# SOIL INVESTIGATION FOR HIGHWAY PROJECT

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**Abstract:** *This study is aimed at bringing out the salient aspects of soil investigation and its study and control aspects of Chennai ORR Phase II, (NH 205), Project undertaken by Tamilnadu Road Development Company Ltd., TNRDC. The project comprises construction of six lane highway that involves several vehicle and people underpasses, major bridges, grade separators, etc. One of the major components is a 10x25 Major Bridge at CH 28+900. The bridge will have a 12m carriage way and a 7m service road in both the directions. Geotechnical investigation for the vehicular as well as people underpasses and PUPs and VUPs are investigated and this report is prepared to provide complete investigation data and the recommendations for suitable foundation system for the under passes. People under passes at CH 20+050 and Vehicle under passes at CH 21+100. The investigation for each vehicular underpass comprises two exploratory boreholes up to 15.0m depth at the structure location and four exploratory boreholes of 6.0m deep for the approach embankments. The investigation for people underpass comprises four exploratory Shallow boreholes and four exploratory boreholes respectively. Soil data available from the investigation for abutment locations can be used for having better understanding about the soil variations.*

*The report describes the procedure of investigation adopted and then presents the complete investigation data. The general sub-soil conditions at these locations and the procedure of analysing the data for arriving at the shear strength and compressibility parameters are described. Important conclusions of this Project work have been drawn subsequently.*

**Key Words / Phrases: Soil Investigation, Shear Strength, Compressibility, Boreholes, People Under passes (PUS), Vehicle Under Passes (VUP), Bearing Capacity.**

## 1. INTRODUCTION

The investigation programme comprised sinking four to six exploratory boreholes at different underpass locations. The locations of boreholes at each underpass are given in the key plan Two number of 15m deep boreholes are executed at every VUP locations, while four number of 6m deep boreholes are sunk along the approach embankment [1,2]. Four number of 6m deep boreholes are sunk at the PUP locations. The details of borehole locations at each PUP and VUP are provided under respective part.

The field-tests in the boreholes included Standard Penetration Tests [1,3], Disturbed Sampling, Identification of different soil layers, Ground water table observation, complete logging of the boreholes, etc. Undisturbed samples were not collected as the clay / sandy clay layers are stiff to very stiff to hard.

Laboratory investigation mainly consisted of classification tests like determination of limit values for samples from clay and sandy clay and grain size distribution analysis for sand samples [6]. Natural moisture contents of different soil layers were determined from properly preserved disturbed soil samples collected using the SPT sampler [11].

### 1.1 Investigation Procedure

Exploratory boreholes were advanced from the existing ground levels using rotary drilling technique supplemented by bentonite mud circulation. The mud circulation was employed through the drill rods and letting it out through the side jets provided in the cutting tool thus preventing any disturbance at the borehole bottom. Mud circulation was used to stabilize the sides and the bottom of the boreholes, and then to bring the soil cuts to the surface. It is important to note that the mud jet is not used to cut the soils as in the case of wash boring technique. Use of drilling mud will also help in preventing the disturbance to the soil at the borehole bottom during drilling operations. Rotary drilling procedure with mud circulation is found most suitable for making exploratory boreholes. Diameter of the borehole is 135mm to 150mm.

Borehole was always kept full with the drilling mud so that a positive head is maintained in the borehole thus preventing any disturbance to the soil within the test zone Standard Penetration Tests were conducted at regular depth intervals in the boreholes and N values were recorded [14]. These tests were carried out manually using manila rope attached to the SPT Hammer. The hammer was lifted with the help of a guide rod and allowed to fall on the anvil from 75cm height. The expected energy level is roughly 60 to 65%. The N value resulting from this procedure may be considered equivalent to N the samples collected through the SPT sampler were packed in two layers of polythene bags to retain the natural moisture content. Some of these samples were subjected to natural moisture content determination.

Different soil layers collected from different levels were identified and classified The Atterberg's limit values were determined directly from the natural soil adding necessary amount of distilled water to the soil specimens. The tests were conducted using Casagrande apparatus. Grain size analyses on selected samples were conducted on oven dried samples since accurate dry weights of test specimen prior to washing through 75micron sieve is necessary in this case. Some of the samples with more silt and clay were then subjected to hydrometer analysis for obtaining the gradation of soil particles smaller than 75 microns.

All the field and laboratory tests were conducted according to the procedures stipulated in relevant IS Codes.

### 1.2 Investigation Data

All the field test results are recorded in the bore logs and presented as annexures in the relevant parts of the report [8,9]. Field N values at different depths and the depths from which the samples were collected are recorded in the bore log. The depths and thickness of different soil layers are also presented in these bore logs. Laboratory test results are summarized in the relevant parts.

## 2. SUB-SOIL, SHEAR STRENGTH PROFILE AND COMPRESSIBILITY PROFILE

### 2.1 Soil Profile and Topography

The locations of PUPs and VUPs are having more or less uniform ground level. The reduced level of borehole locations are reported with respect the project bench mark system.

The subsoil profile comprises several river / sedimentary deposits of sandy silty clay, clayey silty sand, dirty fine to medium sand, clayey silty very fine to fine sand, clayey sandy silt, silty clay, etc. for the investigated depth. Most of the grain size distribution curves are having typical 'S' shape suggesting that most of the subsoil is derived by sedimentary deposit.

Since the stratification at different borehole locations varied significantly, common description of a generalized sub-soil profile is provided in the respective bore logs in which the soil identification is suitably modified incorporating the laboratory test results. Soil profile sections are drawn between adjacent boreholes. Two such profiles are generated along the approach embankment alignments of each PUP and VUP [16].

### 2.2 Groundwater Table

The water level in different boreholes were measured during the investigation and found to vary between 0.50m to 2.50m with respect to the respective ground levels. Very consistent levels were not recorded since the boring procedure required introduction of water/drilling mud. Moreover, frequent rains during the investigation also caused large fluctuations in the water level recorded in different boreholes.

### 2.3 Shear strength

Standard Penetration Test blow counts N is measured at different levels in the borehole. Mainly these N values are used to assess the shear strength of different soil layers [13].

**2.4 Sand Layers:** The sand layers found here are of sedimentary type. Conventional method of estimating the angle of shearing resistance corresponding to the relative density and the grain size distribution is adopted for these sedimentary deposits.

The classification of N values in moderate to high plasticity sedimentary clay deposits developed by Terzaghi used for estimating the unconfined compression strength and undrained shear strength of medium stiff to hard silty clay, clayey silt and sandy silty clay layers. The undrained cohesion is taken as 0.5Nt/m. However, the undrained shear strength is usually more than half the N value (in terms of t/m) N values for very hard clays.

### 2.5 Compressibility

The boreholes did not show the presence of very weak layers that are highly compressible. The structure being bridge piers and abutments, the foundation is recommended as bored cast-in-situ piles. The settlement of pile groups under the pier and abutment may be of importance and hence the compressibility parameters of different soil layers towards depth are important.

Establishment of cone resistance (q) profile may be appropriate here for estimating the compressibility of different sand layers found here. Schmertmann uses a deformation modulus estimated from cone resistance by multiplying q by a factor 2.5 to 3.5 depending upon axisymmetric and plain strain situations for estimating the settlement of shallow footings. Busman De Beer also uses the cone resistance to estimate the modulus using a correlation E = 1.5q.

Since the investigation consists of exploratory boreholes with SPT only, N values are used for estimating approximate cone resistance values. Many authors have developed correlation between cone resistance and N for sedimentary deposits, the soil with respect to the percentage of plastic fines, the following correlations may be used for rough estimation of cone resistance of different soil layers present here.

For dirty fine to coarse sand, q = 35 N t/m (Field N).

For dirty fine to medium sand, q = 30 to 32 N t/m (Field N)

For clayey silty fine to medium sand, q = 28 N t/m (Field N)

For clayey silty very fine sand, q = 25 N t/m (Field N)

## 3. BEARING CAPACITY OF SOIL AND FOUNDATION

The discussions on suitable foundation system for different PUPs and VUPs are made in subsequent parts of this report. The subsoil profiles at the specific locations, shear strength profiles, suitable foundation system and conclusions for different PUPs and VUPs are presented in the following parts.

PART – A PUP AT CH: 20+050.

PART – B VUP AT CH: 21+100.

Conclusions on foundation types and depths are drawn for different PUP and VUP locations as discussed in the relevant parts.

## 4. PEOPLE UNDERPASS

### 4.1. Site Topography and Soil Profile:

The locations of exploratory boreholes sunk in this stretch are shown in Figure 1. Other details of the borehole locations are as below.

Table 1. Details of Borehole Locations

| BH No | Location co-ordinates | GL RL, m | Depth, m |
|---|---|---|---|
| PBH/01 | E:411638.767; N:1461505.032 | 10.199 | 6.00 M |
| PBH/02 | E:411654.207; N:1461469.300 | 10.292 | 6.00 M |
| PBH/03 | E:411770.518, N:1461561.577 | 10262 | 6.00 M |
| PBH/04 | E:411785.246, N:1461521.090 | 10.152 | 6.00 M |

The ground level along the approach embankment alignment is more or less same. All the field test results are recorded in the bore logs and presented in Annexure 1 to Annexure 4 Field N values at different depths and the depths from which the samples were collected are recorded in the bore log. The depths and thickness of different soil layers are also presented in these bore logs. Laboratory test results are summarized in Table 1, while the grain size distribution curves for different soil layers along with the distribution from hydrometer analysis are presented in Annexure G

The ground at different boreholes is at more or less at same level close to 10.200m RL the entire profile comprises layers of sandy silty clay and silty clay except in the case of PBH/01 in which clayey silty fine sand is present below 4.80m depth. The clay layers are stiff.

The sandy clay and silty clay layers recorded medium plasticity to high plasticity with plasticity index PI in the range of 15% to 32%. These layers are classified as SC-CI to SC-CH.

### 4.2 Groundwater Table:

The boreholes recorded water at 0.30m to 1.60m depth. The variations in the water table are because of rains during the investigation. The ground water table is expected to be at very shallow depth or close to the ground level during rains.

Since ground water table will affect the foundation, ground water table at ground level is considered while estimating the bearing capacity of shallow foundations.

### 4.3 Shear Strength Parameters

The shear strength parameters in terms of angle of friction and undrained cohesion c of different soil layers found in these boreholes are estimated as discussed in Section 3.3 of the report and summarized in Appendix A.

### 4.4 Bearing capacity of soil and foundation

The proposed construction is a people underpass below a 6-lane highway. The width of under pass is about 7.0m. Usually the underpass structure is designed as a box transferring the entire load from the road section and the earth pressure from the embankment fill on both side of the box through the bottom slab of sufficient thickness.

The approach embankment is planned as RE wall construction with almost vertical sides. The width of RE Wall construction may be 2.00m to 3.00m for the expected embankment height of 3.50m to 4.00m from the existing ground level.

The depth of foundation for box culvert is recommended as 1.00m below GL. If the thickness of bottom slab is smaller than 1000mm, the gap between PCC and the founding level shall be filled with well compacted rubble soling so that the founding level can be treated as 1.00m below GL. Similarly, the depth of RE wall foundation is also recommended as 1.00m so that adequate stability against sliding is available for the reinforced mass.

The bottom slab of underpass box structure is treated as wide strip raft foundation. Similarly, the foundation for RE wall section is also treated as a strip foundation. The net safe bearing capacity of strip foundations of 2.0m to 7.0m wide are estimated as illustrated.

Table 2. Net SBC of Strip Footings at 1.00m below GL (9.00m RL)

| 2.00m | 3.00m | 4.00m | 5.00m | 6.00m | 7.00m |
|---|---|---|---|---|---|
| 8.80t/m2 | 9.40 t/m2 | 10.20 t/m2 | 11.00 t/m2 | 11.8 t/m2 | 11.9 t/m2 |

The net SBC of strip is adequate for supporting the PUP structure and also the RE wall if the width of foundation is equal to or more than 3.0m. Gross Allowable Bearing Pressure: The gross allowable bearing pressure may be estimated by adding the effective overburden pressure at the founding level to the net allowable bearing pressure. The submerged density of soil between the existing ground level and the founding level may be taken as 0.85 t/m for estimating the gross SBC.

The load from additional filling shall be added to the load on foundation while proportioning the footing sizes. The bulk density of additional filling soil (preferably 1.90 t/m) may be used for calculating the additional load.

## 5. VECHILE UNDER PASSES

### 5.1 Site topography and soil profile.

The locations of exploratory bore holes sunk in this stretch are shown fig. 1. Other details of borehole locations are given in table below.

| BH No | Location co-ordinates | GL RL, m | Depth, m |
|---|---|---|---|
| RWBH/09 | E:412620.787, N:1461932.144 | 10.570 | 6.00m |
| RWBH/10 | E:412637.147, N:1461897.059 | 9.625 | 6.00m |
| RWBH/11 | E:412842.283, N:1462049.836 | 10.650 | 6.00m |
| RWBH/12 | E:412862.407, N:1462017.051 | 10.885 | 6.00m |
| BH/23 | E:412743.769; N:1461992.963 | 10.845 | 15.00m |
| BH/24 | E:412765.739; N:1461959.905 | 10.810 | 15.00m |

Table 2. Details of Borehole Locations

The boreholes RWBH/9 & 10 and the VUP structure, there is a pond that to be trained for the construction of approach embankment. Contour of the pond bed shall be drawn for deciding the procedure of treating this pond area before construction of the approach road. This report is prepared without specific recommendations for the treatment within the pond area, but shall be addressed before finalizing the design of approach embankment.

All the field test results are recorded in the bore logs and presented in Annexure 1 and Annexure 2. Field N values at different depths and the depths from which the samples were collected are recorded in the bore log. The depths and thickness of different soil layers are also presented in these bore logs.

The ground at different boreholes is at more or less at same level except in the case of RWB/10 that is about 1.00m below the other locations. The average ground level RL of other locations is 10.70m RL. The ground level RL of RWBH/10 is 9.65m.

Yellowish grey and brownish grey silty clay found at shallow depths are of medium to high plasticity with liquid limit 44% to 64%. The plasticity index PI is 21% to 35%. The differential free swell index is 15% to 31% classifying the soil as low to moderate swelling type.

Figure 1. Boreholes at Different Locations

**5.2 Groundwater Table:**

The boreholes recorded water at 1.60m to 3.00m depth. The variations in the water table are because of rains during the investigation. The ground water table is expected to be at very shallow depth or close to the ground level during rains.

Since ground water table will affect the foundation, ground water table at ground level is considered while estimating the bearing capacity of shallow foundations.

**Shear Strength Parameters**

The shear strength parameters in terms of angle of friction and undrained cohesion c of different soil layers found in these boreholes are estimated and summarized in Appendix A.

**5.3 Bearing capacity of soil and foundation**

The proposed construction is a vehicular underpass below a 6 lane highway The width of under pass is about 7.0m. Usually the underpass structure is designed as a box transferring the entire load from the road section and the earth pressure from the embankment fill on both side of the box through the bottom slab of sufficient thickness.

The approach embankment is planned as RE wall construction with almost vertical sides. The width of RE Wall construction may be 2.50m to 4.00m for the expected embankment height of 4.50m to 5.00m from the existing ground level.

The depth of foundation for box culvert is recommended as 1.20m below GL so as to accommodate the sub-base and base courses of the road construction. Similarly, the depth of RE wall foundation is also recommended as 1.20m so that adequate stability against sliding is available for the reinforced mass.

The bottom slab of underpass box structure is treated as wide strip raft foundation. The width of the raft is more than 7.0m as the carriage width is 7.0m. The soil conditions near BH/23 and BH/24 vary between medium dense sand and stiff sandy silty clay. The sand layers near BH/23 have angle of friction equal to 33.5º and the stiff sandy clay near BH/24 has undrained cohesion equal to 7.0 t/m to 10.5 t/m. The founding stratum in the latter case is assumed as a two-clay layer system to take advantage of better shear strength towards depth the net safe bearing capacity of strip foundations of 5.0m and 7.0m wide are estimated and illustrated in Appendix E for these two subsoil conditions. The summary of estimations for different footings widths is presented below.

Table 3. Net SBC of Strip Footings at 1.20m below GL (9.50m RL) for VUP

| BH No: | 5.00m | 6.00m | 7.00m |
|---|---|---|---|
| BH/23 | 25. 8 t/m2 | 29.4t/m2 | 33.0t/m2 |
| BH/24 | 17.2t/m2 | 18.0t/m2 | 18.9t/m2 |

The width of reinforced earth section may vary between 2.0m and 4.0m for accommodating the maximum height of about 6.00m above the founding level. The SBCs of 2.0m to 4.0m wide strip foundation for the worst soil conditions near RWBH/10 are estimated as illustrated in Appendix D.

The depth of foundation is taken as 1.20m, same as that of the VUP structure the foundation soil in this case is stiff cay with undrained cohesion c equal to 5.5 t/m. The detailed estimations for strip footings of 2.0m, 3.0m and 4.0m wide resulted the following values.

Table 4. Net SBC of Strip Footings at 1.20m below GL (9.50m RL) (RE walls)

| BH NO: | 2.00M | 3.00M | 4.00M |
|---|---|---|---|
| RWBH/10 | 10.60t/m2 | 10.20t/m2 | 10.00t/m2 |

APPENDIX-A
BEARING CAPACITY STRIP FOOTINGS AT 1.0M BELOW GL (PBH/04)
TWO LAYER SYSTEM TWO SANDY CLAY LAYERS
ULTIMATE BEARING CAPACITY = **$CN_C+\gamma DN_q+0.5\gamma BN\gamma$** $N_C$ FACTOR REVISED

**SOIL DATA**
REFERENCE BOREHOLE ———— PBH/04
TYPE OF SOIL ———— SANDY CLAY
BULK DENSITY ABOVE GWL ———— 1.80 gm/cc.
BULK DENSITY BELOW GWL ———— 1.90gm/cc
GROUND WATER TABLE ———— 0.00 m
FACTOR OF SAFTY ———— 3.00.

FOR $C_R$ δ 1 $N_{CS} = \frac{1.5\delta\, d1}{B} + 5.14\, C_R$ 5.14 (FOR STRIP FOOTING).

$N_{CR} = \frac{3.0\delta\, d1}{B} + 6.05\, C_R$ 6.05 (FOR ROUND BASE).

FOR $C_R > 1$ COMPUTE: $N_S = 4.14 + \frac{0.5\ TO\ 1.1B}{d1}$ STRIP.

$N_S = 5.05 + \frac{0.33\ TO\ 0.66B}{d1}$ ROUND BASE.

**TWO CLAY LAYERS SYSTEMS:**
SHEAR STRENGTH OF 1ST LAYERS $C_1$.
SHEAR STRENGTH OF 2ND LAYERS $C_2$
RATIO OF SHEAR STRENGTH CR $\frac{C2}{C1}$
THICKNESS OF 1ST LAYERS BELOW FL $d_1$
WIDTH OF FOOTING B

**INTERMEDIATE VALUES FOR RECTANGLE FOOTINGS ESTIMATION**

**FOR SINGLELAYER CASE**

| | | | $N_I$ | $S_I$ | $D_I$ | $I_I$ | N | ULTIMATE |
|---|---|---|---|---|---|---|---|---|
| THICKNESS OF 1ST LAYER | 1.00 m | | | | | | | |
| COHESION OF 1ST LAYER $C_1$ | 4.50 t/m$^2$ | $N_C$ | 5.14 | 1.00 | 1.05 | 1.00 | 5.40 | 24.3 |
| COHESION OF 2ND LAYER $C_2$ | 8.00 t/m$^2$ | $N_q$ | 1.00 | 1.00 | 1.00 | 1.00 | 0.00 | 0.0 |
| DEPTH OF FOUNDATION | 1.00 m | $N_r$ | 0.00 | 1.00 | 1.00 | 1.00 | 0.00 | 0.0 |

SHAPE OF FOOTING STRIP TOTAL ULTIMATE BEARING CAPACITY 24.3 t/m$^2$
WIDTH OF FOUNDATION 4.00 m SAFE BEARING CAPACITY 8.10 t/m$^2$

**FOR TWO LAYER CASE**
RATIO OF SHEAR STRENGTH ($C_R$) = 1.8 TOTAL ULTIMATE BEARING CAPACITY 30.6 t/m$^2$.
BEARING CAPACITTY FACTOR ($N_C$)= 6.47 NET SAFE BEARING CAPACITY 10.2 t/m$^2$

FACTOR OF SAFETY ($F_S$)= 3.0 LIMIT OF NET SBC TO CONTROL SQUEEZ 13.1 t/m²

**Selected net safe bearing capacity 10.2t/m²**

APPENDIX-B
BEARING CAPACITY STRIP FOOTINGS AT 1.0M BELOW GL (PBH/04)
TWO LAYER SYSTEM TWO SANDY CLAY LAYERS
ULTIMATE BEARING CAPACITY = $\mathbf{CN_C+\gamma DN_q+0.5\gamma BN\gamma}$ $N_C$ FACTOR REVISED

**SOIL DATA**

| | |
|---|---|
| REFERENCE BOREHOLE | PBH/04 |
| TYPE OF SOIL | SANDY CLAY |
| BULK DENSITY ABOVE GWL | 1.80 gm/cc. |
| BULK DENSITY BELOW GWL | 1.90gm/cc |
| GROUND WATER TABLE | 0.00 m |
| FACTOR OF SAFTY | 3.00. |

FOR $C_R\,\delta\,1$ $N_{CS} = \frac{1.5\delta\, d1}{B} + 5.14\, C_R$ 5.14 (FOR STRIP FOOTING).

$N_{CR} = \frac{3.0\delta\, d1}{B} + 6.05\, C_R$ 6.05 (FOR ROUND BASE).

FOR $C_R > 1$ COMPUTE: $N_S = 4.14 + \frac{0.5\ TO\ 1.1B}{d1}$ STRIP.

$N_S = 5.05 + \frac{0.33\ TO\ 0.66B}{d1}$ ROUND BASE.

**TWO CLAY LAYERS SYSTEMS:**

| | |
|---|---|
| SHEAR STRENGTH OF 1ST LAYERS | $C_1$. |
| SHEAR STRENGTH OF 2ND LAYERS | $C_2$ |
| RATIO OF SHEAR STRENGTH CR | $\frac{C2}{C1}$ |
| THICKNESS OF 1ST LAYERS BELOW FL | $d_1$ |
| WIDTH OF FOOTING | B |

**INTERMEDIATE VALUES FOR RECTANGLE FOOTINGS**

**ESTIMATION**

**FOR SINGLELAYER CASE**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| THICKNESS OF 1ST LAYER | 1.00 m | | $N_I$ | $S_I$ | $D_I$ | $I_I$ | | N | ULTIMATE |
| COHESION OF 1ST LAYER $C_1$ | 4.50 t/m² | $N_C$ | 5.14 | 1.00 | 1.05 | 1.00 | 5.40 | 24.3 | |
| COHESION OF 2ND LAYER $C_2$ | 8.00 t/m² | $N_q$ | 1.00 | 1.00 | 1.00 | 1.00 | 0.00 | 0.0 | |
| DEPTH OF FOUNDATION | 1.00 m | $N_r$ | 0.00 | 1.00 | 1.00 | 1.00 | 0.00 | 0.0 | |

SHAPE OF FOOTING STRIP TOTAL ULTIMATE BEARING CAPACITY 24.3 t/m²
WIDTH OF FOUNDATION 4.00 m SAFE BEARING CAPACITY 8.10 t/m²

**FOR TWO LAYER CASE**

RATIO OF SHEAR STRENGTH ($C_R$) = 1.8 TOTAL ULTIMATE BEARING CAPACITY 30.6 t/m² .

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| | |
|---|---|
| BEARING CAPACITTY FACTOR ($N_C$)= 6.47 | NET SAFE BEARING CAPACITY 10.2 t/m$^2$ |
| FACTOR OF SAFETY ($F_S$)= 3.0 | LIMIT OF NET SBC TO CONTROL SQUEEZ 13.1 t/m$^2$ |

**Selected net safe bearing capacity 10.2t/m$^2$**

**APPENDIX-E-1**

**BEARING CAPACITY ESTIMATION FOR VUP STRUCTURE**

BEARING CAPACITY: STRIP RAFT AT 1.2M BELOW GL (BH/23)

STRUCTURE: VECHILE UNDER PASSES

ULTIMATE BEARING CAPACITY = $\mathbf{CN_C+\gamma DN_q+0.5\gamma BN\gamma}$

**SOIL DATA:**

REFERENCE BORE HOLE BH/24

TYPE OF SOIL SOIL

CORRECTED SPT (N) 25

BULK DENSITY ABOVE FL 1.80 gm/cc.

BULK DENSITY BELOW FL 1.90 gm/cc.

GROUND WATER TABLE 0.00 m.

COHESION (C) 0.00 m

FACTOR OF SAFTY 3.00.

**FAILUR CASE:**

- LOCAL SHEAR FAILUR WHEN ANGLE OF FRICTION IS 28$^0$ OR LESS.
- ANGLE OF FRICTION IS ADJESTED TO 0.67 tan ($\pi$).
- GENERAL SHEAR FAILURE WHEN ANGLE OF FRICTION IS 36$^0$ OR MORE.
- ANGLE OF FRICTION ISEQUAL TO ORIGINAL VALUE INTERMEDIATE CASE WHEN $<\pi<36^0$ ANGLE OF FRICTION IS INTERPOLATED

**ESTIMATION-1**

DEPTH OF FOUNDATION 1.2 m

SHAPE FOOTING STRIP

WIDTH OF FOUNDATION 5.00m

ANGLE OF FRICTION 33.5$^0$.

FAILURE CASE INTERMEDIATE.

DESIGN ANGLE OF FRICTION 30.5$^0$.

| | $N_i$ | $S_i$ | $D_i$ | $I_i$ | N | ULTIMATE |
|---|---|---|---|---|---|---|
| $N_C$ | 31.40 | 1.00 | 1.08 | 1.00 | 34.0 | 0.0 |
| $N_q$ | 19.49 | 1.00 | 1.04 | 1.00 | 19.3 | 20.8 |
| $N_R$ | 24.14 | 1.00 | 1.04 | 1.00 | 25.2 | 56.6 |

Total ultimate bearing capacity 77.4 t/m$^2$

Net safe bearing capacity 25.8 t/m$^2$

**ESTIMATION-2:**

DEPTH OF FOUNDATION 1.2 m

SHAPE FOOTING STRIP

WIDTH OF FOUNDATION 6.00m

ANGLE OF FRICTION 33.5$^0$.

FAILURE CASE INTERMEDIATE.

DESIGN ANGLE OF FRICTION 30.5$^0$.

| | $N_i$ | $S_i$ | $D_i$ | $I_i$ | N | ULTIMATE |
|---|---|---|---|---|---|---|
| $N_C$ | 31.40 | 1.00 | 1.07 | 1.00 | 33.6 | 0.0 |
| $N_q$ | 19.49 | 1.00 | 1.03 | 1.00 | 19.1 | 20.7 |
| $N_R$ | 24.14 | 1.00 | 1.03 | 1.00 | 25.0 | 67.5 |

Total ultimate bearing capacity = 88.1 t/m$^2$

Net safe bearing capacity = 29.4 t/m$^2$

**APPENDIX-E-2**

**BEARING CAPACITY ESTIMATION FOR REWALLFOUNDATION**

BEARING CAPACITY: STRIP RAFT AT 1.2M BELOW GL.

STRUCTURE: REWALL FOUNDATION

ULTIMATE BEARING CAPACITY = $\mathbf{CN_C+\gamma DN_q+0.5\gamma BN\gamma}$

**SOIL DATA:**

REFERENCE BORE HOLE RWBH/10

TYPE OF SOIL CLAY

CORRECTED SPT (N) 25

BULK DENSITY ABOVE FL 1.80 gm/cc.

BULK DENSITY BELOW FL 1.90 gm/cc.

GROUND WATER TABLE 0.00 m.

COHESION (C) 0.00 m

FACTOR OF SAFTY 3.00.

**FAILUR CASE:**

- GENERAL FAILURE CASE IS CONSIDERED IN ALL CASES ASSUMING NO PUNCHING SHEAR BECAUSE OF WIDE BASE

**ESTIMATION-1**

Depth of foundation 1.2 m

Shape of footing STRIP

Width of foundation 5.00m

Cohesion (C) 5.5 t/m².

LOADING CASES:

Eccentricity ($e_L$) NO.

Eccentricity ($e_B$) NO.

Slope of ground NO.

| | $N_i$ | $S_i$ | $D_i$ | $I_i$ | N | ULTIMATE |
|---|---|---|---|---|---|---|
| $N_C$ | 5.14 | 1.00 | 1.12 | 1.00 | 5.8 | 31.7 |
| $N_q$ | 1.00 | 1.00 | 1.04 | 1.00 | 0.0 | 0.0 |
| $N_R$ | 0.00 | 1.00 | 1.00 | 1.00 | 0.0 | 0.0 |

Total ultimate bearing capacity = 31.7 t/m²

Net safe bearing capacity = 10.6 t/m²

**ESTIMATION-2:**

Depth of foundation 1.2 m

Shape of footing STRIP

Width of foundation 3.00m

LOADING CASES:

Eccentricity ($e_L$) NO.

Eccentricity ($e_B$) NO.

Slope of ground NO.

| | $N_i$ | $S_i$ | $D_i$ | $I_i$ | N | ULTIMATE |
|---|---|---|---|---|---|---|
| $N_C$ | 5.14 | 1.00 | 1.08 | 1.00 | 5.6 | 30.5 |
| $N_q$ | 1.00 | 1.00 | 1.00 | 1.00 | 0.0 | 0.0 |
| $N_R$ | 0.00 | 1.00 | 1.00 | 1.00 | 0.0 | 0.0 |

Total ultimate bearing capacity = 30.5 t/m²

Net safe bearing capacity = 10.2 t/m²

**6. CONCLUSIONS AND RECOMMENDATIONS**

I. The sub-soil conditions are not uniform along alignment of VUP. There are also variations in the subsoil conditions along the RE wall construction alignment on either side of the approach embankments. There is a pond before the location of VUP that is to be trained properly for the construction of approach embankment.

II. All the boreholes except BH/23 recorded stiff sandy clay at shallow depths. Borehole BH/23 recorded a thick layer of medium dense fine to coarse sand from the surface. Borehole RWBH/10 represents the worst condition having medium stiff to stiff clay with undrained cohesion c equal to 5.50 t/m up to 6.0m depth.

III. The net SBC of strip footings placed at 1.20m below GL is estimated since the RE wall height is marginally larger than that of PUPs. The whole width of the reinforced section of RE wall is treated as the foundation width. The height of wall is expected to be about 6.00m from the founding level and accordingly the width of reinforced section may be 3.0m to 4.0m. The net SBCs of strip footings of width 2.0m to 4.0m are hence estimated and reported.

IV. The underpass structure may be designed as an RCC box structure, by which the bottom slab will act like a full raft foundation (strip raft). The net SBC of wide strip raft foundations placed at 1.20m below GL are estimated and reported.

V. Detailed settlement estimations are made to arrive at the allowable bearing pressure for a limiting settlement of 75mm. The estimated net allowable bearing pressure is 12.0 t/m²

**Foundation Recommendations**

- The foundation recommendation for the proposed RE walls is as follows:

| | |
|---|---|
| Type of foundation | Strip footing (RE wall width). |
| Recommended depth of foundation | 1.20m below ground level* |
| Type of soil at foundation depth | Sandy clay, except near BH/23** |
| Minimum width for foundation | 2.00m |
| Recommended net sbc*** | 10t/m2 (net allowable bearing pressure) |
| Expected settlement | < 60mm (IS 1904-1986 table 1). |

*The ground is at about 10.70m RL and the recommended founding level is +9.50m RL

** The soil at the proposed founding level is sandy clay in most of the cases. The excavation surface shall be compacted well using heavy compaction accessories so that the surface is leveled and free from loose pockets.

*** The gross allowable bearing pressure may be estimated by adding the effective overburden pressure at the founding level to the net allowable bearing pressure. The submerged density of soil between the existing ground level and the founding level may be taken as 0.85 t/m for estimating the gross SBC. Any load from additional filling shall be added to the load on foundation while proportioning the footing sizes. The bulk density of additional filling soil (preferably 1.9 t/m) may be used for calculating the additional load.

- The foundation recommendation for the proposed vehicle under passage is as follows:

| | |
|---|---|
| Type of foundation | RCC footing (RE wall width). |
| Recommended depth of foundation | 1.20m below ground level* |
| Type of soil at foundation depth | Sandy clay, except near BH/23** |
| Minimum width for foundation | 4.00m |
| Recommended net sbc*** | 12t/m2 (net allowable bearing pressure) |
| Expected settlement | < 75mm (IS 1904-1986 table 1). |

*The ground is at about 10.70m RL and the recommended founding level is +9.50m RL. If the thickness of bottom slab along with the PCC and the pavement course is smaller than 1200mm, the remaining thickness shall be compensated with well compacted rubble soling.

**The soil at the proposed founding level is sandy clay or fine to coarse sand. The excavation surface shall be compacted well using heavy compaction accessories so that the surface is leveled and free from loose pockets.

***The gross allowable bearing pressure may be estimated by adding the effective overburden pressure at the founding level to the net allowable bearing pressure. The submerged density of soil between the existing ground level and the founding level may be taken as 0.85 t/m for estimating the gross SBC. Any load from additional filling shall be added to the load on foundation while proportioning the footing sizes. The bulk density of additional filling soil (preferably 1.9 t/m) may be used for calculating the additional load.

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