were taken from Table 1 to Table 4. Safe bearing capacity and settlement computations were made for all the nine-borehole 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 2.5 m and width of foundation as 2.5 m. The safe bearing capacity thus computed is shown in Table 5. 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 5, the safe bearing capacity keeps varying as 228 kN/m$^2$ to 957 kN/m$^2$ respectively for BH 1 to BH 4 locations. Among the bore holes, the BH 2 yielded the lowest safe bearing capacity value.

**TABLE 5 Net Safe Bearing Capacity of the proposed Site (Depth of Foundation is 2.5 m and Width of Foundation is 2.5 m)**

| Borehole Locations | Design Shear Strength Parameters | | Net Safe Bearing Capacity (kN/m$^2$) IS 6403-1981 Equation |
|---|---|---|---|
| | 'c' (kN/m$^2$) | Φ in Degrees | |
| BH 1 | 0.00 | 35.00 | 350.00 |
| BH 2 | 58.40 | 26.00 | 228.00 |
| BH 3 | 0.00 | 41.10 | 957.00 |
| BH 4 | 0.00 | 37.50 | 503.00 |

## 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,



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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 sand. Hence, only the immediate settlement is computed for those Weathered Gneiss layer exists in the influence depth of "2B" below the foundation depth. The settlement computations are made for 2.5 x 6.0 m size with 225 kN/m$^2$ footing pressure. The settlement has been computed up to the influence depth of "2B" below the foundation. ***The allowable settlement as per IS 1904 Table I 1986 is limited to 50 mm for individual footing.*** The Table 6 shows the elastic settlement of foundation. The settlement values varied between 6.89 mm to 17.23 mm for BH 1 to BH 4 locations respectively which is very much lower than the permissible settlement of 50 mm for individual footing.

**TABLE 6 Settlement calculations for the proposed Site (Depth of Foundation is 2.5 m)**

| Borehole Locations | Size of Foundation (m) | Footing Pressure (kN/m$^2$) | Elastic Settlement (mm) |
|---|---|---|---|
| BH 1 | 2.5 x 6.0 | 225 | 12.10 |
| BH 2 | | | 17.23 |
| BH 3 | | | 6.89 |
| BH 4 | | | 12.35 |

## 6.0 COMPUTATION OF SAFE PILE CARRYING CAPACITY

In case if the actual footing pressure exceeds the assumed pressure of 225 kN/m$^2$, then pile foundation is preferable. Hence, in the absence of shallow foundation, pile foundation can be provided. Attempts are 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 500 mm, 600 mm, 700 mm, 900 mm and 1000 mm and the length of the pile is taken as 22 m to 24 m for different borehole locations. Safe pile carrying capacity computations were made for all four-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.



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For calculating the skin friction along the pile length of 22 m to 24 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 7. The calculations of pile carrying capacity by static formula (IS 2911: 2010) and Meyerhof formula (1959) are presented in Annexure 2. 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.

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 S 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 8.

**TABLE 7 Safe Load carrying capacity of Bored Cast-In-Situ Pile of 22 m to 24 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 | | | | |
| | 500 | 600 | 700 | 900 | 1000 | 500 | 600 | 700 | 900 | 1000 |
| BH 1 | 1515 | 2026 | 2605 | 3972 | 4759 | 1394 | 1880 | 2435 | 3753 | 4516 |
| BH 2 | 1470 | 1971 | 2542 | 3890 | 4668 | 1418 | 1909 | 2470 | 3797 | 4565 |
| BH 3 | 1543 | 2059 | 2644 | 4022 | 4814 | 1471 | 1972 | 2543 | 3891 | 4669 |
| BH 4 | 1561 | 2081 | 2669 | 4054 | 4850 | 1429 | 1922 | 2484 | 3816 | 4586 |



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TABLE 8 Safe Uplift Capacity of 22 m to 24 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) | 500 | 600 | 700 | 900 | 1000 |
| BH 1 | 645 | 802 | 967 | 1324 | 1517 |
| BH 2 | 601 | 747 | 902 | 1237 | 1418 |
| BH 3 | 671 | 833 | 1003 | 1371 | 1569 |
| BH 4 | 691 | 858 | 1034 | 1414 | 1618 |

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## 7. CONCLUSIONS AND RECOMMENDATIONS

Considering the discussions made in sections 3, 4, 5 and 6, the following conclusions are recommended for the Reconstruction of Slum Tenements at Nattan Thottam in TNSCB, Division – VI, Chennai.

**Option – 1 (Shallow Foundation)**

1) It is recommended to provide SHALLOW OPEN FOUNDATION.

2) The recommended depth of Shallow Open Foundation is 2.5 m from the lowest borehole level of the site.

3) The recommended safe bearing capacity at 2.5 m, from the existing borehole level of the site, is 225 kN/m$^2$. The permissible settlement for individual footing is 50 mm.

4) It is recommended to provide 2.5 m wide Strip Raft Foundation or Combined Footings at 2.5 m depth (from the existing ground level) with respect to varying superstructure load.

5) The computed settlement of soil for 2.5 m x 6.0 m foundation with 225 kN/m$^2$ foundation pressure is varying between 6.89 mm to 17.23 mm which is lower than the permissible settlement of 50 mm.

6) It is recommended to replace medium stiff silty clay layer by quarry sand / river sand if encountered below the foundation depth of 2.5 m.



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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 the actual footing pressure exceeds the assumed pressure of 225 kN/m$^2$, 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 pile carrying capacity and uplift of the 22 m to 24 m length of 'bored cast in-situ pile' for varying diameter is shown in Table 9. 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 22 m to 24 m in 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 or M 40.



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**TABLE 9 Safe Load carrying capacity and Lateral Load Capacity of Bored Cast-In-Situ Pile for varying diameter and for a length of 22 m to 24 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) |
|---|---|---|---|
| 500 | 1300 | 103.70 | 3.65 |
| 600 | 1800 | 138.10 | 4.23 |
| 700 | 2400 | 177.30 | 4.78 |
| 900 | 3600 | 264.30 | 5.85 |
| 1000 | 4400 | 313.50 | 6.36 |

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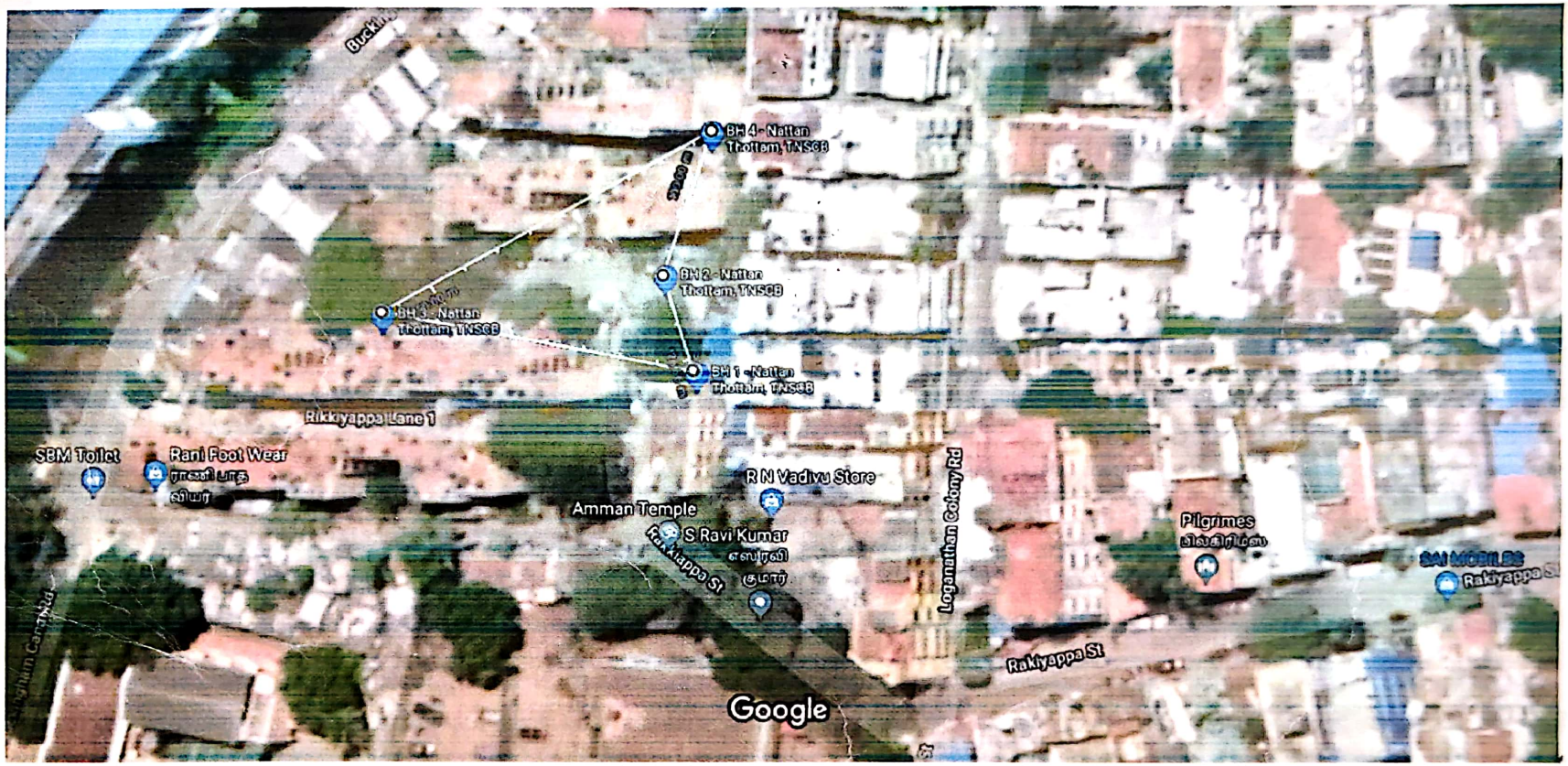
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Google Maps Project : Geotechnical Investigation for the Reconstruction of Slum Tenements at Nattan Thottam, TNSCB, Chennai




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Figure C – 1 Location of Bore Holes

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## FIELD BORE LOG PROFILE

**Project : Reconstruction of Slum Tenements at Nattan Thottam, TNSCB, Chennai**

| | | | | | |
|---|---|---|---|---|---|
| BH NO | BH 1 (N-1441722; E-420941) | NX Size Coring in Rock Strata | DATE OF START | | 20.07.2019 |
| SITE | Nattan Thottam | | DATE OF COMPLETION | | 23.07.2019 |
| DIA OF BORING | 150 mm / 76 mm | | GROUND WATER LEVEL (m) | | 1.45 |
| TYPE OF BORING | Rotary | | RL | | - |

| 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) | 6 | 8 | 9 | 17 | Medium Dense |
| 2.0 | | Brown Sand (SP) | 12 | 15 | 16 | 31 | Dense |
| 3.0 | | Brown Sand (SP) | 12 | 14 | 14 | 28 | Medium Dense |
| 4.0 | | Brown Silty Sand (SM-SP) | 4 | 8 | 12 | 20 | Medium Dense |
| 5.0 | | Brown Sand (SP) | 8 | 12 | 16 | 28 | Medium Dense |
| 6.0 | | Brown Sand (SP) | 40 | 56 | 69 | 125 | Very Dense |
| 7.5 | | Brown Sand (SP) | 36 | $68_{(12\ cm)}$ Rebound | | >100 | Very Dense |
| 9.0 | | Brown Silty Sand (SM-SP) | 44 | $56_{(2\ cm)}$ Rebound | | >100 | Very Dense |
| 10.5 | | Brown Silty Sand (SM-SP) | 48 | 62 | $59_{(2\ cm)}$ Rebound | >100 | Very Dense |
| 12.0 | | Grayish Brown Sand (SP) | 48 | $59_{(2\ cm)}$ Rebound | | >100 | Very Dense |
| 13.5 | | Brown Sand (SP) | 55 | 60 | $58_{(3\ cm)}$ Rebound | >100 | Very Dense |
| 15.0 | | Brown Silty Sand (SM-SP) | 48 | $60_{(12\ cm)}$ Rebound | | >100 | Very Dense |
| 16.5 | | Grayish Brown Silty Sand (SM-SP) | 18 | 30 | 40 | 70 | Very Dense |
| 18.0 | | Grayish Silty Sand (SM-SP) | 14 | 19 | 38 | 57 | Very Dense |
| 19.5 | | Grayish Silty / Clayey Sand (SC) | 20 | 30 | $50_{(10\ cm)}$ Rebound | >100 | Very Dense / Hard |
| 21.0 | | Grayish Brown Silty / Clayey Sand - Weathered Sediments (Grade VI) | $78_{(12\ cm)}$ Rebound | | | >100 | Very Dense / Hard |
| 22.0 | | Grayish Brown Silty Sand - Weathered Sediments (Grade VI) | $56_{(4\ cm)}$ Rebound | | | >100 | Very Dense / Hard |
| 23.0 | | Grayish Brown Weathered Gneiss (Grade V) | $25_{(0\ cm)}$ Rebound; TCR=18%; RQD=0% | | | >100 | Hard / Weak |
| 24.5 | | Grayish Brown Weathered Gneiss (Grade V) | $20_{(0\ cm)}$ Rebound; TCR=8%; RQD=0% | | | >100 | Hard / Weak |
| 26.0 | | Grayish Brown Weathered Gneiss (Grade V) | $20_{(0\ cm)}$ Rebound; TCR=8%; RQD=8% | | | >100 | Hard / Weak |

Bore hole has been terminated at 26.0 m from the existing ground level (EGL). Nx Size Core Barrel with Diamond Cutter was used to drill 22.0 m to 26.0 m depth Rock Stratum

Figure A-1

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## FIELD BORE LOG PROFILE

| Project : Reconstruction of Slum Tenements at Nattan Thottam, TNSCB, Chennai | | | | | |
|---|---|---|---|---|---|
| BH NO | BH 2 (N-1441735; E-420937) | NX Size Coring in Rock Strata | DATE OF START | | 16.07.2019 |
| SITE | Nattan Thottam | | DATE OF COMPLETION | | 19.07.2019 |
| DIA OF BORING | 150 mm / 76 mm | | GROUND WATER LEVEL (m) | | 1.4 |
| TYPE OF BORING | Rotary | | RL | | - |

| 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 Silty Sand (SM-SP) | 4 | 4 | 6 | 10 | Loose |
| 2.0 | | Brown Sand (SP) | 6 | 6 | 12 | 18 | Medium Dense |
| 3.0 | | Brown Silty Clay (CH) | 4 | 4 | 3 | 7 | Medium Stiff |
| 4.0 | | Brown Silty / Clayey Sand (CH) | 6 | 8 | 15 | 23 | Very Stiff |
| 5.0 | | Brown Silty Sand (SM-SP) | 33 | 48 | $59_{(5\ cm)}$ Rebound | >100 | Very Dense |
| 6.0 | | Brown Sand (SP) | 48 | $56_{(1\ cm)}$ Rebound | | >100 | Very Dense |
| 7.5 | | Brown Sand (SP) | 44 | $60_{(5\ cm)}$ Rebound | | >100 | Very Dense |
| 9.0 | | Brown Sand (SP) | 44 | 44 | $52_{(13\ cm)}$ Rebound | >100 | Very Dense |
| 10.5 | | Grayish Brown Silty Sand (SM-SP) | 48 | 6 | 6 | 12 | Medium Dense |
| 12.0 | | Grayish Brown Sand (SP) | 42 | 48 | 58 | 106 | Very Dense |
| 13.5 | | Grayish Brown Sand (SP) | 44 | 54 | $56_{(3\ cm)}$ Rebound | >100 | Very Dense |
| 15.0 | | Grayish Brown Sand (SP) | 42 | 48 | $53_{(2\ cm)}$ Rebound | >100 | Very Dense |
| 16.5 | | Brown Sand (SP) | 10 | 10 | 14 | 24 | Medium Dense |
| 16.0 | | Grayish Brown Silty Sand (SM-SP) | 14 | 18 | 26 | 44 | Dense |
| 19.5 | | Grayish Brown Silty Sand (SM-SP) | 25 | 40 | 49 | 89 | Very Dense |
| 21.0 | | Grayish White Silty Sand- Weathered Sediments (Grade VI) | $58_{(12\ cm)}$ Rebound | | | >100 | Very Dense / Hard |
| 22.0 | | Grayish Brown Weathered Gneiss (Grade V) | $56_{(0\ cm)}$ Rebound; TCR=0%; RQD=0% | | | >100 | Hard / Weak |
| 23.0 | | Grayish Brown Weathered Gneiss (Grade V) | $25_{(0\ cm)}$ Rebound; TCR=9%; RQD=0% | | | >100 | Hard / Weak |
| 24.0 | | Grayish Brown Weathered Gneiss (Grade V) | $20_{(0\ cm)}$ Rebound; TCR=20%; RQD=0% | | | >100 | Hard / Weak |
| 25.0 | | Grayish Brown Weathered Gneiss (Grade V) | $20_{(0\ cm)}$ Rebound; TCR=25%; RQD=0% | | | >100 | Hard / Weak |

Bore hole has been terminated at 25.0 m from the existing ground level (EGL). Nx Size Core Barrel with Diamond Cutter was used to drill 21.0 m to 25.0 m depth Rock Stratum

Figure A-2

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## FIELD BORE LOG PROFILE

**Project : Reconstruction of Slum Tenements at Nattan Thottam, TNSCB, Chennai**

| | | | | | |
|---|---|---|---|---|---|
| BH NO | BH 3 (N-1441730; E-420899) | NX Size Coring in Rock Strata | DATE OF START | | 20.07.2019 |
| SITE | Nattan Thottam | | DATE OF COMPLETION | | 23.07.2019 |
| DIA OF BORING | 150 mm / 76 mm | | GROUND WATER LEVEL (m) | | 1.38 |
| TYPE OF BORING | Rotary | | RL | | - |

| 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 Silty / Clayey Sand (SC-SM) | 4 | 5 | 5 | 10 | Loose |
| 2.0 | | Brown Silty Sand (SM-SP) | 7 | 7 | 13 | 20 | Medium Dense |
| 3.0 | | Brown Sand (SP) | 7 | 11 | 14 | 25 | Medium Dense |
| 4.0 | | Brown Sand (SP) | 11 | 14 | 24 | 38 | Dense |
| 5.0 | | Brown Sand (SP) | $60_{(6\ cm)}$ Rebound | | | >100 | Very Dense |
| 6.0 | | Brown Sandstone (Grade V) | $50_{(0\ cm)}$ Rebound; TCR=12%; RQD=12% | | | >100 | Hard / Weak |
| 7.5 | | Brown Sandstone (Grade V) | $50_{(0\ cm)}$ Rebound; TCR=8%; RQD=0% | | | >100 | Hard / Weak |
| 9.0 | | Brown Sand (SP) | 44 | $56_{(2\ cm)}$ Rebound | | >100 | Very Dense |
| 10.5 | | Brown Sand (SP) | 39 | $59_{(2\ cm)}$ Rebound | | >100 | Very Dense |
| 12.0 | | Brown Sand (SP) | 38 | $55_{(2\ cm)}$ Rebound | | >100 | Very Dense |
| 13.5 | | Brown Sand (SP) | 20 | 24 | 36 | 60 | Very Dense |
| 15.0 | | Grayish Brown Sand (SP) | 18 | 22 | 26 | 48 | Dense |
| 16.5 | | Grayish Brown Sand (SP) | 10 | 18 | 18 | 36 | Dense |
| 18.0 | | Grayish Brown Sand (SP) | 12 | 16 | 18 | 34 | Dense |
| 19.5 | | Grayish Brown Sand (SP) | 30 | 38 | 50 | 88 | Very Dense |
| 21.0 | | Grayish Brown Silty Sand - Weathered Sediments (Grade VI) | 34 | $59_{(2\ cm)}$ Rebound | | >100 | Very Dense / Hard |
| 22.5 | | Grayish Brown Weathered Gneiss (Grade V) | $50_{(0\ cm)}$ Rebound; TCR=0%; RQD=0% | | | >100 | Hard / Weak |
| 24.0 | | Grayish Brown Weathered Gneiss (Grade V) | $25_{(0\ cm)}$ Rebound; TCR=3%; RQD=0% | | | >100 | Hard / Weak |
| 25.0 | | Grayish Brown Weathered Gneiss (Grade V) | $20_{(0\ cm)}$ Rebound; TCR=10%; RQD=10% | | | >100 | Hard / Weak |

- Bore hole has been terminated at 25.0 m from the existing ground level (EGL). Nx Size Core Barrel with Diamond Cutter was used to drill 5.0 m to 7.5 m and 21.0 m to 25.0 m depth Rock Stratum

Figure A-3

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## FIELD BORE LOG PROFILE

**Project : Reconstruction of Slum Tenements at Nattan Thottam, TNSCB, Chennai**

| | | | | | |
|---|---|---|---|---|---|
| BH NO | BH 4 (N-1441754; E-420943) | NX Size Coring in Rock Strata | DATE OF START | | 24.07.2019 |
| SITE | Nattan Thottam | | DATE OF COMPLETION | | 26.07.2019 |
| DIA OF BORING | 150 mm / 76 mm | | GROUND WATER LEVEL (m) | | 1.6 |
| TYPE OF BORING | Rotary | | RL | | - |

| 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 Silty Sand (SM-SP) - Made-Up Soil | 2 | 2 | 4 | 6 | Loose |
| 2.0 | | Grayish Brown Silty Sand (SM-SP) | 4 | 12 | 14 | 26 | Medium Dense |
| 3.0 | | Grayish Brown Sand (SP) | 11 | 16 | 16 | 32 | Dense |
| 4.0 | | Grayish Brown Sand (SP) | 11 | 16 | 18 | 34 | Dense |
| 5.0 | | Grayish Brown Sand (SP) | 4 | 11 | 13 | 24 | Medium Dense |
| 6.0 | | Brown Sand (SP) | 30 | $56_{(6\ cm)}$ Rebound | | >100 | Very Dense |
| 7.5 | | Grayish Brown Sand (SP) | 10 | 15 | 15 | 30 | Dense |
| 9.0 | | Grayish Brown Sand (SP) | 11 | 18 | 18 | 36 | Dense |
| 10.5 | | Grayish Brown Sand (SP) | 42 | $60_{(2\ cm)}$ Rebound | | >100 | Very Dense |
| 12.0 | | Grayish Brown Sand (SP) | 44 | $55_{(5\ cm)}$ Rebound | | >100 | Very Dense |
| 13.5 | | Grayish Brown Sand (SP) | 10 | 16 | 18 | 34 | Medium Dense |
| 15.0 | | Grayish Brown Sand (SP) | 6 | 13 | 18 | 31 | Medium Dense |
| 16.5 | | Grayish Brown Silty Sand (SM-SP) | 22 | 30 | 52 | 82 | Very Dense |
| 18.0 | | Grayish Brown Sand (SP) | 22 | 36 | 62 | 98 | Very Dense |
| 19.5 | | Grayish Silty Clay (CH) | 10 | 12 | 12 | 24 | Very Stiff |
| 21.0 | | Grayish Silty Clay (CH) | 13 | 15 | 16 | 31 | Very Stiff |
| 22.0 | | Grayish Brown Sand (SP) | $60_{(2\ cm)}$ Rebound | | | >100 | Very Dense |
| 23.5 | | Grayish Brown Weathered Gneiss (Grade V) | $25_{(0\ cm)}$ Rebound; TCR=2%; RQD=0% | | | >100 | Hard / Weak |
| 25.0 | | Grayish Brown Weathered Gneiss (Grade V) | $25_{(0\ cm)}$ Rebound; TCR=8%; RQD=0% | | | >100 | Hard / Weak |

- Bore hole has been terminated at 25.0 m from the existing ground level (EGL). Nx Size Core Barrel with Diamond Cutter was used to drill 22.0 m to 25.0 m depth Rock Stratum

Figure A-4

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Table A-1

Project : Reconstruction of Slum Tenements at Nattan Thottam, TNSCB, Chennai

BH No: 1 | Ground Water Table Depth (m): 1.45

LABORATORY TEST RESULTS

| Depth (m) | SPT 'N' Value | Soil Description / Classification | Index Properties | | | | | | Specific Gravity | Grain Size Analysis (%) | | | | | | Direct Shear / Terzaghi and Peck (1974) - Shear Strength Parameters | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Natural Moisture Content / Water Absorption % | 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 | | |
| 1.00 | 17 | Brown Sand (SP) | 13 | 18.11 | NP | NP | NP | NP | 2.63 | 0 | 5 | 69 | 19 | 7 | | 0 | 31.5 |
| 2.00 | 31 | Brown Sand (SP) | 14 | 20.34 | NP | NP | NP | NP | 2.64 | 0 | 7 | 69 | 22 | 2 | | 0 | 38.0 |
| 3.00 | 28 | Brown Sand (SP) | 11 | 19.95 | NP | NP | NP | NP | 2.64 | 0 | 4 | 70 | 19 | 7 | | 0 | 37.0 |
| 4.00 | 20 | Brown Silty Sand (SM-SP) | 8 | 18.69 | NP | NP | NP | NP | 2.63 | 0 | 3 | 63 | 20 | 14 | | 0 | 32.0 |
| 5.00 | 28 | Brown Sand (SP) | 11 | 19.95 | NP | NP | NP | NP | 2.63 | 0 | 8 | 61 | 24 | 7 | | 0 | 37.0 |
| 6.00 | 125 | Brown Sand (SP) | 12 | 22.00 | NP | NP | NP | NP | 2.64 | 0 | 3 | 71 | 23 | 3 | | 0 | 44.0 |
| 7.50 | >100 | Brown Sand (SP) | 12 | 22.00 | NP | NP | NP | NP | 2.63 | 0 | 3 | 70 | 24 | 3 | | 0 | 44.0 |
| 9.00 | >100 | Brown Silty Sand (SM-SP) | 11 | 22.00 | NP | NP | NP | NP | 2.63 | 0 | 4 | 67 | 18 | 11 | | 0 | 43.0 |
| 10.50 | >100 | Brown Silty Sand (SM-SP) | 13 | 22.00 | NP | NP | NP | NP | 2.63 | 0 | 3 | 67 | 18 | 12 | | 0 | 43.0 |
| 12.00 | >100 | Grayish Brown Sand (SP) | 12 | 22.00 | NP | NP | NP | NP | 2.64 | 0 | 5 | 62 | 29 | 4 | | 0 | 44.0 |
| 13.50 | >100 | Brown Sand (SP) | 12 | 22.00 | NP | NP | NP | NP | 2.64 | 0 | 5 | 61 | 31 | 3 | | 0 | 44.0 |
| 15.00 | >100 | Brown Silty Sand (SM-SP) | 6 | 22.00 | NP | NP | NP | NP | 2.64 | 0 | 3 | 63 | 12 | 22 | | 0 | 43.0 |
| 16.50 | 70 | Grayish Brown Silty Sand (SM-SP) | 7 | 22.00 | NP | NP | NP | NP | 2.63 | 0 | 0 | 54 | 27 | 19 | | 0 | 43.0 |
| 18.00 | 57 | Grayish Silty Sand (SM-SP) | 10 | 22.00 | NP | NP | NP | NP | 2.63 | 0 | 3 | 65 | 15 | 17 | | 0 | 43.0 |
| 19.50 | >100 | Grayish Silty / Clayey Sand (SC) | 12 | 22.00 | 32 | 13 | 19 | 10 | 2.66 | 0 | 0 | 52 | 23 | 25 | | 0 | 40.0 |
| 21.00 | >100 | Grayish Brown Silty / Clayey Sand - Weathered Sediments (Grade VI) | 9 | 22.00 | 36 | 15 | 21 | 15 | 2.65 | 0 | 13 | 30 | 25 | 32 | | 0 | 44.0 |
| 22.00 | >100 | Grayish Brown Silty Sand - Weathered Sediments (Grade VI) | 6 | 22.00 | NP | NP | NP | NP | 2.63 | 0 | 18 | 34 | 36 | 12 | | 0 | 44.0 |
| | | | | | Porosity of Rock (%) | | | | | Strength of Rock | | | | | | | |
| | | | | | | | | | | UCS, kN/m$^2$ | | | $I_s$, kN/m$^2$ | | | | |
| 23.00 | >100 | Grayish Brown Weathered Gneiss (Grade V) | 2.42 | 23.40 | 1.32 | | | | | - | | | 250 | | | 0 | 45.0 |
| 24.50 | >100 | Grayish Brown Weathered Gneiss (Grade V) | 2.54 | 23.10 | 1.55 | | | | | - | | | 57 | | | 0 | 45.0 |
| 26.00 | >100 | Grayish Brown Weathered Gneiss (Grade V) | 2.54. | 23.10 | 1.58 | | | | | - | | | 80 | | | 0 | 45.0 |

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## Table A-2

**Project : Reconstruction of Slum Tenements at Nattan Thottam, TNSCB, Chennai**

| BH No: | 2 | Ground Water Table Depth (m): | 1.4 |
|---|---|---|---|

**LABORATORY TEST RESULTS**

| Depth (m) | SPT 'N' Value | Soil Description / Classification | Index Properties | | | | | | Specific Gravity | Grain Size Analysis (%) | | | | | | Direct Shear / Terzaghi and Peck (1974) - Shear Strength Parameters | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Natural Moisture Content / Water Absorption % | 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 | | |
| 1.00 | 10 | Brown Silty Sand (SM-SP) | 9 | 16.33 | NP | NP | NP | NP | 2.63 | 0 | 7 | 43 | 30 | 20 | | 0 | 26.5 |
| 2.00 | 18 | Brown Sand (SP) | 7 | 18.31 | NP | NP | NP | NP | 2.64 | 0 | 19 | 54 | 21 | 6 | | 0 | 32.0 |
| 3.00 | 7 | Brown Silty Clay (CH) | 34 | 15.24 | 70 | 30 | 40 | 80 | 2.62 | 0 | 0 | 6 | 10 | 84 | | 44 | 0 |
| 4.00 | 23 | Brown Silty / Clayey Sand (CH) | 27 | 19.20 | 54 | 25 | 29 | 50 | 2.65 | 0 | 0 | 20 | 20 | 60 | | 124 | 22.0 |
| 5.00 | >100 | Brown Silty Sand (SM-SP) | 11 | 22.00 | NP | NP | NP | NP | 2.64 | 0 | 3 | 49 | 33 | 15 | | 0 | 43.0 |
| 6.00 | >100 | Brown Sand (SP) | 9 | 22.00 | NP | NP | NP | NP | 2.63 | 0 | 0 | 44 | 48 | 8 | | 0 | 44.0 |
| 7.50 | >100 | Brown Sand (SP) | 3 | 22.00 | NP | NP | NP | NP | 2.63 | 0 | 6 | 48 | 40 | 6 | | 0 | 44.0 |
| 9.00 | >100 | Brown Sand (SP) | 8 | 22.00 | NP | NP | NP | NP | 2.64 | 0 | 0 | 77 | 15 | 8 | | 0 | 44.0 |
| 10.50 | 12 | Grayish Brown Silty Sand (SM-SP) | 25 | 16.92 | NP | NP | NP | NP | 2.64 | 0 | 0 | 17 | 72 | 11 | | 0 | 27.5 |
| 12.00 | 106 | Grayish Brown Sand (SP) | 12 | 22.00 | NP | NP | NP | NP | 2.63 | 0 | 0 | 24 | 69 | 7 | | 0 | 44.0 |
| 13.50 | >100 | Grayish Brown Sand (SP) | 10 | 22.00 | NP | NP | NP | NP | 2.63 | 0 | 0 | 54 | 37 | 9 | | 0 | 44.0 |
| 15.00 | >100 | Grayish Brown Sand (SP) | 10 | 22.00 | NP | NP | NP | NP | 2.63 | 0 | 0 | 47 | 46 | 7 | | 0 | 44.0 |
| 16.50 | 24 | Brown Sand (SP) | 8 | 19.36 | NP | NP | NP | NP | 2.64 | 0 | 0 | 66 | 24 | 10 | | 0 | 35.0 |
| 18.00 | 44 | Grayish Brown Silty Sand (SM-SP) | 9 | 21.77 | NP | NP | NP | NP | 2.63 | 0 | 2 | 57 | 26 | 15 | | 0 | 40.0 |
| 19.50 | 89 | Grayish Brown Silty Sand (SM-SP) | 6 | 22.00 | NP | NP | NP | NP | 2.63 | 0 | 29 | 29 | 30 | 12 | | 0 | 42.0 |
| 21.00 | >100 | Grayish White Silty Sand- Weathered Sediments (Grade VI) | 5 | 22.00 | NP | NP | NP | NP | 2.66 | 0 | 19 | 22 | 33 | 26 | | 0 | 44.0 |
| | | | | | Porosity of Rock (%) | | | | | Strength of Rock | | | | | | | |
| | | | | | | | | | | UCS, kN/m$^2$ | | | $I_s$, kN/m$^2$ | | | | |
| 22.00 | >100 | Grayish Brown Weathered Gneiss (Grade V) | 2.48 | 23.1 | 1.42 | | | | | - | | | - | | | 0 | 45.0 |
| 23.00 | >100 | Grayish Brown Weathered Gneiss (Grade V) | 2.54 | 23.1 | 1.45 | | | | | - | | | 55 | | | 0 | 45.0 |
| 24.00 | >100 | Grayish Brown Weathered Gneiss (Grade V) | 2.55 | 23.2 | 1.44 | | | | | - | | | 58 | | | 0 | 45.0 |
| 25.00 | >100 | Grayish Brown Weathered Gneiss (Grade V) | 2.55 | 23.2 | 1.45 | | | | | - | | | 60 | | | 0 | 45.0 |

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## Table A-3

**Project : Reconstruction of Slum Tenements at Nattan Thottam, TNSCB, Chennai**

**BH No: 3** | **Ground Water Table Depth (m): 1.38**

**LABORATORY TEST RESULTS**

| Depth (m) | SPT 'N' Value | Soil Description / Classification | Index Properties | | | | | | Specific Gravity | Grain Size Analysis (%) | | | | | | Direct Shear / Terzaghi and Peck (1974) - Shear Strength Parameters | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Natural Moisture Content / Water Absorption % | 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 | | |
| 1.00 | 10 | Brown Silty / Clayey Sand (SC-SM) | 10 | 16.33 | 24 | 16 | 8 | 10 | 2.66 | 0 | 14 | 29 | 34 | 23 | | 0 | 26.0 |
| 2.00 | 20 | Brown Silty Sand (SM-SP) | 11 | 18.69 | NP | NP | NP | NP | 2.64 | 0 | 4 | 40 | 42 | 14 | | 0 | 33.0 |
| 3.00 | 25 | Brown Sand (SP) | 16 | 19.51 | NP | NP | NP | NP | 2.63 | 0 | 0 | 52 | 45 | 3 | | 0 | 35.5 |
| 4.00 | 38 | Brown Sand (SP) | 14 | 21.16 | NP | NP | NP | NP | 2.63 | 0 | 0 | 54 | 45 | 1 | | 0 | 41.0 |
| 5.00 | >100 | Brown Sand (SP) | 15 | 22.00 | NP | NP | NP | NP | 2.64 | 0 | 16 | 52 | 25 | 7 | | 0 | 44.0 |
| 9.00 | >100 | Brown Sand (SP) | 16 | 22.00 | NP | NP | NP | NP | 2.63 | 0 | 2 | 32 | 62 | 4 | | 0 | 44.0 |
| 10.50 | >100 | Brown Sand (SP) | 15 | 22.00 | NP | NP | NP | NP | 2.63 | 0 | 4 | 30 | 63 | 3 | | 0 | 44.0 |
| 12.00 | >100 | Brown Sand (SP) | 13 | 22.00 | NP | NP | NP | NP | 2.64 | 0 | 0 | 32 | 64 | 4 | | 0 | 44.0 |
| 13.50 | 60 | Brown Sand (SP) | 15 | 22.00 | NP | NP | NP | NP | 2.63 | 0 | 0 | 30 | 66 | 4 | | 0 | 43.0 |
| 15.00 | 48 | Grayish Brown Sand (SP) | 19 | 22.00 | NP | NP | NP | NP | 2.64 | 0 | 0 | 23 | 70 | 7 | | 0 | 42.0 |
| 16.50 | 36 | Grayish Brown Sand (SP) | 17 | 20.94 | NP | NP | NP | NP | 2.63 | 0 | 0 | 43 | 53 | 4 | | 0 | 40.0 |
| 18.00 | 34 | Grayish Brown Sand (SP) | 13 | 20.71 | NP | NP | NP | NP | 2.64 | 0 | 2 | 55 | 35 | 8 | | 0 | 39.5 |
| 19.50 | 88 | Grayish Brown Sand (SP) | 12 | 22.00 | NP | NP | NP | NP | 2.64 | 0 | 0 | 46 | 48 | 6 | | 0 | 43.0 |
| 21.00 | >100 | Grayish Brown Silty Sand - Weathered Sediments (Grade VI) | 17 | 22.00 | NP | NP | NP | NP | 2.63 | 0 | 12 | 37 | 50 | 1 | | 0 | 44.0 |
| | | | | | Porosity of Rock (%) | | | | | Strength of Rock | | | | | | | |
| | | | | | | | | | | UCS, kN/m$^2$ | | | $I_s$, kN/m$^2$ | | | | |
| 6.00 | >100 | Brown Sandstone (Grade V) | 2.28 | 23.50 | 1.22 | | | | | - | | | 471 | | | 0 | 45.0 |
| 7.50 | >100 | Brown Sandstone (Grade V) | 2.28 | 23.90 | 1.23 | | | | | - | | | 2614 | | | 0 | 45.0 |
| 22.50 | >100 | Grayish Brown Weathered Gneiss (Grade V) | - | 22.00 | - | | | | | - | | | - | | | 0 | 45.0 |
| 24.00 | >100 | Grayish Brown Weathered Gneiss (Grade V) | 2.52 | 23.10 | 1.45 | | | | | - | | | 82 | | | 0 | 45.0 |
| 25.00 | >100 | Grayish Brown Weathered Gneiss (Grade V) | 2.52 | 23.90 | 1.45 | | | | | - | | | 6052 | | | 0 | 45.0 |

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## Table A-4

**Project : Reconstruction of Slum Tenements at Nattan Thottam, TNSCB, Chennai**

**BH No: 4** — **Ground Water Table Depth (m): 1.6**

**LABORATORY TEST RESULTS**

| Depth (m) | SPT 'N' Value | Soil Description / Classification | Index Properties | | | | | | Specific Gravity | Grain Size Analysis (%) | | | | | | Direct Shear / Terzaghi and Peck (1974) - Shear Strength Parameters | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Natural Moisture Content / Water Absorption % | 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 | | |
| 1.00 | 6 | Brown Silty Sand (SM-SP) - Made-Up Soil | 16 | 15 | NP | NP | NP | NP | 2.62 | 15 | 15 | 30 | 28 | 12 | | 0 | 24.0 |
| 2.00 | 26 | Grayish Brown Silty Sand (SM-SP) | 14 | 20 | NP | NP | NP | NP | 2.63 | 0 | 10 | 42 | 36 | 12 | | 0 | 36.0 |
| 3.00 | 32 | Grayish Brown Sand (SP) | 12 | 21 | NP | NP | NP | NP | 2.63 | 0 | 6 | 38 | 50 | 6 | | 0 | 38.5 |
| 4.00 | 34 | Grayish Brown Sand (SP) | 15 | 22 | NP | NP | NP | NP | 2.63 | 0 | 2 | 52 | 39 | 7 | | 0 | 39.5 |
| 5.00 | 24 | Grayish Brown Sand (SP) | 15 | 20 | NP | NP | NP | NP | 2.63 | 0 | 16 | 58 | 25 | 1 | | 0 | 35.0 |
| 6.00 | >100 | Brown Sand (SP) | 13 | 22 | NP | NP | NP | NP | 2.64 | 0 | 3 | 29 | 67 | 1 | | 0 | 44.0 |
| 7.50 | 30 | Grayish Brown Sand (SP) | 15 | 21 | NP | NP | NP | NP | 2.64 | 0 | 2 | 47 | 50 | 1 | | 0 | 37.5 |
| 9.00 | 36 | Grayish Brown Sand (SP) | 13 | 22 | NP | NP | NP | NP | 2.63 | 0 | 5 | 67 | 26 | 2 | | 0 | 40.0 |
| 10.50 | >100 | Grayish Brown Sand (SP) | 13 | 22 | NP | NP | NP | NP | 2.64 | 0 | 5 | 16 | 72 | 7 | | 0 | 44.0 |
| 12.00 | >100 | Grayish Brown Sand (SP) | 16 | 22 | NP | NP | NP | NP | 2.64 | 0 | 2 | 29 | 67 | 2 | | 0 | 44.0 |
| 13.50 | 34 | Grayish Brown Sand (SP) | 16 | 22 | NP | NP | NP | NP | 2.63 | 0 | 5 | 41 | 51 | 3 | | 0 | 39.5 |
| 15.00 | 31 | Grayish Brown Sand (SP) | 17 | 21 | NP | NP | NP | NP | 2.63 | 0 | 0 | 41 | 56 | 3 | | 0 | 38.0 |
| 16.50 | 82 | Grayish Brown Silty Sand (SM-SP) | 12 | 22 | NP | NP | NP | NP | 2.64 | 0 | 3 | 51 | 35 | 11 | | 0 | 42.0 |
| 18.00 | 98 | Grayish Brown Sand (SP) | 10 | 22 | NP | NP | NP | NP | 2.63 | 0 | 4 | 44 | 43 | 9 | | 0 | 44.0 |
| 19.50 | 24 | Grayish Silty Clay (CH) | 30 | 20 | 60 | 24 | 36 | 80 | 2.62 | 0 | 0 | 11 | 15 | 74 | | 150 | 0.0 |
| 21.00 | 31 | Grayish Silty Clay (CH) | 30 | 21 | 69 | 26 | 43 | 80 | 2.66 | 0 | 0 | 4 | 4 | 92 | | 194 | 0.0 |
| 22.00 | >100 | Grayish Brown Sand (SP) | 16 | 22 | NP | NP | NP | NP | 2.63 | 0 | 7 | 45 | 44 | 4 | | 0 | 44.0 |
| | | | | | Porosity of Rock (%) | | | | | Strength of Rock | | | | | | | |
| | | | | | | | | | | UCS, kN/m$^2$ | | | $I_s$, kN/m$^2$ | | | | |
| 23.50 | >100 | Grayish Brown Weathered Gneiss (Grade V) | 2.55 | 23.1 | 1.48 | | | | | - | | | - | | | | |
| 25.00 | >100 | Grayish Brown Weathered Gneiss (Grade V) | 2.53 | 23.1 | 1.44 | | | | | - | | | 55 | | | | |

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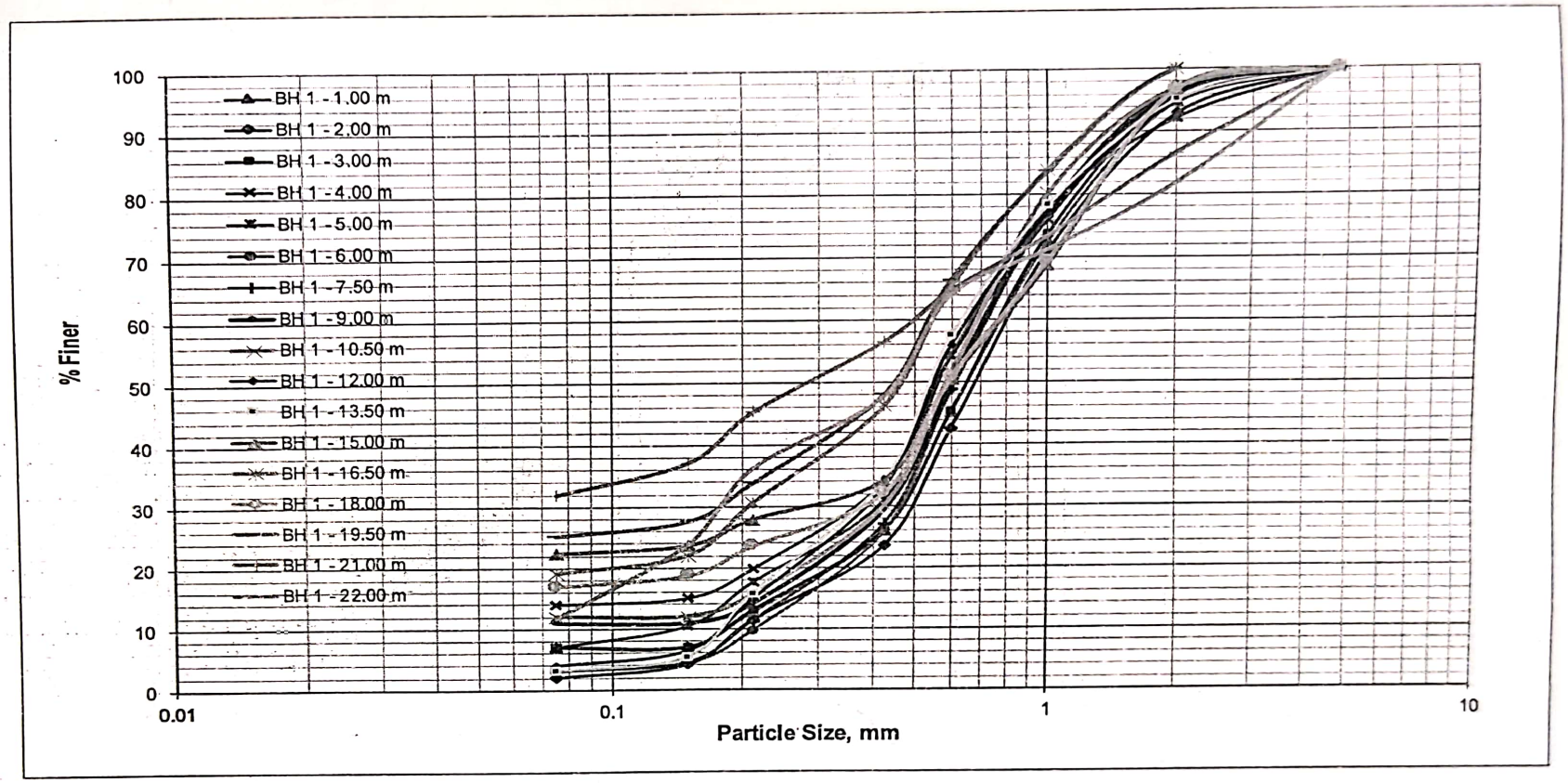



**Figure B-1 Grain Size Distribution Curves of Soil Samples encountered in BH 1 Location**

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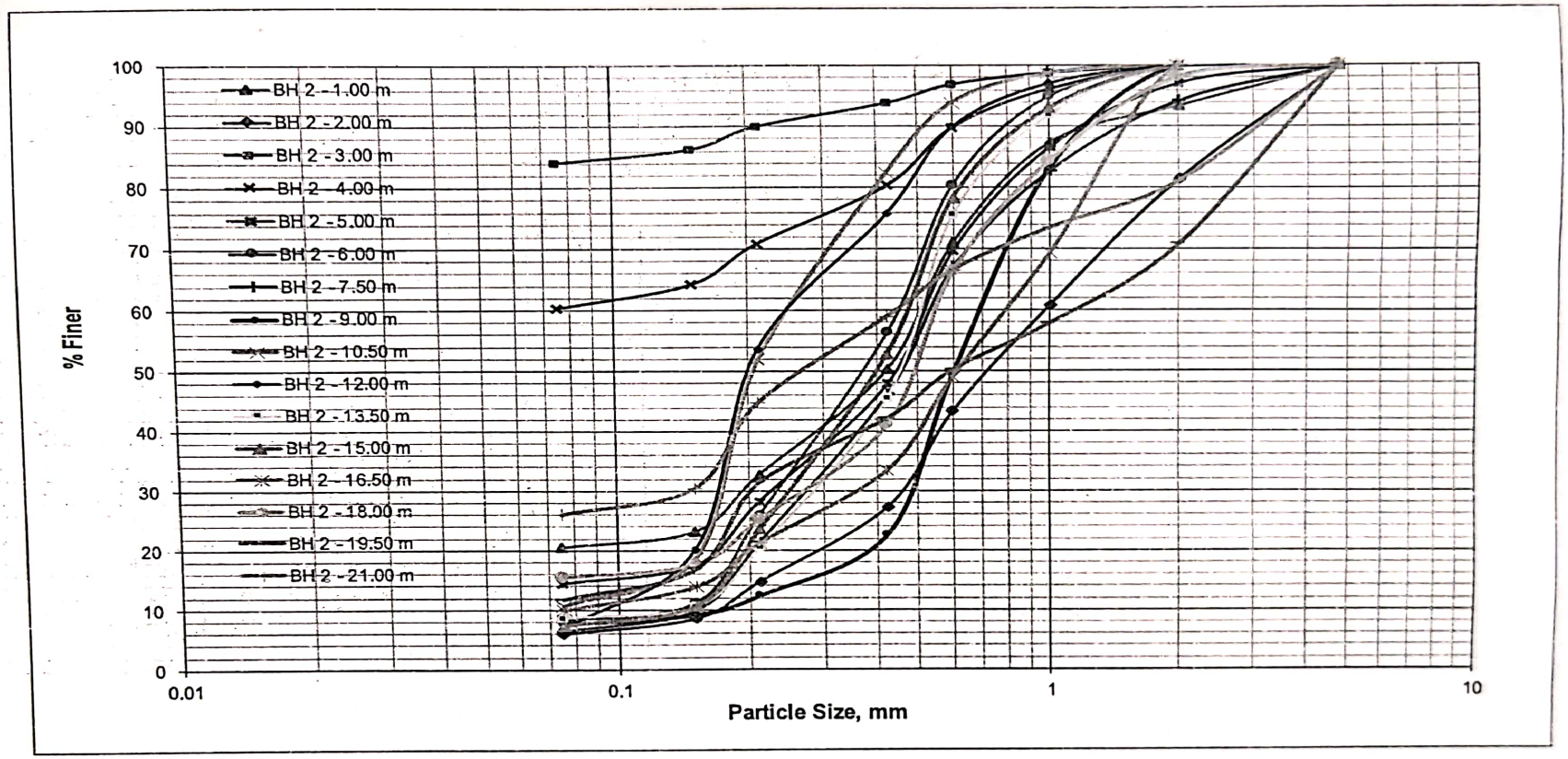



**Figure B-2 Grain Size Distribution Curves of Soil Samples encountered in BH 2 Location**

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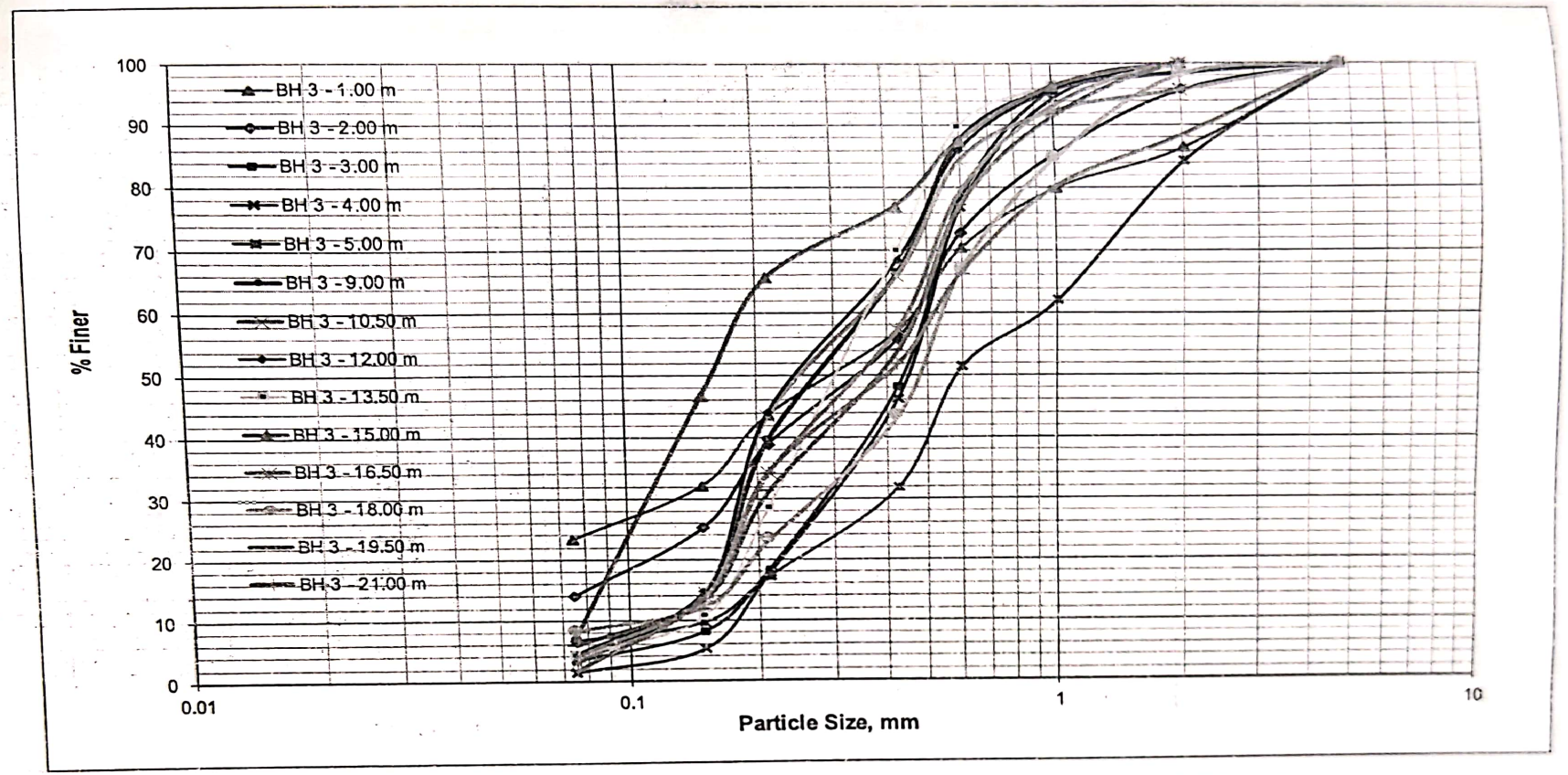



**Figure B-3 Grain Size Distribution Curves of Soil Samples encountered in BH 3 Location**

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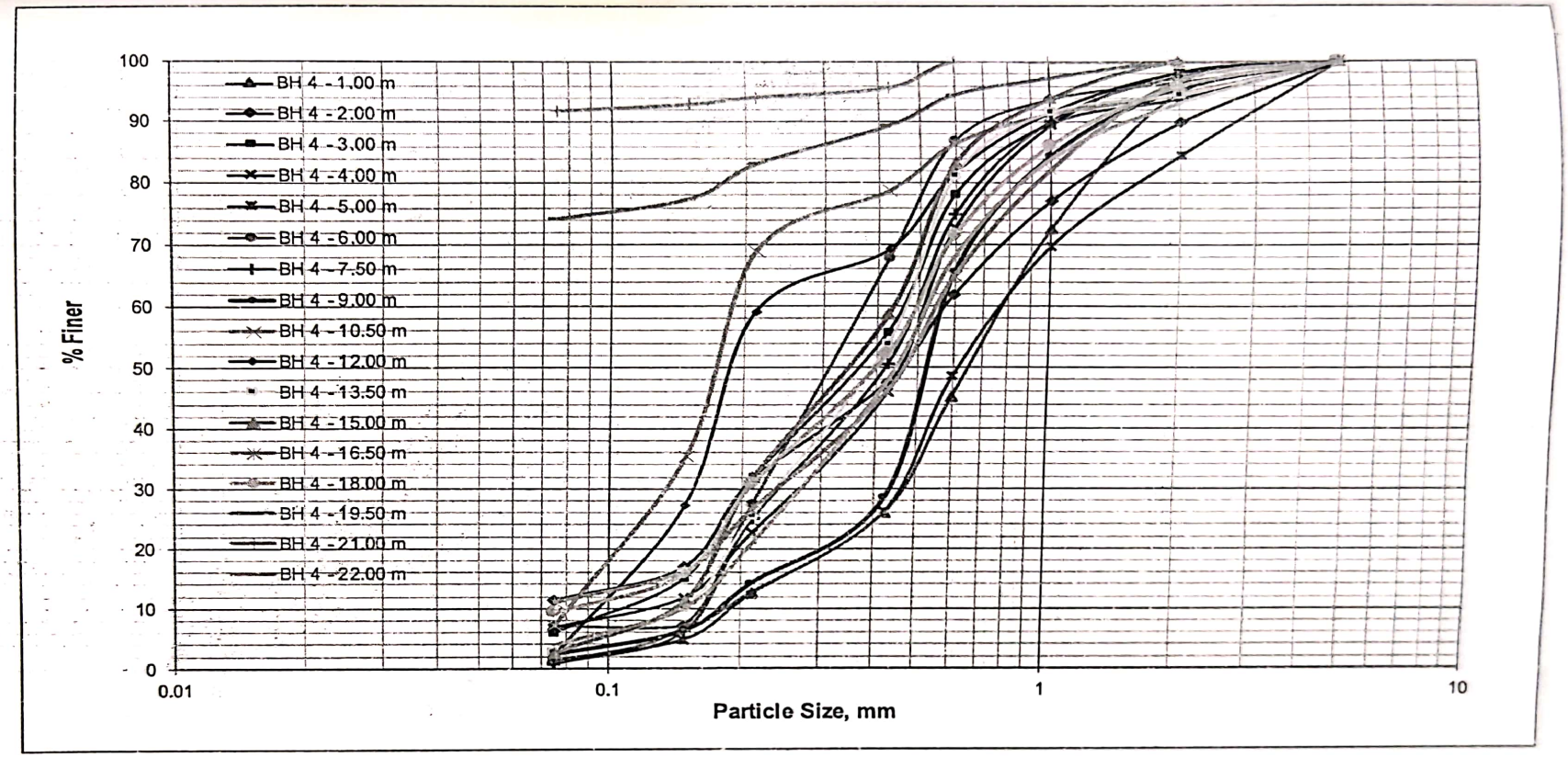



**Figure B-4 Grain Size Distribution Curves of Soil Samples encountered in BH 4 Location**

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# Annexure - 1 - 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/m²
- B - Width of foundation, m
- c - Undraind cohesion value below foundation, kN/m²
- $q_0$ - Effective overburden pressure at foundation level ($\gamma_0$ D), kN/m²
- $\gamma_0$ - Effective unit weight of soil above foundation level
- $\gamma_1$ - Effective unit weight of soil below foundation level
- $N_c$, $N_q$, $N_\gamma$ - Bearing Capacity Factors
- $s_c$, $s_q$, $s_\gamma$ - Shape factors
- $d_c$, $d_q$, $d_\gamma$ - Depth factors
- $i_c$, $i_q$, $i_\gamma$ - 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 Settlement Using the Strain Influence Factor: [Schmertman Method (1978)]

$$Se = C_1\, C_2\, (\bar{q} - q) \sum (I_z / E_s)\, \Delta z$$

where
$I_s$ = strain influence factor
$C_1$ = a correction factor for the depth of foundation embedment
$= 1 - 0.5\, [q / (\bar{q} - q)]$

$C_2$ = a correction factor to account for creep in soil
$= 1 + 0.2 \log$ (time in years /0.1)
$\bar{q}$ = stress at the level of the foundation
$q$ = overburden pressure = $\gamma\ D_f$

The variation of the strain influence factor with depth below the foundation is shown in Figure .
Note that, for square or circular foundations,

$I_z = 0.1$ at $z = 0$
$I_z = 0.5$ at $z = 0.5B$
$I_z = 0$ at $z = 2B$

Similarly, for foundations with L/B ≥ 10

$I_z = 0.2$ at $z = 0$
$I_z = 0.5$ at $z = B$
$I_z = 0$ at $z = 4B$



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# Annexure - 1 (a) - SBC Calculations

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**SBC at 2.5 m Depth in Different Borehole Locations**

**IS 6403 - 1981 Equation**

| | | BH 1 | BH 2 | BH 3 | BH 4 |
|---|---|---|---|---|---|
| **Borehole Location** | = | | | | |
| **Length of foundation (L), m** | = | 6.00 | 6.00 | 6.00 | 6.00 |
| **Width of foundation (B), m** | = | 2.50 | 2.50 | 2.50 | 2.50 |
| **Depth of foundation (D), m** | = | 2.50 | 2.50 | 2.50 | 2.50 |
| Angle of Internal Friction ($\varphi$) in Degrees | = | 35.00 | 26.00 | 41.10 | 37.50 |
| Undraind cohesion value below foundation (c), kN/m$^2$ | = | 0.00 | 58.40 | 0.00 | 0.00 |
| Ground Water Table Depth (GWT), m | = | 0.00 | 0.00 | 0.00 | 0.00 |
| Effective unit weight of soil above foundation level ($\gamma_0$), kN/m$^3$ | = | 9.47 | 6.63 | 8.18 | 8.31 |
| Effective overburden pressure at foundation level ($q_0$), ($\gamma_0$ x D), kN/m$^2$ | = | 23.68 | 16.58 | 20.45 | 20.78 |
| Effective unit weight of soil below foundation level ($\gamma_1$), kN/m$^3$ | = | 9.44 | 9.53 | 11.17 | 10.12 |
| Bearing Capacity Factor ($N_c$) | = | 5.14 | 5.14 | 5.14 | 5.14 |
| Bearing Capacity Factor ($N_q$) | = | 33.30 | 11.85 | 74.96 | 45.81 |
| Bearing Capacity Factor ($N_\gamma$) | = | 48.03 | 12.53 | 132.53 | 71.84 |
| Shape factor ($s_c$) | = | 1.08 | 1.08 | 1.08 | 1.08 |
| Shape factor ($s_q$) | = | 1.08 | 1.08 | 1.08 | 1.08 |
| Shape factor ($s_\gamma$) | = | 0.83 | 0.83 | 0.83 | 0.83 |
| Depth factor ($d_c$) | = | 1.38 | 1.32 | 1.44 | 1.41 |
| Depth factor ($d_q$) | = | 1.19 | 1.16 | 1.22 | 1.20 |
| Depth factor ($d_\gamma$) | = | 1.19 | 1.16 | 1.22 | 1.20 |
| Inclination factor ($i_c$) | = | 1.00 | 1.00 | 1.00 | 1.00 |
| Inclination factor ($i_q$) | = | 1.00 | 1.00 | 1.00 | 1.00 |
| Inclination factor ($i_\gamma$) | = | 1.00 | 1.00 | 1.00 | 1.00 |
| Water table correction factor (W') | = | 0.50 | 0.50 | 0.50 | 0.50 |
| **Net Ulitmate Bearing Capacity ($q_{nu}$), kN/m$^2$** | = | 1051 | 684 | 2870 | 1509 |
| **Factor of Safety** | = | 3.00 | 3.00 | 3.00 | 3.00 |
| **Net Safe Bearing Capacity ($q_{n.safe}$), kN/m$^2$** | = | 350 | 228 | 957 | 503 |



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# Annexure - 1 (b) - Settlement Calculations

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**Settlement Analysis of Foundation for 2.5 m x 6.0 m Foundation at 2.5 m Depth for BH 1 Location**

| | | |
|---|---|---|
| **Length of foundation (L), m** | = | **6.00** |
| **Width of foundation (B), m** | = | **2.50** |
| **Depth of foundation (D), m** | = | **2.50** |
| Effective unit weight of soil above foundation level ($\gamma_0$), kN/m$^3$ | = | 19.47 |
| Effective overburden pressure at foundation level ($q_0$), ($\gamma_0$ x D), kN/m$^2$ | = | 48.68 |
| Stress at the Level of Foundation, (q), kN/m$^2$ | = | 225.00 |
| Depth correction factor ($C_1$) | = | 0.86 |
| Creep correction factor ($C_2$) | = | 1.50 |
| $\sum$(Iz/Es) x $\Delta$z | = | 0.00005321 |
| **Settlement of Foundation (mm)** | = | **12.10** |

| Depth (m) | Soil / Rock Type | 'I$_z$' Value | 'E$_s$' Value (kN/m$^2$) | Depth Below Footing 'z' (m) | $\Delta$z (m) | (I$_z$/E$_s$) x $\Delta$z |
|---|---|---|---|---|---|---|
| 1 | Brown Sand (SP) | | 16000 | | | |
| 2 | Brown Sand (SP) | | 23000 | | | |
| 3 | Brown Sand (SP) | 0.1800 | 21500 | 0.25 | 0.50 | 0.00000419 |
| 4 | Brown Silty Sand (SM-SP) | 0.4200 | 17500 | 1.00 | 1.00 | 0.00002400 |
| 5 | Brown Sand (SP) | 0.4000 | 21500 | 2.00 | 1.00 | 0.00001860 |
| 6 | Brown Sand (SP) | 0.2667 | 70000 | 3.00 | 1.00 | 0.00000381 |
| 7.5 | Brown Sand (SP) | 0.1000 | 57500 | 4.25 | 1.50 | 0.00000261 |
| 9 | Brown Silty Sand (SM-SP) | - | 57500 | 5.75 | 1.50 | - |
| 10.5 | Brown Silty Sand (SM-SP) | - | 57500 | 7.25 | 1.50 | - |
| 12 | Grayish Brown Sand (SP) | - | 57500 | 8.75 | 1.50 | - |
| 13.5 | Brown Sand (SP) | - | 57500 | 10.25 | 1.50 | - |
| 15 | Brown Silty Sand (SM-SP) | - | 57500 | 11.75 | 1.50 | - |
| 16.5 | Grayish Brown Silty Sand (SM-SP) | - | 42500 | 13.25 | 1.50 | - |
| 18 | Grayish Silty Sand (SM-SP) | - | 36000 | 14.75 | 1.50 | - |
| | | | | **Total (2B)=** | **5.00** | **0.00005321** |



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# Annexure - 1 (b) - Settlement Calculations

Division of Soil Mech. & Foundation Engg. CEGC Anna University Chennai-25

**Settlement Analysis of Foundation for 2.5 m x 6.0 m Foundation at 2.5 m Depth for BH 2 Location**

| | | |
|---|---|---|
| Length of foundation (L), m | = | 6.00 |
| Width of foundation (B), m | = | 2.50 |
| Depth of foundation (D), m | = | 2.50 |
| Effective unit weight of soil above foundation level ($\gamma_0$), kN/m$^3$ | = | 16.63 |
| Effective overburden pressure at foundation level ($q_0$), ($\gamma_0$ x D), kN/m$^2$ | = | 41.58 |
| Stress at the Level of Foundation, (q), kN/m$^2$ | = | 225.00 |
| Depth correction factor ($C_1$) | = | 0.89 |
| Creep correction factor ($C_2$) | = | 1.50 |
| $\sum$(Iz/Es) x $\Delta$z | = | 0.00007038 |
| **Settlement of Foundation (mm)** | = | **17.23** |

| Depth (m) | Soil / Rock Type | 'I$_z$' Value | 'E$_s$' Value (kN/m$^2$) | Depth Below Footing 'z' (m) | $\Delta$z (m) | (I$_z$/E$_s$) x $\Delta$z |
|---|---|---|---|---|---|---|
| 1 | Brown Silty Sand (SM-SP) | | 12500 | | | |
| 2 | Brown Sand (SP) | | 16500 | | | |
| 3 | Brown Silty Clay (CH) | 0.1800 | 4160 | 0.25 | 0.50 | 0.00002163 |
| 4 | Brown Silty / Clayey Sand (CH) | 0.4200 | 12160 | 1.00 | 1.00 | 0.00003454 |
| 5 | Brown Silty Sand (SM-SP) | 0.4000 | 57500 | 2.00 | 1.00 | 0.00000696 |
| 6 | Brown Sand (SP) | 0.2667 | 57500 | 3.00 | 1.00 | 0.00000464 |
| 7.5 | Brown Sand (SP) | 0.1000 | 57500 | 4.25 | 1.50 | 0.00000261 |
| 9 | Brown Sand (SP) | - | 57500 | 5.75 | 1.50 | - |
| 10.5 | Grayish Brown Silty Sand (SM-SP) | - | 13500 | 7.25 | 1.50 | - |
| 12 | Grayish Brown Sand (SP) | - | 60500 | 8.75 | 1.50 | - |
| 13.5 | Grayish Brown Sand (SP) | - | 57500 | 10.25 | 1.50 | - |
| 15 | Grayish Brown Sand (SP) | - | 57500 | 11.75 | 1.50 | - |
| 16.5 | Brown Sand (SP) | - | 19500 | 13.25 | 1.50 | - |
| 18 | Grayish Brown Silty Sand (SM-SP) | - | 29500 | 14.75 | 1.50 | - |
| | | | | **Total (2B)=** | **5.00** | **0.00007038** |



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# Annexure - 1 (b) - Settlement Calculations

Division of Soil Mech. & Found. Engg. CEGC Anna University Chennai-25

**Settlement Analysis of Foundation for 2.5 m x 6.0 m Foundation at 2.5 m Depth for BH 3 Location**

| | | |
|---|---|---|
| Length of foundation (L), m | = | 6.00 |
| Width of foundation (B), m | = | 2.50 |
| Depth of foundation (D), m | = | 2.50 |
| Effective unit weight of soil above foundation level ($\gamma_0$), kN/m$^3$ | = | 18.18 |
| Effective overburden pressure at foundation level ($q_0$), ($\gamma_0$ x D), kN/m$^2$ | = | 45.45 |
| Stress at the Level of Foundation, (q), kN/m$^2$ | = | 225.00 |
| Depth correction factor ($C_1$) | = | 0.87 |
| Creep correction factor ($C_2$) | = | 1.50 |
| $\sum$(Iz/Es) x $\Delta$z | = | 0.00002942 |
| **Settlement of Foundation (mm)** | = | **6.89** |

| Depth (m) | Soil / Rock Type | 'I$_z$' Value | 'E$_s$' Value (kN/m$^2$) | Depth Below Footing 'z' (m) | $\Delta$z (m) | (I$_z$/E$_s$) x $\Delta$z |
|---|---|---|---|---|---|---|
| 1 | Brown Silty / Clayey Sand (SC-SM) | | 10000 | | | |
| 2 | Brown Silty Sand (SM-SP) | | 17500 | | | |
| 3 | Brown Sand (SP) | 0.1800 | 20000 | 0.25 | 0.50 | 0.00000450 |
| 4 | Brown Sand (SP) | 0.4200 | 26500 | 1.00 | 1.00 | 0.00001585 |
| 5 | Brown Sand (SP) | 0.4000 | 57500 | 2.00 | 1.00 | 0.00000696 |
| 6 | Brown Sandstone (Grade V) | 0.2667 | 197500 | 3.00 | 1.00 | 0.00000135 |
| 7.5 | Brown Sandstone (Grade V) | 0.1000 | 197500 | 4.25 | 1.50 | 0.00000076 |
| 9 | Brown Sand (SP) | - | 57500 | 5.75 | 1.50 | - |
| 10.5 | Brown Sand (SP) | - | 57500 | 7.25 | 1.50 | - |
| 12 | Brown Sand (SP) | - | 57500 | 8.75 | 1.50 | - |
| 13.5 | Brown Sand (SP) | - | 37500 | 10.25 | 1.50 | - |
| 15 | Grayish Brown Sand (SP) | - | 31500 | 11.75 | 1.50 | - |
| 16.5 | Grayish Brown Sand (SP) | - | 25500 | 13.25 | 1.50 | - |
| 18 | Grayish Brown Sand (SP) | - | 24500 | 14.75 | 1.50 | - |
| | | | | Total (2B)= | 5.00 | 0.00002942 |



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# Annexure - 1 (b) - Settlement Calculations

Division of Soil Mech. & Foundation Engg. CEGC Anna University Chennai-25

**Settlement Analysis of Foundation for 2.5 m x 6.0 m Foundation at 2.5 m Depth for BH 4 Location**

| | | |
|---|---|---|
| Length of foundation (L), m | = | 6.00 |
| Width of foundation (B), m | = | 2.50 |
| Depth of foundation (D), m | = | 2.50 |
| Effective unit weight of soil above foundation level ($\gamma_0$), kN/m$^3$ | = | 18.31 |
| Effective overburden pressure at foundation level ($q_0$), ($\gamma_0$ x D), kN/m$^2$ | = | 45.78 |
| Stress at the Level of Foundation, (q), kN/m$^2$ | = | 225.00 |
| Depth correction factor ($C_1$) | = | 0.87 |
| Creep correction factor ($C_2$) | = | 1.50 |
| $\sum$(Iz/Es) x $\Delta$z | = | 0.00005279 |
| **Settlement of Foundation (mm)** | = | **12.35** |

| Depth (m) | Soil / Rock Type | 'I$_z$' Value | 'E$_s$' Value (kN/m$^2$) | Depth Below Footing 'z' (m) | $\Delta$z (m) | (I$_z$/E$_s$) x $\Delta$z |
|---|---|---|---|---|---|---|
| 1 | Brown Silty Sand (SM-SP) - Made-Up Soil | | 6720 | | | |
| 2 | Grayish Brown Silty Sand (SM-SP) | | 20500 | | | |
| 3 | Grayish Brown Sand (SP) | 0.1800 | 23500 | 0.25 | 0.50 | 0.00000383 |
| 4 | Grayish Brown Sand (SP) | 0.4200 | 24500 | 1.00 | 1.00 | 0.00001714 |
| 5 | Grayish Brown Sand (SP) | 0.4000 | 19500 | 2.00 | 1.00 | 0.00002051 |
| 6 | Brown Sand (SP) | 0.2667 | 57500 | 3.00 | 1.00 | 0.00000464 |
| 7.5 | Grayish Brown Sand (SP) | 0.1000 | 22500 | 4.25 | 1.50 | 0.00000667 |
| 9 | Grayish Brown Sand (SP) | - | 25500 | 5.75 | 1.50 | - |
| 10.5 | Grayish Brown Sand (SP) | - | 57500 | 7.25 | 1.50 | - |
| 12 | Grayish Brown Sand (SP) | - | 57500 | 8.75 | 1.50 | - |
| 13.5 | Grayish Brown Sand (SP) | - | 24500 | 10.25 | 1.50 | - |
| 15 | Grayish Brown Sand (SP) | - | 23000 | 11.75 | 1.50 | - |
| 16.5 | Grayish Brown Silty Sand (SM-SP) | - | 48500 | 13.25 | 1.50 | - |
| 18 | Grayish Brown Sand (SP) | - | 56500 | 14.75 | 1.50 | - |
| | | | | **Total (2B)=** | **5.00** | **0.00005279** |



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Annexure - 2 (DETERMINATION OF PILE CARRYING CAPACITY AS PER IS 2911:2010)

## 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 m²;

$D$ = diameter of pile shaft, in m;

$\gamma$ = effective unit weight of the soil at pile tip, in kN/m³;

$N_\gamma$ and $N_q$ = bearing capacity factors depending upon the angle of internal friction, $\phi$ at pile tip;

$P_D$ = effective overburden pressure at pile tip, in kN/m² (*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 $i$th layer (*see* Note 3);

$P_{Di}$ = effective overburden pressure for the $i$th layer, in kN/m²;

$\delta_i$ = angle of wall friction between pile and soil for the $i$th layer; and

$A_{si}$ = surface area of pile shaft in the $i$th layer, in m².

NOTES

1 $N_\gamma$ 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 $\phi$ varying between 30° and 40°, $K_i$ values in the range of 1 to 1.5 may be used.

4 $\delta$, 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.



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## Annexure - 2 (DETERMINATION OF PILE CARRYING CAPACITY AS PER IS 2911:2010)

### 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 m²;

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

$c_p$ = average cohesion at pile tip, in kN/m²;

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

$\alpha_i$ = adhesion factor for the $i$th layer depending on the consistency of soil, (*see* Note);

$c_i$ = average cohesion for the $i$th layer, in kN/m²; and

$A_{si}$ = surface area of pile shaft in the $i$th layer, in m².

B-3.3 Ultimate skin friction resistance can be approximated to local side friction ($f_s$), in kN/m², obtained from static cone resistance as given in Table 1.

**Table 1 Side Friction for Different Types of Soil**

| Sl No. (1) | Type of Soil (2) | Local Side Friction, $f_s$ kN/m² (3) |
|---|---|---|
| i) | $q_c$ less than 1 000 kN/m² | $q_c/30 < f_s < q_c/10$ |
| 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/m².

### 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 0.6 determination of ultimate load capacity of a pile.

Ultimate end bearing resistance ($q_u$), in kN/m², 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 2$D$ below the pile tip, in kN/m²;

$q_{c1}$ = minimum static cone resistance over the same 2$D$ below the pile tip, in kN/m²;

$q_{c2}$ = average of the envelope of minimum static cone resistance values over the length of pile of 8$D$ above the pile tip, in kN/m²; and

$D$ = diameter of pile shaft.

NOTE — The value of adhesion factor, $\alpha_i$ 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. (1) | Type of Soil (2) | $q_c/N$ (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 |



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# Annexure - 2 (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, $m^2$
- $c$ - Cohesion value of soil at pile base, $kN/m^2$
- $P_D$ - Effective overburden pressure at pile base , $kN/m^2$
- $\gamma$ - Unit weight of soil, $kN/m^3$
- $D$ - Diameter of pile, m
- $A_{si}$ - Surface Area of Pile at respective soil layers, $m^2$
- $\alpha_i$ - 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, $kN/m^2$
- $\Phi$ - Friction angle, degrees
- $N_c$, - Bearing capacity factors based on IS 2911: 2010 and
- $N_q$, $N_\gamma$ IS 6403 -1981

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

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

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:

$\alpha$ = 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 |



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## Annexure - 2 (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 | = | 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 ($\Upsilon_p$), 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 ($N_\gamma$) | = | 271.75 | | | | | |
| Factor of Safety (FS) | = | 2.50 | | | | | |
| Diameter of Pile (D), mm | = | 500 | 600 | 700 | 900 | 1000 | |
| Critical Depth of Pile (20 x D), m | = | 10 | 12 | 14 | 18 | 20 | |
| Effective overburden pressure at Pile Tip ($P_D$), kN/m$^2$ | = | 114.08 | 132.08 | 150.08 | 204.08 | 222.08 | |
| End Bearing Resisrtnce of Pile ($q_p$), kN/m$^2$ using 'c' and 'φ' | = | 40839.08 | 47321.15 | 53803.22 | 73067.36 | 79549.44 | |
| 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$^2$ | = | 11000.00 | 11000.00 | 11000.00 | 11000.00 | 11000.00 | |
| Ultimate End Bearing Capacity of Pile ($Q_p$), kN using 'c' and 'φ' values | = | 2159.84 | 3110.18 | 4233.30 | 6997.90 | 8639.38 | |
| Ultimate End Bearing Capacity of Pile ($Q_p$), kN using 'N' values | = | 2159.84 | 3110.18 | 4233.30 | 6997.90 | 8639.38 | |
| Safe End Bearing Capacity of Pile ($Q_p$), kN using 'c' and 'φ' values | = | 863.94 | 1244.07 | 1693.32 | 2799.16 | 3455.75 | |
| Safe End Bearing Capacity of Pile ($Q_p$), kN using 'N' values | = | 863.94 | 1244.07 | 1693.32 | 2799.16 | 3455.75 | |
| Ultimate Frictional Capacity of Pile ($Q_p$), kN using 'c' and 'φ' values | = | 1782.49 | 2138.99 | 2495.48 | 3208.48 | 3564.98 | |
| Ultimate Frictional Capacity of Pile ($Q_p$), kN using 'N' values | = | 1822.12 | 2186.55 | 2550.97 | 3279.82 | 3644.25 | |
| Negetive Skin Fricton of Pile ($Q_{nf}$), kN using 'c' and 'φ' values | = | 61.60 | 73.91 | 86.23 | 110.87 | 123.19 | |
| Negetive Skin Friction of Pile ($Q_{nf}$), kN using 'N' values | = | 198.97 | 238.76 | 278.55 | 358.14 | 397.94 | |
| Safe Frictional Capacity of Pile ($Q_p$), kN using 'c' and 'φ' values | = | 651.40 | 781.68 | 911.96 | 1172.52 | 1302.80 | |
| Safe Frictional Capacity of Pile ($Q_p$), kN using 'N' values | = | 529.28 | 635.86 | 741.83 | 953.79 | 1059.76 | |
| Self Weight of Pile (W), kN | = | 112.90 | 162.58 | 221.29 | 365.80 | 451.60 | |
| Safe Pile Carrying Capacity of Pile ($Q_{safe}$), kN ('c' and 'φ' ) | = | 1515 | 2026 | 2605 | 3972 | 4759 | |
| Safe Pile Carrying Capacity of Pile ($Q_{safe}$), kN ('N' values ) | = | 1394 | 1880 | 2435 | 3753 | 4516 | |
| **Recommended Safe Pile Carrying Capacity of Pile ($Q_{safe}$), kN** | = | 1455 | 1953 | 2520 | 3862 | 4637 | |
| **Safe Uplift Capacity of Pile ($Q_{up}$), kN using 'c' and 'φ' values** | = | 645 | 802 | 967 | 1324 | 1517 | |



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| Depth (m) | Soil Description | $H_i$ (m) | 'c' kN/m² | 'φ' | 'γ' kN/m³ | $\gamma_{sub}$' kN/m³ | $P_{oi}$(kN/m²) | 'α' | 'K' | N' Value |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Brown Sand (SP) | 1.00 | 0 | 31.5 | 18.11 | 8.11 | 8.11 | 0.00 | 1.00 | 17 |
| 2 | Brown Sand (SP) | 1.00 | 0 | 38.0 | 20.34 | 10.34 | 17.33 | 0.00 | 1.00 | 31 |
| 3 | Brown Sand (SP) | 1.00 | 0 | 37.0 | 19.95 | 9.95 | 27.48 | 0.00 | 1.00 | 28 |
| 4 | Brown Silty Sand (SM-SP) | 1.00 | 0 | 32.0 | 18.69 | 8.69 | 36.79 | 0.00 | 1.00 | 20 |
| 5 | Brown Sand (SP) | 1.00 | 0 | 37.0 | 19.95 | 9.95 | 46.11 | 0.00 | 1.00 | 28 |
| 6 | Brown Sand (SP) | 1.50 | 0 | 44.0 | 22.00 | 12.00 | 60.08 | 0.00 | 1.00 | 125 |
| 7.5 | Brown Sand (SP) | 1.50 | 0 | 44.0 | 22.00 | 12.00 | 78.08 | 0.00 | 1.00 | 100 |
| 9 | Brown Silty Sand (SM-SP) | 1.50 | 0 | 43.0 | 22.00 | 12.00 | 96.08 | 0.00 | 1.00 | 100 |
| 10.5 | Brown Silty Sand (SM-SP) | 1.50 | 0 | 43.0 | 22.00 | 12.00 | 114.08 | 0.00 | 1.00 | 100 |
| 12 | Grayish Brown Sand (SP) | 1.50 | 0 | 44.0 | 22.00 | 12.00 | 132.08 | 0.00 | 1.00 | 100 |
| 13.5 | Brown Sand (SP) | 1.50 | 0 | 44.0 | 22.00 | 12.00 | 150.08 | 0.00 | 1.00 | 100 |
| 15 | Brown Silty Sand (SM-SP) | 1.50 | 0 | 43.0 | 22.00 | 12.00 | 168.08 | 0.00 | 1.00 | 100 |
| 16.5 | Grayish Brown Silty Sand (SM-SP) | 1.50 | 0 | 43.0 | 22.00 | 12.00 | 186.08 | 0.00 | 1.00 | 70 |
| 18 | Grayish Silty Sand (SM-SP) | 1.50 | 0 | 43.0 | 22.00 | 12.00 | 204.08 | 0.00 | 1.00 | 57 |
| 19.5 | Grayish Silty / Clayey Sand (SC) | 1.50 | 0 | 40.0 | 22.00 | 12.00 | 222.08 | 0.00 | 1.00 | 100 |
| 21 | Grayish Brown Silty / Clayey Sand - Weathered Sediments (Grade VI) | 1.00 | 0 | 44.0 | 22.00 | 12.00 | 237.08 | 0.00 | 1.00 | 120 |
| 22 | Grayish Brown Silty Sand - Weathered Sediments (Grade VI) | 1.00 | 0 | 44.0 | 22.00 | 12.00 | 249.08 | 0.00 | 1.00 | 120 |
| 23 | Grayish Brown Weathered Gneiss (Grade V) | 1.00 | 0 | 45.0 | 23.40 | 13.40 | 261.78 | 0.00 | 1.00 | 200 |
| 24.5 | Grayish Brown Weathered Gneiss (Grade V) | 1.50 | 0 | 45.0 | 23.10 | 13.10 | 278.31 | 0.00 | 1.00 | 200 |
| 26 | Grayish Brown Weathered Gneiss (Grade V) | 1.00 | 0 | 45.0 | 23.10 | 13.10 | 294.68 | 0.00 | 1.00 | 200 |

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| Depth (m) | Soil Description | Ultimate Frictional Capacity, kN using 'c' and 'φ' values | | | | | | Ultimate Frictional Capacity, kN using 'α' values | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $q_s$ (kN/m²) | 500 mm | 600 mm | 700 mm | 900 mm | 1000 mm | $q_s$ (kN/m²) | 500 mm | 600 mm | 700 mm | 900 mm | 1000 mm |
| 1 | Brown Sand (SP) | 4.97 | 7.80 | 9.36 | 10.92 | 14.04 | 15.61 | 28.33 | 44.51 | 53.41 | 62.31 | 80.11 | 89.01 |
| 2 | Brown Sand (SP) | 13.54 | 21.27 | 25.52 | 29.78 | 38.29 | 42.54 | 51.67 | 81.16 | 97.39 | 113.62 | 146.08 | 162.32 |
| 3 | Brown Sand (SP) | 20.70 | 32.52 | 39.03 | 45.53 | 58.54 | 65.05 | 46.67 | 73.30 | 87.96 | 102.63 | 131.95 | 146.61 |
| 4 | Brown Silty Sand (SM-SP) | 22.99 | 36.11 | 43.34 | 50.56 | 65.00 | 72.23 | 33.33 | 52.36 | 62.83 | 73.30 | 94.25 | 104.72 |
| 5 | Brown Sand (SP) | 34.75 | 54.58 | 65.49 | 76.41 | 98.24 | 109.16 | 46.67 | 73.30 | 87.96 | 102.63 | 131.95 | 146.61 |
| 6 | Brown Sand (SP) | 58.02 | 136.71 | 164.05 | 191.39 | 246.07 | 273.42 | 208.33 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 |
| 7.5 | Brown Sand (SP) | 75.40 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 | 166.67 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 |
| 9 | Brown Silty Sand (SM-SP) | 89.60 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 | 166.67 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 |
| 10.5 | Brown Silty Sand (SM-SP) | 106.38 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 | 166.67 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 |
| 12 | Grayish Brown Sand (SP) | 127.55 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 | 166.67 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 |
| 13.5 | Brown Sand (SP) | 144.93 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 | 166.67 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 |
| 15 | Brown Silty Sand (SM-SP) | 156.74 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 | 166.67 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 |
| 16.5 | Grayish Brown Silty Sand (SM-SP) | 173.52 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 | 116.67 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 |
| 18 | Grayish Silty Sand (SM-SP) | 190.31 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 | 95.00 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 |
| 19.5 | Grayish Silty / Clayey Sand (SC) | 186.35 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 | 166.67 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 |
| 21 | (Grade VI) | 228.95 | 94.25 | 113.10 | 131.95 | 169.65 | 188.50 | 200.00 | 94.25 | 113.10 | 131.95 | 169.65 | 188.50 |
| 22 | Grayish Brown Silty Sand - Weathered Sediments (Grade VI) | 240.54 | 94.25 | 113.10 | 131.95 | 169.65 | 188.50 | 200.00 | 94.25 | 113.10 | 131.95 | 169.65 | 188.50 |
| 23 | Grayish Brown Weathered Gneiss (Grade V) | 261.78 | 94.25 | 113.10 | 131.95 | 169.65 | 188.50 | 333.33 | 94.25 | 113.10 | 131.95 | 169.65 | 188.50 |
| 24.5 | Grayish Brown Weathered Gneiss (Grade V) | 278.31 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 | 333.33 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 |
| 26 | Grayish Brown Weathered Gneiss (Grade V) | 294.68 | 94.25 | 113.10 | 131.95 | 169.65 | 188.50 | 333.33 | 94.25 | 113.10 | 131.95 | 169.65 | 188.50 |

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Annexure - 2 (Determination of Pile Carrying Capacity as Per IS 2911:2010)

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

**BH 2**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Borehole Location** | | | | | | | |
| Length of Pile (L), m | = | 22.00 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 ($Y_p$), kN/m$^2$ | = | 13.10 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 ($N_\gamma$) | = | 271.75 | | | | | |
| Factor of Safety (FS) | = | 2.50 | | | | | |
| Diameter of Pile (D), mm | = | 500 | 600 | 700 | 900 | 1000 | |
| Critical Depth of Pile (20 x D), m | = | 10 | 12 | 14 | 18 | 20 | |
| Effective overburden pressure at Pile Tip ($P_D$), kN/m$^2$ | = | 103.44 | 117.64 | 135.64 | 185.51 | 203.34 | |
| End Bearing Resisrtnce of Pile ($q_p$), kN/m$^2$ using 'c' and 'φ' | = | 37095.69 | 42240.97 | 48718.97 | 66529.08 | 72947.85 | |
| 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$^2$ | = | 11000.00 | 11000.00 | 11000.00 | 11000.00 | 11000.00 | |
| Ultimate End Bearing Capacity of Pile ($Q_p$), kN using 'c' and 'φ' values | = | 2159.84 | 3110.18 | 4233.30 | 6997.90 | 8639.38 | |
| Ultimate End Bearing Capacity of Pile ($Q_p$), kN using 'N' values | = | 2159.84 | 3110.18 | 4233.30 | 6997.90 | 8639.38 | |
| Safe End Bearing Capacity of Pile ($Q_p$), kN using 'c' and 'φ' values | = | 863.94 | 1244.07 | 1693.32 | 2799.16 | 3455.75 | |
| Safe End Bearing Capacity of Pile ($Q_p$), kN using 'N' values | = | 863.94 | 1244.07 | 1693.32 | 2799.16 | 3455.75 | |
| Ultimate Frictional Capacity of Pile ($Q_p$), kN using 'c' and 'φ' values | = | 1699.53 | 2039.44 | 2379.35 | 3059.16 | 3399.07 | |
| Ultimate Frictional Capacity of Pile ($Q_p$), kN using 'N' values | = | 1615.30 | 1938.36 | 2261.42 | 2907.54 | 3230.60 | |
| Negetive Skin Fricton of Pile ($Q_{nf}$), kN using 'c' and 'φ' values | = | 73.66 | 88.39 | 103.12 | 132.58 | 147.32 | |
| Negetive Skin Friction of Pile ($Q_{nf}$), kN using 'N' values | = | 91.63 | 109.96 | 128.28 | 164.93 | 183.26 | |
| Safe Frictional Capacity of Pile ($Q_p$), kN using 'c' and 'φ' values | = | 606.16 | 727.39 | 848.62 | 1091.08 | 1212.31 | |
| Safe Frictional Capacity of Pile ($Q_p$), kN using 'N' values | = | 554.49 | 665.39 | 776.29 | 998.08 | 1108.98 | |
| Self Weight of Pile (W), kN | = | 107.99 | 155.51 | 211.66 | 349.89 | 431.97 | |
| Safe Pile Carrying Capacity of Pile ($Q_{safe}$), kN ('c' and 'φ' ) | = | 1470 | 1971 | 2542 | 3890 | 4668 | |
| Safe Pile Carrying Capacity of Pile ($Q_{safe}$), kN ('N' values ) | = | 1418 | 1909 | 2470 | 3797 | 4565 | |
| **Recommended Safe Pile Carrying Capacity of Pile ($Q_{safe}$), kN** | = | 1444 | 1940 | 2506 | 3844 | 4615 | |
| **Safe Uplift Capacity of Pile ($Q_{up}$), kN using 'c' and 'φ' values** | = | 601 | 747 | 902 | 1237 | 1418 | |



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| Depth (m) | Soil Description | $H_i$ (m) | 'c' kN/m² | 'φ' | 'γ' kN/m³ | $\gamma_{sub}$ kN/m³ | $P_{i0}$ (kN/m²) | 'α' | Ki | NP Value |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Brown Silty Sand (SM-SP) | 1.00 | 0 | 26.5 | 16.33 | 6.33 | 6.33 | 0.00 | 1.00 | 10 |
| 2 | Brown Sand (SP) | 1.00 | 0 | 32.0 | 18.31 | 8.31 | 13.66 | 0.00 | 1.00 | 18 |
| 3 | Brown Silty Clay (CH) | 1.00 | 44 | 0.0 | 15.24 | 5.24 | 20.43 | 0.60 | 1.00 | 7 |
| 4 | Brown Silty / Clayey Sand (CH) | 1.00 | 124 | 22.0 | 19.20 | 9.20 | 27.65 | 0.30 | 1.00 | 23 |
| 5 | Brown Silty Sand (SM-SP) | 1.00 | 0 | 43.0 | 22.00 | 12.00 | 38.25 | 0.00 | 1.00 | 100 |
| 6 | Brown Sand (SP) | 1.50 | 0 | 44.0 | 22.00 | 12.00 | 53.25 | 0.00 | 1.00 | 100 |
| 7.5 | Brown Sand (SP) | 1.50 | 0 | 44.0 | 22.00 | 12.00 | 71.25 | 0.00 | 1.00 | 100 |
| 9 | Brown Sand (SP) | 1.50 | 0 | 44.0 | 22.00 | 12.00 | 89.25 | 0.00 | 1.00 | 100 |
| 10.5 | Grayish Brown Silty Sand (SM-SP) | 1.50 | 0 | 27.5 | 16.92 | 6.92 | 103.44 | 0.00 | 1.00 | 12 |
| 12 | Grayish Brown Sand (SP) | 1.50 | 0 | 44.0 | 22.00 | 12.00 | 117.64 | 0.00 | 1.00 | 105 |
| 13.5 | Grayish Brown Sand (SP) | 1.50 | 0 | 44.0 | 22.00 | 12.00 | 135.64 | 0.00 | 1.00 | 100 |
| 15 | Grayish Brown Sand (SP) | 1.50 | 0 | 44.0 | 22.00 | 12.00 | 153.64 | 0.00 | 1.00 | 100 |
| 16.5 | Brown Sand (SP) | 1.50 | 0 | 35.0 | 19.36 | 9.36 | 169.66 | 0.00 | 1.00 | 24 |
| 18 | Grayish Brown Silty Sand (SM-SP) | 1.50 | 0 | 40.0 | 21.77 | 11.77 | 185.51 | 0.00 | 1.00 | 44 |
| 19.5 | Grayish Brown Silty Sand (SM-SP) | 1.50 | 0 | 42.0 | 22.00 | 12.00 | 203.34 | 0.00 | 1.00 | 89 |
| 21 | Grayish White Silty Sand- Weathered Sediments (Grade VI) | 1.00 | 0 | 44.0 | 22.00 | 12.00 | 218.34 | 0.00 | 1.00 | 170 |
| 22 | Grayish Brown Weathered Gneiss (Grade V) | 1.00 | 0 | 45.0 | 23.10 | 13.10 | 230.89 | 0.00 | 1.00 | 200 |
| 23 | Grayish Brown Weathered Gneiss (Grade V) | 1.00 | 0 | 45.0 | 23.10 | 13.10 | 243.99 | 0.00 | 1.00 | 200 |
| 24 | Grayish Brown Weathered Gneiss (Grade V) | 1.00 | 0 | 45.0 | 23.20 | 13.20 | 257.14 | 0.00 | 1.00 | 200 |
| 25 | Grayish Brown Weathered Gneiss (Grade V) | 1.00 | 0 | 45.0 | 23.20 | 13.20 | 270.34 | 0.00 | 1.00 | 200 |

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| Depth (m) | Soil Description | Ultimate Frictional Capacity, kN using 'c' and 'φ' values | | | | | | Ultimate Frictional Capacity, kN using 'N' values | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $q_s$ (kN/m$^2$) | 500 mm | 600 mm | 700 mm | 900 mm | 1000 mm | $q_s$ (kN/m$^2$) | 500 mm | 600 mm | 700 mm | 900 mm | 1000 mm |
| 1 | Brown Silty Sand (SM-SP) | 3.16 | 4.96 | 5.95 | 6.95 | 8.93 | 9.92 | 16.67 | 26.18 | 31.42 | 36.65 | 47.12 | 52.36 |
| 2 | Brown Sand (SP) | 8.53 | 13.40 | 16.09 | 18.77 | 24.13 | 26.81 | 30.00 | 47.12 | 56.55 | 65.97 | 84.82 | 94.25 |
| 3 | Brown Silty Clay (CH) | 35.20 | 55.29 | 66.35 | 77.41 | 99.53 | 110.58 | 11.67 | 18.33 | 21.99 | 25.66 | 32.99 | 36.65 |
| 4 | Brown Silty / Clayey Sand (CH) | 48.37 | 75.98 | 91.18 | 106.38 | 136.77 | 151.97 | 38.33 | 60.21 | 72.26 | 84.30 | 108.38 | 120.43 |
| 5 | Brown Silty Sand (SM-SP) | 35.67 | 56.03 | 67.24 | 78.45 | 100.86 | 112.06 | 166.67 | 94.25 | 113.10 | 131.95 | 169.65 | 188.50 |
| 6 | Brown Sand (SP) | 51.43 | 121.17 | 145.40 | 169.64 | 218.10 | 242.34 | 166.67 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 |
| 7.5 | Brown Sand (SP) | 68.81 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 | 166.67 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 |
| 9 | Brown Sand (SP) | 86.19 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 | 166.67 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 |
| 10.5 | Grayish Brown Silty Sand (SM-SP) | 53.85 | 126.88 | 152.26 | 177.63 | 228.39 | 253.76 | 20.00 | 47.12 | 56.55 | 65.97 | 84.82 | 94.25 |
| 12 | Grayish Brown Sand (SP) | 113.60 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 | 176.67 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 |
| 13.5 | Grayish Brown Sand (SP) | 130.98 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 | 166.67 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 |
| 15 | Grayish Brown Sand (SP) | 148.37 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 | 166.67 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 |
| 16.5 | Brown Sand (SP) | 118.79 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 | 40.00 | 94.25 | 113.10 | 131.95 | 169.65 | 188.50 |
| 18 | Grayish Brown Silty Sand (SM-SP) | 155.66 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 | 73.33 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 |
| 19.5 | Grayish Brown Silty Sand (SM-SP) | 183.09 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 | 148.33 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 |
| 21 | Grayish White Silty Sand- Weathered Sediments (Grade VI) | 210.85 | 94.25 | 113.10 | 131.95 | 169.65 | 188.50 | 200.00 | 94.25 | 113.10 | 131.95 | 169.65 | 188.50 |
| 22 | Grayish Brown Weathered Gneiss (Grade V) | 230.89 | 94.25 | 113.10 | 131.95 | 169.65 | 188.50 | 333.33 | 94.25 | 113.10 | 131.95 | 169.65 | 188.50 |
| 23 | Grayish Brown Weathered Gneiss (Grade V) | 243.99 | 94.25 | 113.10 | 131.95 | 169.65 | 188.50 | 333.33 | 94.25 | 113.10 | 131.95 | 169.65 | 188.50 |
| 24 | Grayish Brown Weathered Gneiss (Grade V) | 257.14 | 94.25 | 113.10 | 131.95 | 169.65 | 188.50 | 333.33 | 94.25 | 113.10 | 131.95 | 169.65 | 188.50 |
| 25 | Grayish Brown Weathered Gneiss (Grade V) | 270.34 | 94.25 | 113.10 | 131.95 | 169.65 | 188.50 | 333.33 | 94.25 | 113.10 | 131.95 | 169.65 | 188.50 |

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## Annexure - 2 (Determination of Pile Carrying Capacity as Per IS 2911:2010)

### 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 ($\gamma_p$), kN/m$^2$ | = | 12.00 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 ($N_\gamma$) | = | 271.75 | | | | | |
| Factor of Safety (FS) | = | 2.50 | | | | | |
| Diameter of Pile (D), mm | = | 500 | 600 | 700 | 900 | 1000 | |
| Critical Depth of Pile (20 x D), m | = | 10 | 12 | 14 | 18 | 20 | |
| Effective overburden pressure at Pile Tip ($P_D$), kN/m$^2$ | = | 118.96 | 136.96 | 154.96 | 206.41 | 223.45 | |
| End Bearing Resisrtnce of Pile ($q_{p1}$), kN/m$^2$ using 'c' and 'φ' | = | 42452.93 | 48915.98 | 55379.03 | 73712.12 | 79837.08 | |
| End Bearing Resisrtnce of Pile ($q_{p2}$), 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$^2$ | = | 11000.00 | 11000.00 | 11000.00 | 11000.00 | 11000.00 | |
| Ultimate End Bearing Capacity of Pile ($Q_{p1}$), kN using 'c' and 'φ' values | = | 2159.84 | 3110.18 | 4233.30 | 6997.90 | 8639.38 | |
| Ultimate End Bearing Capacity of Pile ($Q_{p2}$), kN using 'N' values | = | 2159.84 | 3110.18 | 4233.30 | 6997.90 | 8639.38 | |
| Safe End Bearing Capacity of Pile ($Q_{p1}$), kN using 'c' and 'φ' values | = | 863.94 | 1244.07 | 1693.32 | 2799.16 | 3455.75 | |
| Safe End Bearing Capacity of Pile ($Q_{p2}$), kN using 'N' values | = | 863.94 | 1244.07 | 1693.32 | 2799.16 | 3455.75 | |
| Ultimate Frictional Capacity of Pile ($Q_{s1}$), kN using 'c' and 'φ' values | = | 1809.96 | 2171.95 | 2533.95 | 3257.93 | 3619.92 | |
| Ultimate Frictional Capacity of Pile ($Q_{s2}$), kN using 'N' values | = | 1877.10 | 2252.52 | 2627.94 | 3378.78 | 3754.20 | |
| Negetive Skin Fricton of Pile ($Q_{n1}$), kN using 'c' and 'φ' values | = | 44.68 | 53.62 | 62.56 | 80.43 | 89.37 | |
| Negetive Skin Friction of Pile ($Q_{n2}$), kN using 'N' values | = | 143.99 | 172.79 | 206.59 | 259.18 | 287.98 | |
| Safe Frictional Capacity of Pile ($Q_{s1}$), kN using 'c' and 'φ' values | = | 679.30 | 815.16 | 951.02 | 1222.74 | 1358.60 | |
| Safe Frictional Capacity of Pile ($Q_{s2}$), kN using 'N' values | = | 606.85 | 728.22 | 849.59 | 1092.33 | 1213.70 | |
| Self Weight of Pile (W), kN | = | 112.90 | 162.58 | 221.29 | 365.80 | 451.60 | |
| Safe Pile Carrying Capacity of Pile ($Q_{safe1}$), kN ('c' and 'φ' ) | = | 1543 | 2059 | 2644 | 4022 | 4814 | |
| Safe Pile Carrying Capacity of Pile ($Q_{safe2}$), kN ('N' values ) | = | 1471 | 1972 | 2543 | 3891 | 4669 | |
| **Recommended Safe Pile Carrying Capacity of Pile ($Q_{safe}$), kN** | = | **1307** | **2016** | **2594** | **3957** | **4742** | |
| **Safe Uplift Capacity of Pile ($Q_{up}$), kN using 'c' and 'φ' values** | = | **672** | **833** | **1003** | **1371** | **1569** | |



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| Depth (m) | Soil Description | H (m) | 'c' kN/m² | 'ϕ' | 'γ' kN/m³ | 'γsub' kN/m³ | $P_o$ (kN/m²) | 'N' | 'C' | 'N' Value |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Brown Silty / Clayey Sand (SC-SM) | 1.00 | 0 | 28.0 | 18.33 | 8.33 | 8.33 | 1.00 | 1.00 | 12 |
| 2 | Brown Silty Sand (SM-SP) | 1.00 | 0 | 33.0 | 18.69 | 8.69 | 13.85 | 1.00 | 1.00 | 17 |
| 3 | Brown Sand (SP) | 1.00 | 0 | 35.5 | 19.51 | 9.51 | 22.98 | 1.00 | 1.00 | 17 |
| 4 | Brown Sand (SP) | 1.00 | 0 | 41.0 | 21.16 | 11.16 | 33.28 | 1.00 | 1.00 | 23 |
| 5 | Brown Sandstone (Grade V) | 1.00 | 0 | 44.0 | 22.00 | 12.00 | 44.99 | 1.00 | 1.00 | 28 |
| 6 | Brown Sandstone (Grade V) | 1.50 | 0 | 45.0 | 23.50 | 13.50 | 58.99 | 1.00 | 1.00 | 30 |
| 7.5 | Brown Sand (SP) | 1.50 | 0 | 45.0 | 23.90 | 13.90 | 72.89 | 1.00 | 1.00 | 30 |
| 9 | Brown Sand (SP) | 1.50 | 0 | 44.0 | 22.00 | 12.00 | 86.89 | 1.00 | 1.00 | 30 |
| 10.5 | Brown Sand (SP) | 1.50 | 0 | 44.0 | 22.00 | 12.00 | 100.89 | 1.00 | 1.00 | 30 |
| 12 | Brown Sand (SP) | 1.50 | 0 | 44.0 | 22.00 | 12.00 | 114.89 | 1.00 | 1.00 | 30 |
| 13.5 | Brown Sand (SP) | 1.50 | 0 | 44.0 | 22.00 | 12.00 | 128.89 | 1.00 | 1.00 | 30 |
| 15 | Grayish Brown Sand (SP) | 1.50 | 0 | 43.0 | 22.00 | 12.00 | 142.89 | 1.00 | 1.00 | 30 |
| 16.5 | Grayish Brown Sand (SP) | 1.50 | 0 | 42.0 | 22.00 | 12.00 | 156.89 | 1.00 | 1.00 | 30 |
| 18 | Grayish Brown Sand (SP) | 1.50 | 0 | 40.0 | 20.94 | 10.94 | 170.83 | 1.00 | 1.00 | 26 |
| 19.5 | Grayish Brown Sand (SP) | 1.50 | 0 | 39.5 | 20.71 | 10.71 | 184.41 | 1.00 | 1.00 | 26 |
| 21 | Grayish Brown Silty Sand - Weathered Sediments (Grade V) | 1.50 | 0 | 43.0 | 22.00 | 12.00 | 198.41 | 1.00 | 1.00 | 30 |
| 22.5 | Grayish Brown Weathered Gneiss (Grade V) | 1.50 | 0 | 44.0 | 22.00 | 12.00 | 212.41 | 1.00 | 1.00 | 30 |
| 24 | Grayish Brown Weathered Gneiss (Grade V) | 1.50 | 0 | 45.0 | 22.00 | 12.00 | 226.41 | 1.00 | 1.00 | 30 |
| 25 | Grayish Brown Weathered Gneiss (Grade V) | 1.00 | 0 | 45.0 | 23.10 | 13.10 | 239.51 | 1.00 | 1.00 | 30 |
| | | | | | 23.90 | 13.90 | 253.41 | 1.00 | 1.00 | 30 |

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| Depth (m) | Soil Description | Ultimate Frictional Capacity, kN using 'c' and 'φ' values | | | | | | Ultimate Frictional Capacity, kN using 'N' values | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $q_u$ (kN/m²) | 500 mm | 600 mm | 700 mm | 900 mm | 1000 mm | $q_u$ (kN/m²) | 500 mm | 600 mm | 700 mm | 900 mm | 1000 mm |
| 1 | Brown Silty / Clayey Sand (SC-SM) | 3.09 | 4.85 | 5.82 | 6.79 | 8.74 | 9.71 | 16.67 | 26.18 | 31.42 | 36.65 | 47.12 | 52.36 |
| 2 | Brown Silty Sand (SM-SP) | 8.99 | 14.12 | 16.95 | 19.77 | 25.42 | 28.25 | 33.33 | 52.36 | 62.83 | 73.30 | 94.25 | 104.72 |
| 3 | Brown Sand (SP) | 16.37 | 25.71 | 30.85 | 35.99 | 46.27 | 51.42 | 41.67 | 65.45 | 78.54 | 91.63 | 117.81 | 130.90 |
| 4 | Brown Sand (SP) | 28.93 | 45.45 | 54.54 | 63.63 | 81.80 | 90.89 | 63.33 | 94.25 | 113.10 | 131.95 | 169.65 | 188.50 |
| 5 | Brown Sand (SP) | 43.33 | 68.06 | 81.67 | 95.28 | 122.50 | 136.11 | 166.67 | 94.25 | 113.10 | 131.95 | 169.65 | 188.50 |
| 6 | Brown Sandstone (Grade V) | 60.99 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 | 250.00 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 |
| 7.5 | Brown Sandstone (Grade V) | 81.54 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 | 250.00 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 |
| 9 | Brown Sand (SP) | 97.50 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 | 166.67 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 |
| 10.5 | Brown Sand (SP) | 114.88 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 | 166.67 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 |
| 12 | Brown Sand (SP) | 132.27 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 | 166.67 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 |
| 13.5 | Brown Sand (SP) | 144.51 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 | 100.00 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 |
| 15 | Grayish Brown Sand (SP) | 155.74 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 | 80.00 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 |
| 16.5 | Grayish Brown Sand (SP) | 159.57 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 | 60.00 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 |
| 18 | Grayish Brown Sand (SP) | 170.15 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 | 56.67 | 133.52 | 160.22 | 186.92 | 240.33 | 267.04 |
| 19.5 | Grayish Brown Sand (SP) | 208.37 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 | 146.67 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 |
| 21 | Grayish Brown Silty Sand - Weathered Sediments (Grade VI) | 233.16 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 | 200.00 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 |
| 22.5 | Grayish Brown Weathered Gneiss (Grade V) | 259.45 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 | 333.33 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 |
| 24 | Grayish Brown Weathered Gneiss (Grade V) | 275.00 | 94.25 | 113.10 | 131.95 | 169.65 | 188.50 | 333.33 | 94.25 | 113.10 | 131.95 | 169.65 | 188.50 |
| 25 | Grayish Brown Weathered Gneiss (Grade V) | 288.50 | 94.25 | 113.10 | 131.95 | 169.65 | 188.50 | 333.33 | 94.25 | 113.10 | 131.95 | 169.65 | 188.50 |

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## Annexure - 2 (Determination of Pile Carrying Capacity as Per IS 2911:2010)

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

**Borehole Location** BH 4

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Length of Pile (L), m | = | 24.00 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 ($\gamma_p$), kN/m$^2$ | = | 13.10 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 ($N_\gamma$) | = | 271.75 | | | | | |
| Factor of Safety (FS) | = | 2.50 | | | | | |
| Diameter of Pile (D), mm | = | 500 | 600 | 700 | 900 | 1000 | |
| Critical Depth of Pile (20 x D), m | = | 10 | 12 | 14 | 18 | 20 | |
| Effective overburden pressure at Pile Tip ($P_D$), kN/m$^2$ | = | 106.13 | 124.13 | 141.16 | 191.71 | 207.73 | |
| End Bearing Resisrtnce of Pile ($q_p$), kN/m$^2$ using 'c' and 'φ' | = | 38035.57 | 44513.56 | 50653.47 | 68702.08 | 74486.74 | |
| 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$^2$ | = | 11000.00 | 11000.00 | 11000.00 | 11000.00 | 11000.00 | |
| Ultimate End Bearing Capacity of Pile ($Q_p$), kN using 'c' and 'φ' values | = | 2159.84 | 3110.18 | 4233.30 | 6997.90 | 8639.38 | |
| Ultimate End Bearing Capacity of Pile ($Q_p$), kN using 'N' values | = | 2159.84 | 3110.18 | 4233.30 | 6997.90 | 8639.38 | |
| Safe End Bearing Capacity of Pile ($Q_p$), kN using 'c' and 'φ' values | = | 863.94 | 1244.07 | 1693.32 | 2799.16 | 3455.75 | |
| Safe End Bearing Capacity of Pile ($Q_p$), kN using 'N' values | = | 863.94 | 1244.07 | 1693.32 | 2799.16 | 3455.75 | |
| Ultimate Frictional Capacity of Pile ($Q_s$), kN using 'c' and 'φ' values | = | 1854.82 | 2225.79 | 2596.75 | 3338.68 | 3709.65 | |
| Ultimate Frictional Capacity of Pile ($Q_s$), kN using 'N' values | = | 1831.29 | 2197.54 | 2563.80 | 3296.32 | 3662.57 | |
| Negetive Skin Fricton of Pile ($Q_{ns}$), kN using 'c' and 'φ' values | = | 44.67 | 53.60 | 62.54 | 80.40 | 89.34 | |
| Negetive Skin Friction of Pile ($Q_{ns}$), kN using 'N' values | = | 167.55 | 201.06 | 234.57 | 301.59 | 335.10 | |
| Safe Frictional Capacity of Pile ($Q_s$), kN using 'c' and 'φ' values | = | 697.26 | 836.71 | 976.16 | 1255.07 | 1394.52 | |
| Safe Frictional Capacity of Pile ($Q_s$), kN using 'N' values | = | 564.96 | 677.96 | 790.95 | 1016.93 | 1129.93 | |
| Self Weight of Pile (W), kN | = | 117.81 | 169.65 | 230.91 | 381.70 | 471.24 | |
| Safe Pile Carrying Capacity of Pile ($Q_{safe}$), kN ('c' and 'φ' ) | = | 1561 | 2081 | 2669 | 4054 | 4850 | |
| Safe Pile Carrying Capacity of Pile ($Q_{safe}$), kN ('N' values ) | = | 1429 | 1922 | 2484 | 3816 | 4586 | |
| **Recommended Safe Pile Carrying Capacity of Pile ($Q_{safe}$), kN** | = | **1495** | **2001** | **2577** | **3935** | **4718** | |
| **Safe Uplift Capacity of Pile ($Q_{up}$), kN using 'c' and 'φ' values** | = | **691** | **858** | **1034** | **1414** | **1618** | |



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Annexure - 2 (Determination of Pile Carrying Capacity)

| Depth (m) | Soil Description | $H_i$ (m) | 'c' kN/m² | 'φ' | 'γ' kN/m³ | 'γ$_{sub}$' kN/m³ | $P_{Oi}$ (kN/m²) | '$\alpha_i$' | '$K_i$' | N' Value |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Brown Silty Sand (SM-SP) - Made-Up Soil | 1.00 | 0 | 24.0 | 14.79 | 4.79 | 4.79 | 0.00 | 1.00 | 6 |
| 2 | Grayish Brown Silty Sand (SM-SP) | 1.00 | 0 | 36.0 | 19.66 | 9.66 | 12.02 | 0.00 | 1.00 | 26 |
| 3 | Grayish Brown Sand (SP) | 1.00 | 0 | 38.5 | 20.47 | 10.47 | 22.09 | 0.00 | 1.00 | 32 |
| 4 | Grayish Brown Sand (SP) | 1.00 | 0 | 39.5 | 20.71 | 10.71 | 32.68 | 0.00 | 1.00 | 34 |
| 5 | Grayish Brown Sand (SP) | 1.00 | 0 | 35.0 | 19.36 | 9.36 | 42.71 | 0.00 | 1.00 | 24 |
| 6 | Brown Sand (SP) | 1.50 | 0 | 44.0 | 22.00 | 12.00 | 56.39 | 0.00 | 1.00 | 100 |
| 7.5 | Grayish Brown Sand (SP) | 1.50 | 0 | 37.5 | 20.22 | 10.22 | 73.05 | 0.00 | 1.00 | 30 |
| 9 | Grayish Brown Sand (SP) | 1.50 | 0 | 40.0 | 20.94 | 10.94 | 88.92 | 0.00 | 1.00 | 36 |
| 10.5 | Grayish Brown Sand (SP) | 1.50 | 0 | 44.0 | 22.00 | 12.00 | 106.13 | 0.00 | 1.00 | 100 |
| 12 | Grayish Brown Sand (SP) | 1.50 | 0 | 44.0 | 22.00 | 12.00 | 124.13 | 0.00 | 1.00 | 100 |
| 13.5 | Grayish Brown Sand (SP) | 1.50 | 0 | 39.5 | 20.71 | 10.71 | 141.16 | 0.00 | 1.00 | 34 |
| 15 | Grayish Brown Sand (SP) | 1.50 | 0 | 38.0 | 20.34 | 10.34 | 156.96 | 0.00 | 1.00 | 31 |
| 16.5 | Grayish Brown Silty Sand (SM-SP) | 1.50 | 0 | 42.0 | 22.00 | 12.00 | 173.71 | 0.00 | 1.00 | 82 |
| 18 | Grayish Brown Sand (SP) | 1.50 | 0 | 44.0 | 22.00 | 12.00 | 191.71 | 0.00 | 1.00 | 98 |
| 19.5 | Grayish Silty Clay (CH) | 1.50 | 150 | 0 | 19.36 | 9.36 | 207.73 | 0.45 | 1.00 | 24 |
| 21 | Grayish Silty Clay (CH) | 1.00 | 194 | 0 | 20.34 | 10.34 | 219.92 | 0.30 | 1.00 | 31 |
| 22 | Grayish Brown Sand (SP) | 1.50 | 0 | 44.0 | 22.00 | 12.00 | 234.10 | 0.00 | 1.00 | 100 |
| 23.5 | Grayish Brown Weathered Gneiss (Grade V) | 1.50 | 0 | 45.0 | 23.10 | 13.10 | 252.92 | 0.00 | 1.00 | 200 |
| 25 | Grayish Brown Weathered Gneiss (Grade V) | 1.00 | 0 | 45.0 | 23.10 | 13.10 | 269.30 | 0.00 | 1.00 | 200 |

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| Depth (m) | Soil Description | Ultimate Frictional Capacity, kN using 'c' and 'φ' values | | | | | | Ultimate Frictional Capacity, kN using 'N' values | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $q_s$ (kN/m²) | 500 mm | 600 mm | 700 mm | 900 mm | 1000 mm | $q_s$ (kN/m²) | 500 mm | 600 mm | 700 mm | 900 mm | 1000 mm |
| 1 | Brown Silty Sand (SM-SP) - Made-Up Soil | 2.13 | 3.35 | 4.02 | 4.69 | 6.03 | 6.71 | 10.00 | 15.71 | 18.85 | 21.99 | 28.27 | 31.42 |
| 2 | Grayish Brown Silty Sand (SM-SP) | 8.73 | 13.72 | 16.46 | 19.21 | 24.70 | 27.44 | 43.33 | 68.07 | 81.68 | 95.29 | 122.52 | 136.14 |
| 3 | Grayish Brown Sand (SP) | 17.57 | 27.60 | 33.12 | 38.64 | 49.68 | 55.19 | 53.33 | 83.78 | 100.53 | 117.29 | 150.80 | 167.55 |
| 4 | Grayish Brown Sand (SP) | 26.94 | 42.31 | 50.78 | 59.24 | 76.16 | 84.63 | 56.67 | 89.01 | 106.81 | 124.62 | 160.22 | 178.02 |
| 5 | Grayish Brown Sand (SP) | 29.91 | 46.98 | 56.38 | 65.77 | 84.56 | 93.96 | 40.00 | 62.83 | 75.40 | 87.96 | 113.10 | 125.66 |
| 6 | Brown Sand (SP) | 54.46 | 128.31 | 153.98 | 179.64 | 230.96 | 256.63 | 166.67 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 |
| 7.5 | Grayish Brown Sand (SP) | 56.06 | 132.08 | 158.50 | 184.91 | 237.74 | 264.16 | 50.00 | 117.81 | 141.37 | 164.93 | 212.06 | 235.62 |
| 9 | Grayish Brown Sand (SP) | 74.62 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 | 60.00 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 |
| 10.5 | Grayish Brown Sand (SP) | 102.49 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 | 166.67 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 |
| 12 | Grayish Brown Sand (SP) | 119.87 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 | 166.67 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 |
| 13.5 | Grayish Brown Sand (SP) | 116.37 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 | 56.67 | 133.52 | 160.22 | 186.92 | 240.33 | 267.04 |
| 15 | Grayish Brown Sand (SP) | 122.63 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 | 51.67 | 121.74 | 146.08 | 170.43 | 219.13 | 243.47 |
| 16.5 | Grayish Brown Silty Sand (SM-SP) | 156.41 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 | 136.67 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 |
| 18 | Grayish Brown Sand (SP) | 185.14 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 | 163.33 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 |
| 19.5 | Grayish Silty Clay (CH) | 67.50 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 | 40.00 | 94.25 | 113.10 | 131.95 | 169.65 | 188.50 |
| 21 | Grayish Silty Clay (CH) | 58.20 | 91.42 | 109.70 | 127.99 | 164.56 | 182.84 | 51.67 | 81.16 | 97.39 | 113.62 | 146.08 | 162.32 |
| 22 | Grayish Brown Sand (SP) | 226.06 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 | 166.67 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 |
| 23.5 | Grayish Brown Weathered Gneiss (Grade V) | 252.92 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 | 333.33 | 141.37 | 169.65 | 197.92 | 254.47 | 282.74 |
| 25 | Grayish Brown Weathered Gneiss (Grade V) | 269.30 | 94.25 | 113.10 | 131.95 | 169.65 | 188.50 | 333.33 | 94.25 | 113.10 | 131.95 | 169.65 | 188.50 |

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## Annexure - 2 (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 application 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 ($n_h$) | = | 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$^2$ | | | | |
| Diameter of Pile (D), mm | = | 500 | 600 | 700 | 900 | 1000 |
| Moment of Inertia of Pile Section (I), m$^4$ | = | 0.00307 | 0.00636 | 0.01179 | 0.03221 | 0.04909 |
| Stiffness Factor, (T) | = | 1.92 | 2.22 | 2.52 | 3.08 | 3.35 |
| 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/f) | = | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| (Z/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), m | = | 3.65 | 4.23 | 4.78 | 5.85 | 6.36 |
| 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 | = | 103.70 | 138.10 | 177.30 | 264.30 | 313.50 |



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Annexure – 3 Site Photographs



Plate 1 SPT test is in progress at the Reconstruction of Slum Tenements Site at Nattan Thottam, TNSCB, Chennai

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Plate 2 View of Soil / Rock Samples collected in 4 borehole locations of the proposed site

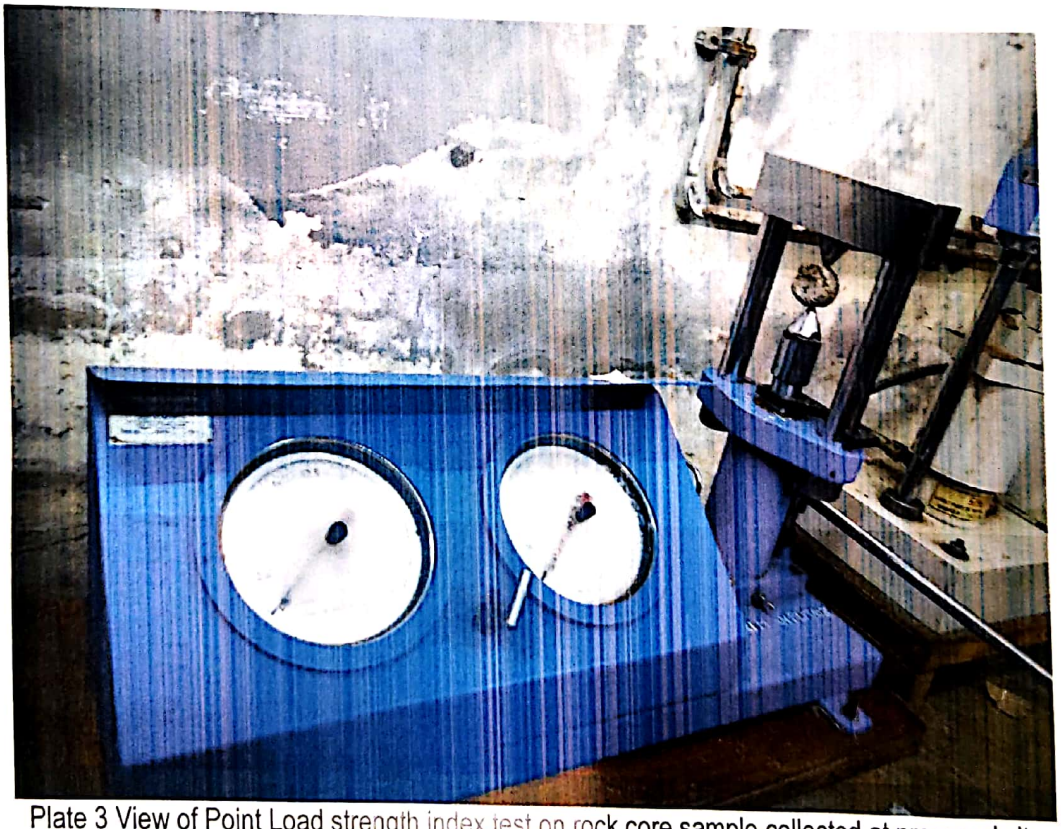


Plate 3 View of Point Load strength index test on rock core sample collected at proposed site

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