CIVIL GLOBE CONSULTANT

Civil Globe Material & Soil Testing Lab
Laboratory: Sr. No. 23,1/1/6/6, Near Alankar Chowk, Ambegaon, Budruk, Pune 411046
Office & Customer Support: +91 9561420336
E-Mail: info@civilglobe.co.in Website:www.civilglobe.co.in

GEOTECHNICAL SITE INVESTIGATION REPORT

FOR

CONSTRUCTION OF RIVER BRIDGE ACROSS SENAPATI BAPAT MARG TO WESTERN EXPRESS HIGHWAY BANDRA, MUMBAI.

CLIENT

Spectrum Techno Consultants Pvt Ltd, Mumbai
MAHARASHTRA

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Mahesh Hanmawale
M. Tech (Geotech) IIT Roorkee
Authorized Signatory

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1. INTRODUCTION

This report summarizes the geotechnical investigation campaign carried out for Construction of River Bridge across Senapati Bapat marg to Western express highway Bandra, Mumbai. The report interprets the available geological information at the Site and describes the in-situ tests. It provides interpretation and recommendations for the structural design including material properties, quality of bedrock, and bearing capacity of foundation material for Bridge foundation.

1.1. Project Description

Municipal Corporation of Brihan Mumbai (MCBM) plans the Construction of River Bridge across Senapati Bapat marg to Western express highway Bandra, Mumbai. The Preliminary Geotechnical Investigations are completed by Civil Globe Consultants Pune. A vicinity map is presented in Fig.1.

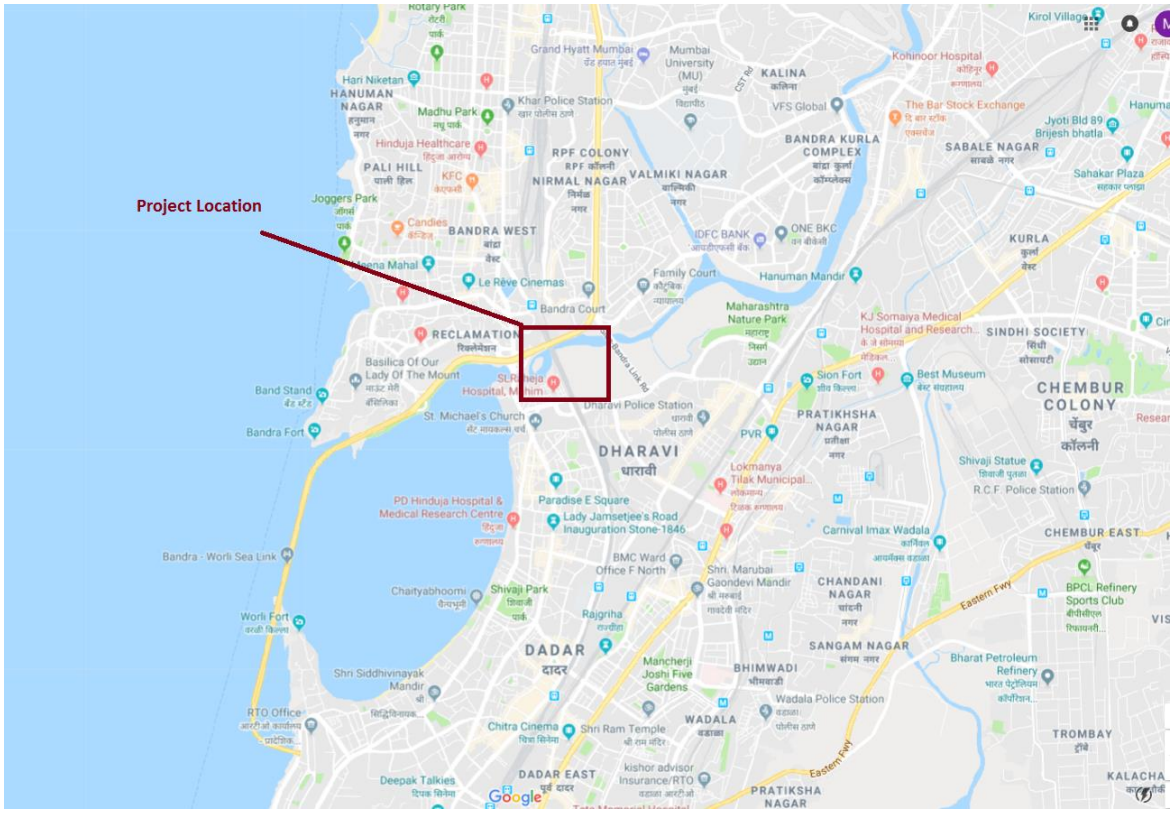

Figure 1: Project Location Map

1.2. Scope of work

The Geotechnical work includes:

- Carrying out site investigation work at Site location
- Assessment of subsurface conditions
- Performing geotechnical analyses to develop recommendations for foundation design and construction

This report has been prepared in order to provide a brief documentation of the above activities and present the results of the geotechnical analyses as well as the recommendations for foundation design.

The soil investigations scope of work consist the followings:

- Collecting information and maps particular to the project site such as public services, site plan and land use maps.
- Mobilize personnel and equipment's to the site.
- Moving and setting up drilling rigs at the location of boreholes.
- Drilling of 4 boreholes to depth ranging between 17.5m & 24.0m, all below the existing ground level.
- Taking representative disturbed and undisturbed samples from the investigated points in order to determine the type, thickness, sequence conditions and properties of the soils.
- Carrying out the required and necessary laboratory tests on samples obtained from investigated points.
- Clear the site and demobilized personnel and equipment.
- Prepare and submit report on the results of the fieldwork and laboratory testing along with engineering analysis.

Plan showing boreholes are presented in Fig.2 of this report.

Figure 2: Plan showing Borehole locations

1.3. Site Description

The project is near Mahim and Western Bandra, Mumbai. Site is majorly divided into three layers as Yellowish/Brownish Clayey Silt with some fine sand and Filled Material Boulders and Murum as top most layer, Completely to moderately weathered yellowish

fractured calcareous Sandstone/Siltstone and Highly to moderately weathered greyish Volcanic Tuffs as subsequent layer.

2. FIELD EXPLORATION AND LABORATORY TESTING

2.1. Field Exploration

2.1.1. Drilling

4 numbers of boreholes were drilled on the period between November 03th & December 29th 2017 to depth ranging between 17.5m to 24.0m, all below existing ground level. The work done is in general accordance with IS: 1892– 1979.
Details of the drilled boreholes are summarized in Table 1.

Table 1: Details of the Drilled Boreholes

BH No.	Drilling Duration		Terminated Depth (m)	Water Table below GL (m)
	Starting Date	Completion Date		
BH-02	08-12-2017	14-12-2017	20.00	2.0
BH-03	03-11-2017	08-11-2017	21.50	2.0
BH-04	10-11-2017	15-11-2017	17.50	4.0
BH-06	16-12-2017	29-12-2017	24.00	9.0

The holes were advanced in soil by wash& rotary drilling method using Diamond bits in rock.
Casing was used to support the sides of boreholes up to the competent, hard strata. The logs of the drilled boreholes are presented in Appendix A in this report.

2.1.2. Sampling

Disturbed samples were obtained from the boreholes locations as bulk soil samples and by the split spoon sampler where the SPT performed. Undisturbed samples were also obtained using double tube wire line core barrel 54mm inside diameter with continuous core recovery in the competent rock formation. The samples recovered were examined, described classified, identified and coded by our Geotechnical Engineers, covered by water proof plastic sheets, put in proper sequence in heavy duty wooden boxes, and were taken to our laboratories for testing and storage. Care was taken in placing the samples in sequence in the wooden boxes to avoid getting displaced.
DS/UDS samples are taken at every 1.5m interval up to 10m depth and beyond at 3minterval up to termination of bore hole. Sampler is coupled together with a sampler head to form a sampling assembly. The sampler head provide a non-flexible connection between the sampling tube and the drill rods. Vent holes are provided in the sampler head to allow escape of water from the top of sampler tube during penetration.
The wooden boxes were particularly designed and made to have the shape of a of 1.6m-lengthand 6.5m height, with parallel longitudinal wooden partitions to house five

meters length of continuous cores. The wooden boxes were fixed with wooden lids to protect the samples during transport. On each box the number of boreholes, the sequence of samples as they were drawn, and initial and final depths of the samples were clearly marked and written on the box.

2.2. Field Testing

2.2.1. Visual Examinations

Visual examinations were carried out on the samples obtained from the investigated points. The examinations were performed according to the procedure outlined in:

- IS: 1892-1979 (Reaffirmed 2002), "Code of Practice for Subsurface Investigation for Foundations".

2.2.2. Standard Penetration Test

Standard Penetration Test using open shoe with split spoon sampler (SPT) performed through the cohesion less soil materials. The test results will be used in order to obtain the approximate relative densities and consistencies of the ground materials. The tests were performed in accordance with:

- IS2131:1981, (Reaffirmed 2002), "Method for Standard Penetration test for Soils".

The standard penetration tests are conducted in each bore at every 1.5m interval up to30m depth and beyond at 3m interval up to termination of bore hole as per IS: 2131: 1981(Reaffirmed 1987). The split spoon sampler resting on the bottom of bore hole is allowed to sink under its own weight, then the split spoon sampler is seated 15 cm with the blows of hammer falling through 750mm. The driving assembly consists of a driving head and a 63.5 kg weight. It is ensured that the energy of the falling weight is not reduced by friction between the drive weight and the guides or between ropes. The rods to which the sampler is attached for driving are straight, tightly coupled and straight in alignment. There after the split spoon sampler is further driven by 30cm. The number of blows required to drive each 15cm penetration is recorded. The first 15cm of drive considered as seating drive. The total blows required for the second and third 15cm penetration is termed as a penetration resistance - N value.

The test results are shown on the boring logs at depths of the tests.

2.2.3. Laboratory Testing

In order to determine the physical and mechanical of the ground materials, Laboratory tests were performed on selected samples from the investigated points and the test results are presented in Appendix c of this report. The following tests were performed according to Indian Standard (IS) as presented in Table 2:

Table 2: List of Codes & Standards

SrNo	Test Name	IS Code
1	Grain Size Distribution (Sieve Analysis)	IS - 2720 (Part-IV)
2	Atterberg's limits (liquid limit and plastic limit)	IS - 2720 (Part -V)
3	Linear Shrinkage	IS 2720(Part VI)
4	Engineering Classification of Soil	IS-1498

5	Specific Gravity Determination	IS-2720(Part-III)
6	Field Dry Density & Field Moisture Content	IS 2720 part – II & XXIX
7	Free swell index Test	IS-2720 part- XL
8	Unit Weight, Specific Gravity, Moisture Absorption & porosity on Rock	IS-13030
9	Point Load test on Rock	IS-8764
10	Uniaxial Compressive Strength of Rock	IS-9143

3. SUMMARYOF SURFACE CONDITION

3.1. General Subsurface Stratigraphy

The profiles were constructed by direct interpolation between the materials encountered in the boreholes. The lines connecting the various ground strata are made for illustration purposes only and not to be considered as actual field conditions. The geological description of the ground materials at the site and depths at which they were encountered in the investigated points are presented in the logs of boreholes, Appendices I. The surface and subsurface ground materials in the study area can be divided into the following types and summarized with its approximate boundaries.

As may be observed from the borehole logs, Site is majorly divided into three layers as Yellowish/Brownish Clayey Silt with some fine sand and Filled Material Boulders and Murum as top most layer, Completely to moderately weathered yellowish fractured calcareous Sandstone/Siltstone and Highly to moderately weathered greyish Volcanic Tuffs as subsequent layer to the proven depth of 24.00m.

In general BH-02, 03, 04 and 06 comprises yellowish/brownish Clayey Silt with some fine sand and Filled Material Boulders and Murum on top up to an elevation 9.0 from ground level. This strata is designated as Unit 1, Completely to moderately weathered yellowish fractured calcareous Sandstone/Siltstone recovered from 2.2 to 8.5m in BH 02 to 06, this stratum designated as Unit 2. The boreholes have been terminated in highly to moderately weathered greyish Volcanic Tuffs. This stratum is designated as Unit 3. Schematic idealization of subsurface profile is presented in Table 3 as below.

Table 3: Schematic Idealization of Subsurface Profile

Sr. No.	Soil Description	Designated As	Thickness Encountered in the Boreholes (m)		
			Max.	Min.	Average
1	Yellowish/Brownish Clayey Silt with some fine sand and Filled Material Boulders and Murum	Unit 1	9.00 BH-06	6.30 BH-03	7.57

2	Completely to moderately weathered yellowish fractured calcareous Sandstone/Siltstone	Unit 2	8.50 BH-02	2.20 BH-03	6.05
3	Highly to moderately weathered greyish Volcanic Tuffs	Unit 3	13.00 BH-03	upto end of boring	7.40

The drilled boreholes show that there are general similarities and continuities of the subsurface materials, in spite of some local variations. Generalized subsurface profiles with min. and max. SCR and RQD values are presented in following Tables:

Table 4: List of Subsurface Profiles per Boreholes

Borehole No: BH 02

Depth (m)	Description of Strata	SPT	SCR (%)	RQD (%)
0.0-7.5	Yellowish/Brownish Clayey Silt with some fine sand	7-50	-	-
7.5-16.0	Completely to highly weathered yellowish fractured calcareous Sandstone/Siltstone	-	30-82	Nil-60
16.0-20.0	Highly to moderately weathered greyish Volcanic Tuffs	-	59-83	10-80

Borehole No: BH 03

Depth (m)	Description of Strata	SPT	SCR (%)	RQD (%)
0.0-6.3	Yellowish/Brownish Clayey Silt with some fine sand	23-50	-	-
6.3-8.5	Highly to moderately weathered yellowish fractured calcareous Sandstone/Siltstone	-	68-73	56-59
8.5-21.5	Completely to moderately weathered greyish Volcanic Tuffs	-	17-96	Nil-96

Borehole No: BH 04

Depth (m)	Description of Strata	SPT	SCR (%)	RQD (%)
0.0-7.5	Filled Material Boulders and Murum	50	-	-
7.5-13.0	Completely to highly weathered yellowish fractured calcareous Sandstone/Siltstone	-	18-60	Nil-45
13.0-17.5	Highly to moderately weathered greyish Volcanic Tuffs	-	76-94	61-94

Borehole No: BH 06

Depth (m)	Description of Strata	SPT	SCR (%)	RQD (%)
0.0-9.0	Filled Material Boulders and Murum	50	-	-
9.0-16.0	Completely to highly weathered yellowish fractured calcareous Sandstone/Siltstone	-	10-98	Nil-51
16.0-24.0	Moderately weathered greyish Volcanic Tuffs	-	89-99	74-94

4. IN-SITU TEST RESULTS AND LABORATORY TEST RESULTS

Field and laboratory test results for the retrieved samples from investigated points are presented in the following tables for each layer along with the geotechnical description and the engineering properties analysis.

4.1. In-situ Test Results

(a) Standard Penetration Test (SPT) and Core Recovery

Standard penetration test is conducted at various depths in the boreholes to understand the variation of relative densities of ground at different depth and different locations

As depicted in Borehole logs, the Standard Penetration Test (SPT) results (N values) obtained have been found 07 to 50.

Solid core recovery (SCR) and rock quality designation (RQD) of the underlying rock strata are indicated on the borehole logs. Figure 3 and Figure 4 are presented in below which represent the variation of SCR and RQD with elevation.

The average SCR and RQD are 67% and 50%, respectively.

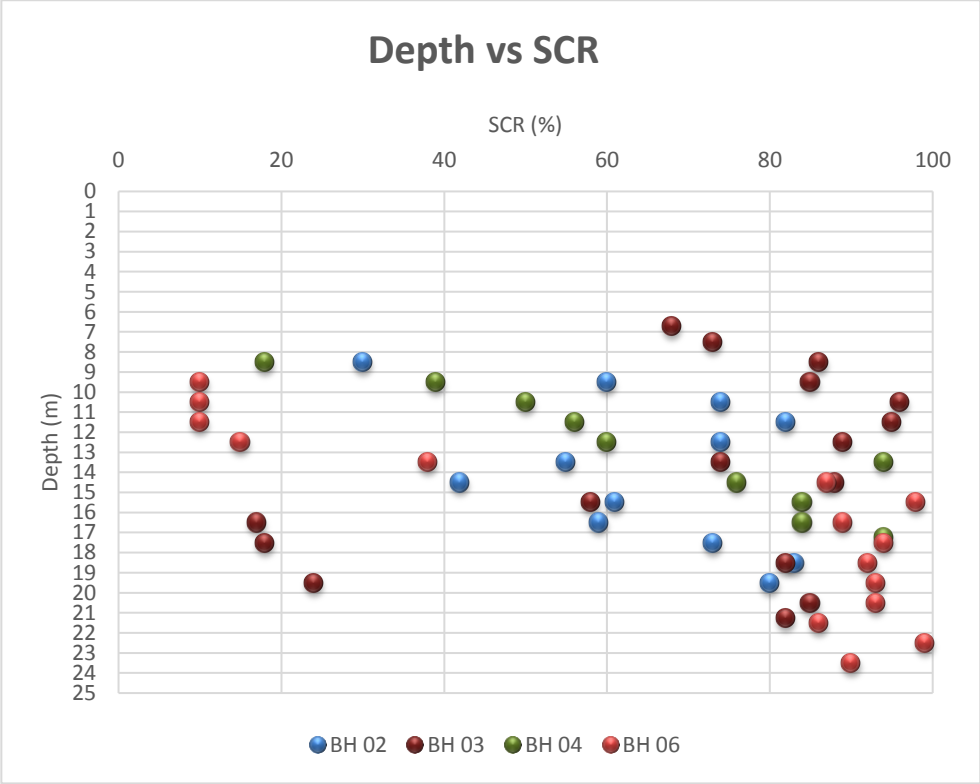

Figure 3: BH Depth vs SCR (%)

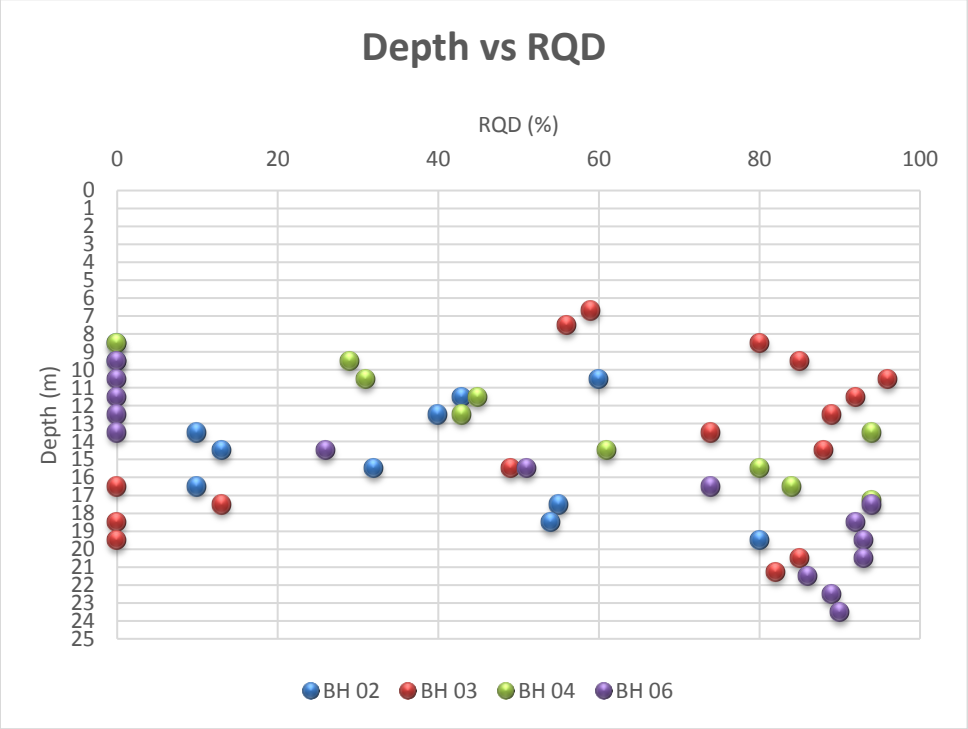

Figure 4: BH Depth vs RQD (%)

(b) Groundwater Table

Ground water was encountered in the drilled boreholes at a depth ranging between 2.0 to 9.0 m below Natural Ground Level. It should be mentioned that the water levels mentioned in the boring logs might vary due to seasonal variation effects or induced artificially. The design ground water level is considered at ground surface.

4.2. Laboratory Test Results

The laboratory tests were conducted on soil and selected rock core samples collected from the test locations:

- Specific Gravity
- Water Absorption
- Porosity
- Unconfined Compressive Strength (UCS) Test

(a) Unconfined Compressive Strength (UCS)

A total of Twenty-six (26) unconfined compression tests were performed on representative rock core samples. The test results are collated and presented in Appendix III. Based on these results the average value of UCS for Intact rock core for completely to highly weathered yellowish sandstone/siltstone 474.95 T/m^2 and highly to moderately weathered greyish volcanic tuff 1135.81 T/m^2. Figure 5 is presented in below which represent the variation of UCS (T/m^2) with elevation.

Table: UCS (T/m^2)

	Max.	Min.	Average
Yellowish Sandstone/Siltstone	897.11	137.15	474.95
Weathered Volcanic Tuff	1655.73	874.74	1135.81

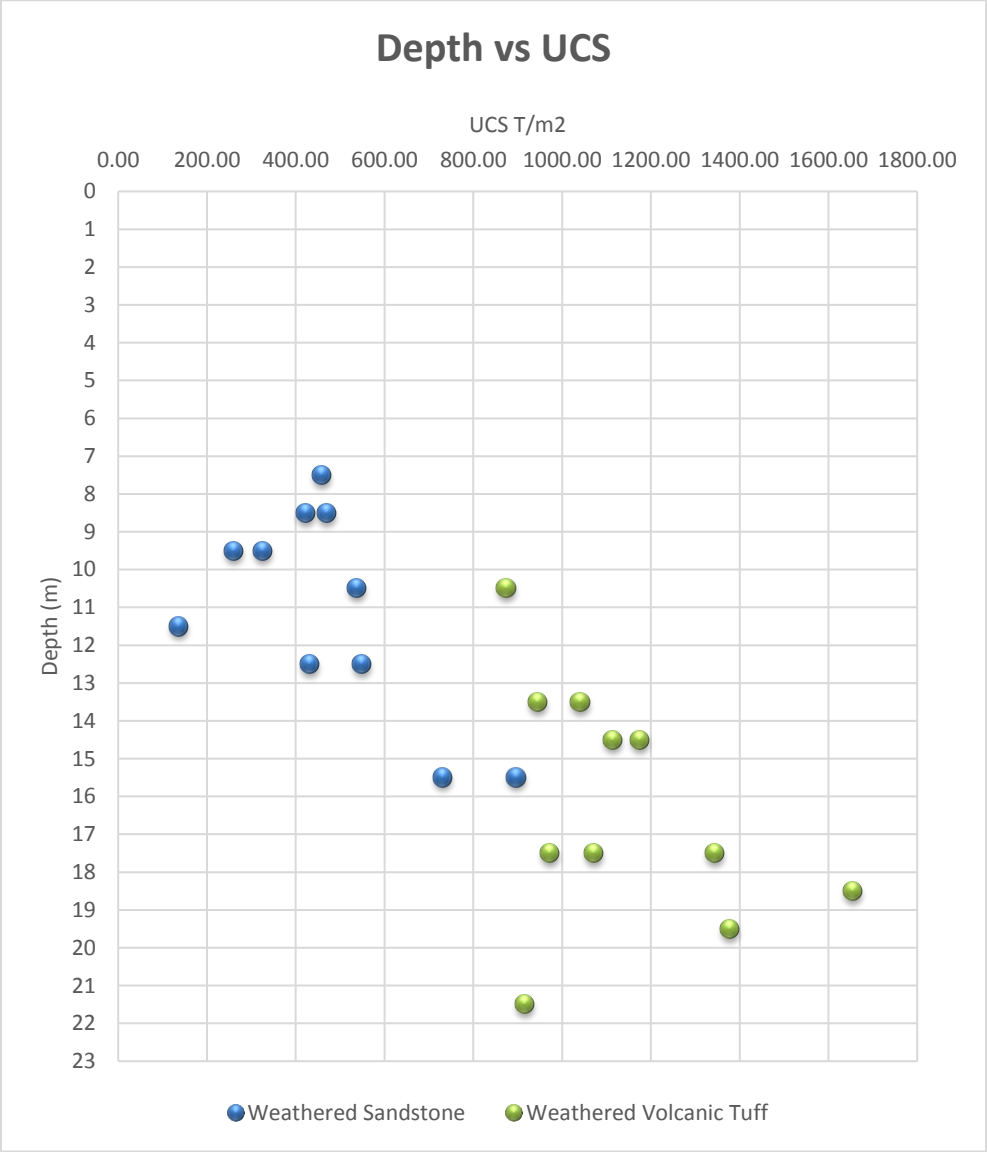

Figure 5: BH Depth vs UCS (T/m^2)

Porosity (%)	4.28-23.17
Water Absorption (%)	2.03-11.62
Specific Gravity	1.79-2.29

5. GEOTECHNICAL ANALYSIS

The methodologies followed for determining the bearing capacity and settlement values for the foundations resting in rock are explained as follows.

5.1.Technical Specifications

SPT 'N' values are co-related with relative density of non-cohesive stratum and with consistency of cohesive stratum. Co-relations are tabulated below.

CO-RELATION FOR SATURATED SAND/NON-PLASTIC SILT

Relative Density	Penetration Value (Blows/30 cm)
Very Loose	0-4 blows
Loose	4-10 Blows
Medium	10-30 Blows
Dense	30-50 Blows
Very Dense	50 and above

CO-RELATION FOR SATURATED CLAY/PLASTIC SILT

Relative Density	Penetration Value (Blows/30 cm)
Very Soft	0-2 blows
Soft	2-4 Blows
Medium Stiff	4-8 Blows
Stiff	8-16 Blows
Very Stiff	16-32 Blows
Hard	50 and above

Rock classification in terms of weathering and state of fractures and strength is carried out in the following manner. Tabulations given in below explain it briefly.

SCALE OF WEATHERING GRADES OF ROCK MASS

Terms	Description	Grade
Fresh	No visible sign of rock material weathering; perhaps slight discoloration on major discontinuity surfaces.	I
Slightly Weathered	Discoloration indicates weathering of rock material and discontinuity surfaces. All the rock material may be discoloured by weathering.	II
Moderately Weathered	Less than half of the rock material is decomposed or disintegrated to a soil. Fresh or discolored rock is present either as a continuous framework or as corestones.	III
Highly Weathered	More than half of the rock material is decomposed or disintegrated to a soil. Fresh or discolored rock is present either as a discontinuous framework or as corestones	IV
Completely Weathered	All rock material is decomposed and / or disintegrated to soil. The original mass structure is still largely intact.	V
Residual Soil	All rock material is converted to soil. The mass structure and material fabric are destroyed. There is a large change in volume, but the soil has not been significantly transported.	VI

It should be understood that all grades of weathering may not be seen in a given rock mass and that in some cases a particular grade may be present to a very small extent. Distribution of the various weathering grades of rock material in the rock mass may be

related to the porosity of the rock material and the presence of open discontinuities of all types in the rock mass.

Rock quality is further measured by frequency of natural joints in rock mass. Rock Quality Designation (RQD) is used to define state of fractures or massiveness of rock. Following table defines the quality of rock mass.

RELATION BETWEEN RQD AND IN-SITU ROCK QUALITY

RQD Classification	RQD (%)
Excellent	91 to 100
Good	76 to 90
Fair	51 to 75
Poor	26 to 50
Very Poor	0 to 25

The IAEG (anon 1979a) has proposed a table grouping the strata on strength of dry density and porosity in Five classes.

ROCK CLASSES WITH RESPECT TO DRY DENSITY & POROSITY (IAEG:Anon 1979a)

Class	Dry Density kg/m³	Description	Porosity %	Description
I	Less than 1.80	Very Low	Over 30	Very High
II	1.80-2.20	Low	30-15	High
III	2.20-2.55	Moderate	15-5	Medium
IV	2.55-2.75	High	5-1	Low
V	over 2.75	Very High	less than 1	Very Low

The classification of Rock as per IRC 78:2000 is given below along with the site Identification criterion for identification of Rocky formation.

CLASSIFICATION OF ROCKS AS PER IRC 78:2014

Rock Type	Description	Unconfined Compressive Strength (UCS) in MPa
Extremely Strong	Cannot be scratched with knife or sharp pick. Breaking of specimen could be done by sledge hammer only	>200
Very Strong	Cannot be scratched with knife or sharp pick. Breaking of specimen requires several hard blows of geologists pick.	100 to 200
Strong	Can be scratched with knife or pick with difficulty. Hard blow of hammer required to detach hand specimen	50-100
Moderately Strong	Can be scratched with knife or pick, 6mm deep gouges or grooves can be made by hand blow of geologists pick. Hand specimen can be detached by moderate blow.	12.5-50

Moderately Weak	Can be grooved or gouged 1.5mm deep by firm pressure of knife or pick point. Can be broken in to pieces or chips of about 2.5mm maximum size by hard blows of the points of geologists pick.	5-12.5
Weak	Can be grooved or gouged easily with knife or pick point. Can be break down in chips to pieces several cm's in size by moderate blows of pick point. Small thin pieces can be broken by finger pressure	1.25-5
Very Weak	Can be carved with knife. Can be broken easily with point of pick. Pieces 25mm or more in thickness can be broken by finger pressure. Can be scratched easily by finger nail	<1.25

5.2. Bearing Capacity Analysis

Bearing capacities for isolated/ raft foundations resting on rock are calculated using the bearing capacity equations as shown in the Table below:

Bearing Capacity equations for foundations in rock

Method of Calculation	Bearing capacity equation
Buisman - Terzaghi	$q_{ult} = cN_c + 0.5\gamma BN_\gamma + \gamma DN_q$
Goodman, 1980	$q_{ult} = q_{uc}(N_\emptyset + 1)$

Where,

a) Buisman-Terzaghi,

- $N_\emptyset = \tan^2\left(45 + \frac{\emptyset}{2}\right)$;
- $N_q = {N_\emptyset}^2$;
- $N_c = 2{N_\emptyset}^{1/2}(N_\emptyset + 1)$;
- $N_\gamma = {N_\emptyset}^{1/2}\left({N_\emptyset}^2 - 1\right)$

q_{ult} = The ultimate bearing capacity
γ_{mass} = Effective unit weight of the rock
B = Width of foundation
D = Depth of foundation below ground surface
C = The cohesion intercepts for the rock mass
ϕ = Angle of internal friction for the rock mass

b) Goodman, 1980,

- q_{uc} = unconfined compressive strength of intact rock
- $N_\emptyset = \tan^2\left(45 + \frac{\emptyset}{2}\right)$

c) When no test data of c and ϕ is available for the rock,

According to the code of Practice for Design and Construction of shallow Foundations on Rocks (IS12070-1987 Reaffirmed 2010), The safe bearing capacity should be estimated from the equation:

$$q_s = q_c.N_j$$

where,

q_s- Safe bearing pressure

q_c- Avg. uniaxial compressive strength of rock cores

N_j- emperical coefficient depending on the spacing of discontinuities.

d) Bieniawski's classification system Rock mass rating (RMR) using for the SBC calculations(IS:12070-1987 Reaffirmed 2010)

5.3. Settlement Analyses – Elastic Settlements for Foundations on Rock

a) Rock

The immediate elastic settlement underneath foundations is evaluated using equation proposed by Schleicher (1926) as follows:

$$\delta v = \left(Cd * q * B\,(1-\mu^2)\right)/E$$

where,

Cd	the parameter which accounts for the shape of the loaded area and the position of the point for which settlement is being calculated
q	the net applied footing pressure
μ	Poisson's ratio,
B	Characteristic dimension of the loaded area, which for a circular area is diameter and for a rectangular area is the smaller dimension
E	Young's Modulus (Deformation Modulus) of rock mass
δv	Vertical settlement

One of the important parameters for determining the estimated settlement is the Elastic modulus of the rock mass and the various equations used for determining this parameter are presented in the following:

- $Emass = j * Mr * quc$……...Tomlinson(2001)

where,

j = a mass factor related to the discontinuity spacing in the rock mass (in the present analysis lower bound value i.e. 0.2 is considered)

M_r = the ratio between the deformation modulus and the unconfined compressive strength, quc, of the intact rock

q_{uc} = Unconfined Compressive strength of intact rock

- $E_{mass}=E_i*(RQD/350)$, if RQD<70
  $E_{mass}=E_i*(0.2+(RQD-70)/37.5)$, if RQD>70……Beiniwasky(1980)

where,

RQD = Rock Quality Designation

E_i = Elastic Modulus of Intact Rock mass

- Emass = α*Ei……Gardner (1980)

where,

$$\alpha = 0.0231*RQD - 1.32 \ (\geq 0.15)$$

5.4. Foundation Type

The foundation design for the Piers and Abutment will be carried out in accordance with IRC 78-2014 and IS 12070-1987 (Reaffirmed-2010),
The adequacy of the proposed foundation system shall be verified ensuring compliance with the following criteria:

- The foundation must be stable against shear failure of the supporting soil.
- Foundation settlement, both total and differential settlements, must be controlled within the tolerable limits defined in the Code to avoid damage to the structure,

The type of foundations for the structure is chosen in light of the results of the site investigation, the structural loads, and the allowable settlements. The methodology to be adopted for the foundation design consists of evaluating the simpler, practical, and most cost-effective alternatives first, before assessing more exhaustive and costly options.

In general, the foundations systems and design criteria that will be adopted for the various project components.

Deep foundations (bored cast-in-situ) will be considered for Pier and abutment structures

Piles will be designed to safely support the applied vertical and lateral loadings and maintain deformations within acceptable limits.

As per clause 9.1 Appendix-5, in IRC78-2014, In situations where strata is highly fragmented, where RQD is nil or (CR+RQD)/2 is less than 30 percent, or where strata is not classified as a granular or clayey soil, or when the crushing strength is less than 1 0 MPa, the approach described in method 2 shall be used. Also, for weak rock like chalk, mud stone, clay stone, shale and other intermediate rocks, method 2 is applicable. The Method 2 as below:

Pile Foundation:

Load Carrying Capacity of Piles Socketed In Rock/ Rock Masses as per IRC 78-2014

Capacity of piles in Intermediate Geo-material and Rock as Per IRC 78-2014

The ultimate load carrying capacity in rock as per Appendix 5, Cl 9 of IRC 78:2014

$Q_u = R_e + R_{af}$

$= K_{sp} q_c d_f A_b + A_s C_{us}$

Where,
Q_u- Ultimate capacity of pile socketed into rock.
R_e - Ultimate end bearing.
R_{af} - Ultimate side socket shear.
K_{sp} - An empirical co-efficient whose value ranges from 0.3 to 1.2.

$\frac{(CR+RQD)}{2}$	Ksp
30%	0.3
100%	1.2

q_c-Average unconfined compressive strength of rock core below base of pile for the depth twice the diameter/least lateral dimension in MPa.
A_b- Cross sectional area of base of pile.
D_f - Depth factor = 1+0.4*(length of socket/dia of socket)
Length of socket may be limited to 0.5 x dia of socket.
A_s - Surface area of socket.
C_{us}- Ultimate shear along the socket value of q_s = 0.225xsqrt(q_c). For calculation of Socketresistance, the same should be restricted to 3 MPa.

Pile Load Carrying Capacity of Piles for Weathered or Weak Rock/Rock masses

When Geo-material is highly fragmented. The shear strength of Geo-material is obtained from its Correlation with extrapolated SPT values for 30 cm of penetration as given in table below:

Shear Strength/Consistency	Moderately Weak	Weak	Very Weak
Approx. N Value	300-200	200-100	100-60
Shear Strength Cohesion in MPa	3.3-1.9	1.9-0.7	0.7-0.4

$Q_u = R_e + R_{af}$

$= C_{ub} N_c A_b + A_s C_{us}$

$Q_{allow} = (R_e/3)+(R_{af}/6)$

where

C_{ub} = Avg shear strength below base of pile, for the depth equal to twice the diameter least lateral dimension of pile, based on average N value of this region.

C_{us} = Ultimate shear strength along socket length, to be obtained from table, based on average 'N' value of socket portion. This shall be restricted to shear capacity of concrete of the pile, to be taken as 3.0 MPa for M35 concrete in confined condition, which for other strengths of concrete can be modified by a factor (fck/35)^0.5 immediate values C_{ub} and C_{us} can be interpolated linearly.

L = Length of Socket

N_c = 9

Q_{allow} = Allowable capacity of pile

Maximum allowable end bearing to be limited to 20 Kg/cm^2. (As per Tender)

The extrapolated values of N greater than 300 shall be limited to 300 while using this method

Settlement Analysis (Elastic Method BM Das)

a) Settlement of pile due to deformation of the pile shaft

The elastic settlement of the utilized piles, for deformation of the pile shaft was estimated by the equation given below;

$$S_{e(1)} = \frac{(Q_{wp} + \xi Q_{ws})\, L}{A_p * E_p}$$

Where,

Q_{wp}:Load carried by pile point

Q_{ws}:Load carried by frictional resistance

L :Pile length

A_p:Area of pile cross section

E_p :Modulus of elasticity of the pile material

ξ :Coefficient of unit skin distribution (0.5 rectangular & parabolic, 0.67 triangular) = 0.67

b) Settlement of pile caused by the load at the pile tip

The elastic settlement of the pile caused by the load at the pile tip was estimated according to the following equation;

$$S_{e(2)} = \frac{q_{wp} * D * (1 - \mu_s{}^2) * I_{wp}}{E_s}$$

Where,

q_{wsp}:Point load per unit area (Q_{wp}/A_p)

I_{wp}: Influence factor = 0.88

D: Pile Diameter

E_s: Modulus of elasticity of soil

μ_s: Poisson's ratio of soil

Accordingly, the elastic settlement for 1.0m diameter pile is as follow;

c) Settlement of pile caused by the load transmitted along the pile shaft

The elastic settlement of the pile due to the load at pile tip was estimated according to the following equation;

$$S_{e(3)} = \frac{Q_{ws} * D * (1 - \mu_s{}^2) * I_{ws}}{p * L * E_s}$$

Where,

Q_{WS}: Load carried by frictional resistance

p :Pile perimeter

L : Embedded length of the pile

D :Pile Diameter

E_s: Modulus of elasticity of soil

μ_s: Poisson's ratio of soil

I_{ws}: Influence factor

Influence factor is derived from a following empirical relation (Vesic, 1977)

$$I_{ws} = 2 + 0.35\,(\frac{L}{D})\text{^}0.5$$

Pile Capacity and settlement Summary:

Pile dia. (m)	Allowable vertical load carrying capacity in tonne and Socketed length		
	2D	3D	4D
0.80	130.00	145.00	170.00
1.00	205.00	230.00	255.00
1.20	295.00	335.00	370.00
1.50	465.00	520.00	580.00

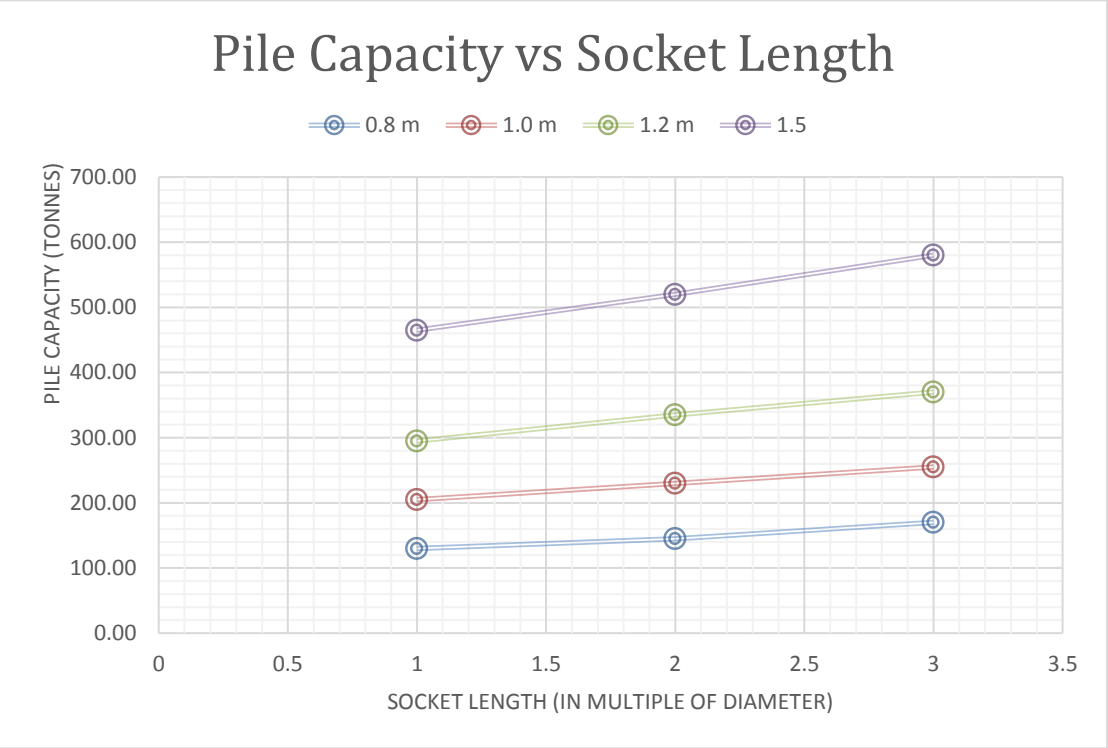

Figure 6: Pile Capacity (tonne) vs Socket Length (In multiple of pile Diameter)

At location of BH-02

Location of hard statum(top level)= 10 m

Pile Dia. (m)	Socketed Length (m)	Pile Length (m)	Compressive Vertical Pile Capacity (T)	Settlement mm	Pile Stiffness T/m
0.8	1.60	11.60	130.0	9.92	13000
	2.40	12.40	145.0	10.17	14000
	3.60	13.60	170.0	10.56	16000
1.0	2.00	12.00	205.0	12.07	17000
	3.00	13.00	230.0	12.36	19000
	4.00	14.00	255.0	12.67	20000
1.2	2.40	12.40	295.0	14.36	21000
	3.60	13.60	335.0	14.74	23000
	4.80	14.80	370.0	15.09	25000
1.5	3.00	13.00	465.0	17.66	26000
	4.50	14.50	520.0	18.08	29000
	6.00	16.00	580.0	18.53	31000

At location of BH-03

Location of hard statum(top level)= 8 m

Pile Dia. (m)	Socketed Length (m)	Pile Length (m)	Compressive Vertical Pile Capacity (T)	Settlement mm	Pile Stiffness T/m
0.8	1.60	9.60	130.0	9.92	13000
	2.40	10.40	145.0	10.17	14000
	3.60	11.60	170.0	10.56	16000
1.0	2.00	10.00	205.0	12.07	17000
	3.00	11.00	230.0	12.36	19000
	4.00	12.00	255.0	12.67	20000
1.2	2.40	10.40	295.0	14.36	21000
	3.60	11.60	335.0	14.74	23000
	4.80	12.80	370.0	15.09	25000
1.5	3.00	11.00	465.0	17.66	26000
	4.50	12.50	520.0	18.08	29000
	6.00	14.00	580.0	18.53	31000

At location of BH-04

Location of hard statum(top level)= 11 m

Pile Dia. (m)	Socketed Length (m)	Pile Length (m)	Compressive Vertical Pile Capacity (T)	Settlement mm	Pile Stiffness T/m
0.8	1.60	12.60	130.0	9.92	13000
	2.40	13.40	145.0	10.17	14000
	3.60	14.60	170.0	10.56	16000
1.0	2.00	13.00	205.0	12.07	17000
	3.00	14.00	230.0	12.36	19000
	4.00	15.00	255.0	12.67	20000
1.2	2.40	13.40	295.0	14.36	21000
	3.60	14.60	335.0	14.74	23000
	4.80	15.80	370.0	15.09	25000
1.5	3.00	14.00	465.0	17.66	26000
	4.50	15.50	520.0	18.08	29000
	6.00	17.00	580.0	18.53	31000

At location of BH-06

Location of hard statum(top level)= 15 m

Pile Dia. (m)	Socketed Length (m)	Pile Length (m)	Compressive Vertical Pile Capacity (T)	Settlement mm	Pile Stiffness T/m
0.8	1.60	12.60	130.0	9.92	13000
	2.40	13.40	145.0	10.17	14000
	3.60	14.60	170.0	10.56	16000
1.0	2.00	13.00	205.0	12.07	17000
	3.00	14.00	230.0	12.36	19000
	4.00	15.00	255.0	12.67	20000
1.2	2.40	13.40	295.0	14.36	21000
	3.60	14.60	335.0	14.74	23000
	4.80	15.80	370.0	15.09	25000
1.5	3.00	14.00	465.0	17.66	26000
	4.50	15.50	520.0	18.08	29000
	6.00	17.00	580.0	18.53	31000

LOAD CARRYING CAPACITY OF PILES WEATHERED/WEAK ROCK/ ROCK MASSES

When Geo-material is highly fragmented. The shear strength of Geo-material is obtained from its Correlation with extrapolated SPT values for 30 cm of penetration as givan in table below:

Shear Strength/Consistency	Moderately Weak	Weak	Very Weak
Approx. N Value	300-200	200-100	100-60
Shear StrengthCohesion in MPa	3.3-1.9	1.9-0.7	0.7-0.4

$$Q_u = R_e + R_{af}$$

$$= C_{ub} N_c A_b + A_s C_{us}$$

$$Q_{allow} = (R_e/3)+(R_{af}/6)$$

where

C_{ub}	=	Avg shear strength below base of pile, for the depth equal to twice the diameter least lateral dimension of pile, based on average N value of this region.
C_{us}	=	Ultimate shear strength along socket length, to be obtained from table, based on average 'N' value of socket portion. This shall be restricted to shear capacity of concrete of the pile, to be taken as 3.0 Mpa for M35 concrete in confined condition, which for other strengths of concrete can be modified by a factor (fck/35)^0.5 immediate values Cub and Cus can be interpolated linearly.
L	=	Length of Socket
N_c	=	9
Q_{allow}	=	Allowable capacity of pile

Maximum allowable end bearing to be limited to 20 Kg/cm2.

The extrapolated values of N greater than 300 shall be limited to 300 while using this method

Diameter of pile (D)	=	1.0	m
Socketed length (l_s)	=	3.0	m
Location of hard statum(top layer)	=	15.0	m
Length of the pile	=	18.0	m
Grade of concrete	=	35	MPa
N	=	100	
q_c	=	0.7	MPa
C_{us}	=	0.7	MPa
C_{ub}	=	0.7	MPa
N_c	=	9	
A_b	=	0.785	m^2
A_s	=	9.425	m^2
R_e	=	494.80	t
R_{af}	=	461.81	t
Factor of safety for R_e	=	3	
Factor of safety for R_{af}	=	6	
Working end resistance	=	157.08	t
Working shaft resistance	=	76.97	t
Working pile capacity	=	234.05	t

In seismic case 25% end resistance can be increased, So

Seismic case pile capacity=	=	273.32	t

Structural Capacity of Pile

Diameter of pile (D)	=	1.0	m
Grade of concrete	=	35	MPa
Working Stress of concrete	=	8.75	MPa
Pile Area (A)	=	0.785	m^2
Structural Pile Capacity	=	687.2234	t

CALCULATIONS FOR LATERAL LOAD CARRYING CAPACITY OF PILE

INTRODUCTION : -

The calculations lateral load carying capacity for pile for Bridge at Senapati Bapat marg to Weatern Bandra are presented here. Pile capacity has been calculated for Bored cast-in-situ piles of dia 0.8, 1.0,1.2 and 1.5m and length m (M35 grade). The load carrying capacity of pile is calculated in accordance with specifications based upon Static formula as per IS:2911(PartI/Sec2).

The design data for pile design by static formula has been taken from Design Specifications and Sub-Soil Investigation Report

The design has been done as per procedure given in IS code IS:2911(PartI/Sec2)-2010. The vertical and lateral load carrying capacity calculated here shall be compared with result of initial load test carried on test piles and minimum of the two values shall be adopted for design.

CALCULATIONS FOR LOAD CARRYING CAPACITY OF PILE

DESIGN DATA : -

Type of pile	=	Bored cast-in-situ			
Diameter of Pile	=	dia	=	1.20	m
Length of Pile (from pile cap bottom)	=	leng	=	20.00	m
Minimum Height of Soil above Pile Cap	=	mhsplca	=	0.00	m
Pile Cap Thickness	=	plcth	=	1.50	m
Grade of Concrete for Pile			=	**35.00**	MPa

Clear cover to main Reinforcement	=	75	mm

HORIZONTAL LOAD CARRYING CAPACITY CALCULATIONS

{Annex C , IS:2911(PartI/Sec2)}

As per Specifications, maximum lateral load on any pile under normal condition shall not exceed the value corresponding to 5mm horizontal deflection (produced at cut-off level) .

The lateral load capacity, depth of fixity amd maximum moment in pile is calculated as per Annex C of IS:2911(PartI/Sec2)-2010. Minimum value of lateral load capacity is adopted for Design.

Depth of Fixity

Depth of Fixity for pile (z_f) is given by plots in Fig. 3 (Annex C) of IS:2911 between L_1/R or L_1/T.

Where

z_f = Depth of Fixity

e = Height above ground level of Lateral Forces

$T = (EI/ h_h)^{1/5}$

Here

E =	Young's Modulus of the Pile Material (i.e. M35 grade concrete)			
	As per IRC 21:2000	=	2.96E+06	t/m^2
I =	pi * $(dia)^4$ / 64	=	0.1018	m^4
h_h =	Constant (from Table 3 of Annex C)	=	0.200	Kg/cm^3
	(for Silty Sandy in submerged condition)	=	200.0	t/m^3

(As per the BH logs Description, avg groundwater level below 0.5m)

Therefore

T =	(E * I $/h_h)^{1/5}$	=	4.32	
L_1 =	(for Fixed Head Piles)	=	0.0	m

for Fixed Head Piles in Sands and Normally Loaded Clays, from Fig.3 of Annex C

z_f/T =	Depth of Fixity	=	2.20

z_f = 2.2 * T = 2.2 * 4.32 = 9.505 m

Pile Head Deflection (Y) is given by

$Y = Q (e + z_f)^3 / 12EI$ (for Fixed Head piles, refer to Cl. C.4.2 of Annex C)

or $Q = 12EI * Y / (e + z_f)^3$

Where

Q = Lateral Load Capacity

Y = 12 mm = 0.012 m

(Maximum Deflection, as per codal provision)

Therefore

$Q = 12EI * Y / (e + z_f)^3$

= 12 * 2,958,040 * 0.102 * 0.012 / (0.0 + 9.51)^3 = 50.5 ton

Therefore

Q = 50.5 ton (say)

i.e. Lateral Load Carrying Capacity of Pile under Normal Condition = Q_{lat} = **50.5** **ton**

Thus, Lateral Load Carrying Capacity of Pile

Under Normal Condition = 50.5 ton

Under Seismic Condition = 63.1 ton

SUMMARY OF DESIGN FORCES

Lateral Load Carrying Capacity of Pile

Pile Dia.			
0.8 m	**=**	**17.0**	**ton**
1.0 m	**=**	**31.0**	**ton**
1.2 m	=	**50.0**	**ton**
1.5 m	=	**90.0**	**ton**

6. GEOTECHNICAL RECOMMENDATIONS

6.1. Foundation Recommendations

- Pile foundations shall be used to support the structures.
- All foundations shall rest on one type of stratum to avoid differential settlement.
- Bored cast-in-situ concrete piles are to be used.
- The Contractor shall carry out the works in accordance with a method statement for execution and pile testing that must be approved by the Engineer before work commencement.
- Prior to carrying out any pile tests, the Contractor shall submit its detailed method statement for integrity and load testing to the Engineer for review and approval. The Contractor shall also propose the location of testing for both preliminary and working piles to the Engineer's approval.
- Prior to commencing the execution of the working piles, the Contractor shall perform preliminary pile load test in accordance with IS Code and shall submit the pile test report to the Engineer for its review and approval.
- Pile integrity and load (preliminary and working) shall be carried out in accordance with the IS code.
- During piles construction, it is recommended that a professional geotechnical engineer supervise all specified testing, and oversee the contractor's piling operations.
- The bottom of the excavation shall be flooded with water for at least 48hours then left to dry. Any soft spots encountered due to flooding/drying procedure should be removed and replaced with cyclopean concrete.
- Whenever foundations are placed on rock, it is essential to ensure that there are no loose pockets on rock surface. In case of loose pockets or over excavation, it shall be filled by cyclopean concrete.
- Open excavation may be executed at a slope of 1.5H:1V in soil 1H:3V in rock mass. If there is not enough horizontal space at the periphery, excavation supports and protection systems shall be designed, provided, installed, monitored and maintained for supporting the sides of the excavation. Contractor shall be responsible for ensuring and maintaining the safety of all excavation.
- If required, an appropriate dewatering method is to be applied to lower the water level to at least 0.50m below the bottom of the excavation. A dewatering system is to be designed, provided, installed, and maintained in a manner accepted to the engineer, at the contractor's sole risk and responsibility. Dewatering works are to be carried out carefully to ensure that no fines are drawn with the effluent and groundwater table below the adjacent structure is not affected such that no damage takes place to adjacent structures.

Mahesh Hanmawale
M. Tech (Geotech) IIT Roorkee

Notes:
This report is issued based on the subsoil condition revealed at the location of boreholes and laboratory tests performed on recovered samples. If during construction of foundations it is observed that sub soil conditions vary from those revealed during investigation it is essential that Civil Globe Consultants shall be contacted so that on confirmation supplementary report shall be issued.

List of Codes and Standards:

IRC: 78 Code of Practice for Road Bridges Foundation and Substructures

IS: 1904 Code of practice for design and construction of foundations in soils: General requirements

IS: 2911 Code of practice for design and construction of pile foundations (Relevant parts)

IS: 6403 Code of practice for determination of allowable bearing pressure on shallow foundation

IS: 8009 Code of practice for calculation of settlement of Part-I foundation subjected to symmetrical vertical loads -Shallow foundations

IS: 12070 Code of practice for design and construction of shallow foundations on rocks

IRC: 78 Code of Practice for Road Bridges Foundation and Substructures

IS: 1892 Code of practice for subsurface Investigation for foundation

IS: 2131 Method of standard penetration test for soils

IS: 2132 Code of practice for thin walled tube sampling of soils

IS: 4464 Code of practice for presentation of drilling information and core description in foundation investigation

IS: 5313 Guide for core drilling observations

Appendix I

Borehole Logs

BH-02

Project : Senapati Bapat Marg to Weastern Express Highway, Mahim, Mumbai.	**Total Depth :** 20.00 m
Client : Spectrum Techno Consultants Pvt. Ltd, Navi Mumbai	**Borehole Location :** N--------- E--------
Location : Fisherman Colony Chainage: ----------	**Borehole Elevation :** ---------
BOREHOLE No: . BH-02	**Final Water Table Depth :** 2.00 m
Drilling Method : Wash Boring / Rotary	**Water Table Level :** ---------- m
Casing Size (ID) : 76.2 mm	**Date Started :** 08/12/2017
Core Bit Size : 54.7 mm	**Date Finished :** 14/12/2017 **Page: 1 of 2**

CASING	Depth (m)	R.L. (M)	THICKNESS OF LAYER	MATERIALS DESCRIPTION	LOG	FIELD TEST SPT (15 / 15 / 15 / 15 / N)	Sample Type	Sample No.	RECOVERY %	RQD %	Remarks
'Nx' DOUBLE TUBE CORE BARREL	0 – 7.5	-------	7.50m	Yellowish/Brownish Clayey Silt with some fine sand		4 5 12 10 17	DS / WS1 / SPT1				G.W.L 2.00
						2 4 3 5 7	WS2 / SPT2				
							DS				
						2 4 4 7 8	WS3 / SPT3				
						3 4 6 8 10	WS4 / SPT4				
						55 >50	WS5 / SPT5				
	7.5 – 16	-------	8.50m	Completely to highly weathered yellowish fractured calcareous Sandstone/Siltstone			CORE	1-7	30		
								8-21	60		
								22-28	74	60	
								29-37	82	43	
								38-46	74	40	
								47-55	55	10	
								56-60	42	13	
								61-68	61	32	
								69-78	59	10	
								79-85	73	55	
								86-92	83	54	
	16 – 19	-------	up to end of boring (4.00m)	Highly to moderately weathered greyish Volcanic Tuffs							

LEGEND

- Silty Clay Soil
- Sand with Gravels
- Moorum with Boulders
- Yellowish Basalt
- Completely Weathered Rock
- Fractured Basalt
- Greyish Basalt
- Volcanic Tuff

ABBRV

- DS : DISTURBED SAMPLE
- WS : WASH SAMPLE
- WO : DISTURBED SAMPLE
- UDS : UNDISTURBED SAMPLE
- C.P : CORE PIECES
- SP : SMALL PIECES
- SPT : STANDARD PENETRATION TEST
- VST : VANE SHEAR TEST

SCALE:- V 1:100
H N.T.S
DATE:- 14-12-2017
DRAWN BY:- SP
CHECKED BY:- MH

Civil Globe Consultants
Email:- info@civilglobe.in
mahesh.han@gmail.com
Contact-09561420336

BH-02

Project : Senapati Bapat Marg to Weastern Express Highway, Mahim, Mumbai.	**Total Depth :** 20.00 m
Client : Spectrum Techno Consultants Pvt. Ltd, Navi Mumbai	**Borehole Location : N--------- E--------**
Location : Fisherman Colony Chainage: ----------	**Borehole Elevation : ---------**
BOREHOLE No: . BH-02	**Final Water Table Depth :** 2.00 m
Drilling Method : Wash Boring / Rotary	**Water Table Level :** ---------- m
Casing Size (ID) : 76.2 mm	**Date Started :** 08/12/2017
Core Bit Size : 54.7 mm	**Date Finished :** 14/12/2017 **Page: 2 of 2**

CASING	Depth (m)	R.L. (M)	THICKNESS OF LAYER	MATERIALS DESCRIPTION	LOG	FIELD TEST SPT					Sample Type	Sample No.	RECOVERY %				RQD %				Remarks
						15	15	15	15	N			25	50	75	100	25	50	75	100	
	19	-------	up to end of boring (4.00m)	Highly to moderately weathered greyish Volcanic Tuffs							CORE	93-95	80				80				
	20	-------		**END OF LOG**																	
	21																				
	22																				
	23																				
	24																				
	25																				
	26																				
	27																				

LEGEND

- Silty Clay Soil
- Sand with Gravels
- Moorum with Boulders
- Yellowish Basalt
- Completely Weathered Rock
- Fractured Basalt
- Greyish Basalt
- Volcanic Tuff

ABBRV

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SCALE:- V 1:100
H N.T.S
DATE:- 14-12-2017
DRAWN BY:- SP
CHECKED BY:- MH

Civil Globe Consultants
Email:- info@civilglobe.in
mahesh.han@gmail.com
Contact-09561420336

BH-03

Project : Senapati Bapat Marg to Weastern Express Highway, Mahim, Mumbai.	**Total Depth :** 21.50 m
Client : Spectrum Techno Consultants Pvt. Ltd, Navi Mumbai	**Borehole Location :** N--------- E--------
Location : Fisherman Colony Chainage: ----------	**Borehole Elevation :** ---------
BOREHOLE No: . BH-03	**Final Water Table Depth :** 0.00 m
Drilling Method : Wash Boring / Rotary	**Water Table Level :** ---------- m
Casing Size (ID) : 76.2 mm	**Date Started :** 03/11/2017
Core Bit Size : 54.7 mm	**Date Finished :** 08/11/2017 **Page: 1 of 2**

CASING	Depth (m)	R.L. (M)	THICKNESS OF LAYER	MATERIALS DESCRIPTION	LOG	FIELD TEST SPT (15 / 15 / 15 / 15 / N)	Sample Type	Sample No.	RECOVERY %	RQD %	Remarks
'Nx' DOUBLE TUBE CORE BARREL	0 – 1.5	-------	6.30m	Yellowish/Brownish Clayey Silt with some fine sand		6 10 20 15 30	DS / WS1 SPT1				G.W.L 2.00
	2.1 – 3.0					6 11 25 15 36	WS2 SPT2 / DS				
	3.6 – 4.5					8 10 13 15 23	WS3 SPT3				
	5.1 – 6.0					8 54 9/R >50	WS4 SPT4				
	6.3 – 8	-------	2.20m	Highly to moderately weathered yellowish fractured calcareous Sandstone/Siltstone			CORE	1-5	68	59	
								6-11	73	56	
								12-17	86	80	
								18-21	85	85	
								22-25	96	96	
								26-30	95	92	
								31-34	89	89	
								35-36	74	74	
								37-39	88	88	
								40-41	58	49	
								42-44	17		
								45-46	18	13	
			up to end of boring (13.0m)	Completely to moderately weathered greyish Volcanic Tuffs				47-48	82	82	

LEGEND

Silty Clay Soil; Sand with Gravels; Moorum with Boulders; Yellowish Basalt; Completely Weathered Rock; Fractured Basalt; Greyish Basalt; Volcanic Tuff

ABBRV

DS : DISTURBED SAMPLE
WS : WASH SAMPLE
WO : DISTURBED SAMPLE
UDS : UNDISTURBED SAMPLE
C.P : CORE PIECES
SP : SMALL PIECES
SPT : STANDARD PENETRATION TEST
VST : VANE SHEAR TEST

SCALE:- V 1:100
H N.T.S
DATE:- 08-11-2017
DRAWN BY:- SP
CHECKED BY:- MH

Civil Globe Consultants
Email:- info@civilglobe.in
mahesh.han@gmail.com
Contact-09561420336

BH-03

Project : Senapati Bapat Marg to Weastern Express Highway, Mahim, Mumbai.	**Total Depth :** 21.50 m
Client : Spectrum Techno Consultants Pvt. Ltd, Navi Mumbai	**Borehole Location : N--------- E--------**
Location : Fisherman Colony Chainage: ----------	**Borehole Elevation : ---------**
BOREHOLE No: . BH-03	**Final Water Table Depth :** 0.00 m
Drilling Method : Wash Boring / Rotary	**Water Table Level :** ---------- m
Casing Size (ID) : 76.2 mm	**Date Started :** 03/11/2017
Core Bit Size : 54.7 mm	**Date Finished :** 08/11/2017 **Page: 2 of 2**

CASING	Depth (m)	R.L. (M)	THICKNESS OF LAYER	MATERIALS DESCRIPTION	LOG	FIELD TEST SPT					Sample Type	Sample No.	RECOVERY %				RQD %				Remarks
						15	15	15	15	N			25	50	75	100	25	50	75	100	
	19	-------	up to end of boring (13.0m)	Completely to Moderately weathered greyish Volcanic Tuffs							CORE	49-52	24								
	20											53-56	85				85				
	21	-------										57-59	82				82				
	22			END OF LOG																	
	23																				
	24																				
	25																				
	26																				
	27																				

LEGEND

Silty Clay Soil | Sand with Gravels | Moorum with Boulders | Yellowish Basalt

Completely Weathered Rock | Fractured Basalt | Greyish Basalt | Volcanic Tuff

ABBRV

DS : DISTURBED SAMPLE
WS : WASH SAMPLE
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SCALE:- V 1:100
H N.T.S
DATE:- 08-11-2017
DRAWN BY:- SP
CHECKED BY:- MH

Civil Globe Consultants
Email:- info@civilglobe.in
mahesh.han@gmail.com
Contact-09561420336

BH-04

Project : Senapati Bapat Marg to Weastern Express Highway, Mahim, Mumbai.	**Total Depth :** 17.50 m
Client : Spectrum Techno Consultants Pvt. Ltd, Navi Mumbai	**Borehole Location :** N--------- E--------
Location : Fisherman Colony Chainage: ----------	**Borehole Elevation :** ---------
BOREHOLE No: . BH-04	**Final Water Table Depth :** 4.00 m
Drilling Method : Wash Boring / Rotary	**Water Table Level :** ---------- m
Casing Size (ID) : 76.2 mm	**Date Started :** 10/11/2017
Core Bit Size : 54.7 mm	**Date Finished :** 15/11/2017 **Page: 1 of 2**

CASING	Depth (m)	R.L. (M)	THICKNESS OF LAYER	MATERIALS DESCRIPTION	LOG	FIELD TEST SPT (15 / 15 / 15 / 15 / N)	Sample Type	Sample No.	RECOVERY % (25 50 75 100)	RQD % (25 50 75 100)	Remarks
'Nx' DOUBLE TUBE CORE BARREL	0 – 19	-------	7.50m	Filled Material Boulders and Murum		45 >50 >50	DS; WS1/SPT1; WS2/SPT2; DS				G.W.L 4.00
	7.5 / 7.65	--------	5.50m	Completely to highly weathered yellowish fractured calcareous Sandstone/Siltstone		>50	CORE	1-4 / 5-8 / 9-13 / 14-17 / 18-22	18 / 39 / 50 / 56 / 60	29 / 31 / 45 / 43	
	13	--------	up to end of boring (4.50m)	Highly to moderately weathered greyish Volcanic Tuffs			CORE	23-26 / 27-31 / 32-35 / 36-39 / 40-42	94 / 76 / 84 / 84 / 94	94 / 61 / 80 / 84 / 94	
	17.5			**END OF LOG**							

LEGEND

- Silty Clay Soil
- Sand with Gravels
- Moorum with Boulders
- Yellowish Basalt
- Completely Weathered Rock
- Fractured Basalt
- Greyish Basalt
- Volcanic Tuff

ABBRV

DS	: DISTURBED SAMPLE
WS	: WASH SAMPLE
WO	: DISTURBED SAMPLE
UDS	: UNDISTURBED SAMPLE
C.P	: CORE PIECES
SP	: SMALL PIECES
SPT	: STANDARD PENETRATION TEST
VST	: VANE SHEAR TEST

SCALE:- V 1:100
H N.T.S
DATE:- 15-11-2017
DRAWN BY:- SP
CHECKED BY:- MH

Civil Globe Consultants
Email:- info@civilglobe.in
mahesh.han@gmail.com
Contact-09561420336

BH-06

Project : Senapati Bapat Marg to Western Express Highway, Mahim, Mumbai.	**Total Depth :** 24.00 m
Client : Spectrum Techno Consultants Pvt. Ltd, Navi Mumbai	**Borehole Location :** N--------- E--------
Location : Bandra Side Chainage: ----------	**Borehole Elevation :** ---------
BOREHOLE No: . BH-06	**Final Water Table Depth :** 9.00 m
Drilling Method : Wash Boring / Rotary	**Water Table Level :** ---------- m
Casing Size (ID) : 76.2 mm	**Date Started :** 16/12/2017
Core Bit Size : 54.7 mm	**Date Finished :** 29/12/2017 **Page: 1 of 2**

CASING	Depth (m)	R.L. (M)	THICKNESS OF LAYER	MATERIALS DESCRIPTION	LOG	FIELD TEST SPT (15 / 15 / 15 / 15 / N)	Sample Type	Sample No.	RECOVERY %	RQD %	Remarks
'Nx' DOUBLE TUBE CORE BARREL	0	-------	9.00m	Filled Material Boulders and Murum		>50 >50 >50 >50 N	DS WS1/SPT1 WS2/SPT2 DS WS3/SPT3				G.W.L 9.00
	9	--------	7.00m	Completely to highly weathered yellowish fractured calcareous Sandstone/Siltstone			SP		10 10 10		
							CORE	1-4	15		
								5-10	38		
								11-25	87	26	
								26-38	98	51	
	16	--------	up to end of boring (8.00m)	Moderately weathered greyish Volcanic Tuffs				39-45	89	74	
							CORE	46-50	94	94	
	19							51-54	92	92	

LEGEND

Silty Clay Soil; Sand with Gravels; Moorum with Boulders; Yellowish Basalt; Completely Weathered Rock; Fractured Basalt; Greyish Basalt; Volcanic Tuff

ABBRV

DS : DISTURBED SAMPLE
WS : WASH SAMPLE
WO : DISTURBED SAMPLE
UDS : UNDISTURBED SAMPLE
C.P : CORE PIECES
SP : SMALL PIECES
SPT : STANDARD PENETRATION TEST
VST : VANE SHEAR TEST

SCALE:- V 1:100
H N.T.S
DATE:- 29-12-2017
DRAWN BY:- SP
CHECKED BY:- MH

Civil Globe Consultants
Email:- info@civilglobe.in
mahesh.han@gmail.com
Contact-09561420336

BH-06

Project : Senapati Bapat Marg to Weastern Express Highway, Mahim, Mumbai.	**Total Depth :** 24.00 m
Client : Spectrum Techno Consultants Pvt. Ltd, Navi Mumbai	**Borehole Location : N--------- E--------**
Location : Fisherman Colony Chainage: ----------	**Borehole Elevation : ---------**
BOREHOLE No: . BH-06	**Final Water Table Depth :** 9.00 m
Drilling Method : Wash Boring / Rotary	**Water Table Level :** ---------- m
Casing Size (ID) : 76.2 mm	**Date Started :** 16/12/2017
Core Bit Size : 54.7 mm	**Date Finished :** 29/12/2017 **Page: 2 of 2**

CASING	Depth (m)	R.L. (M)	THICKNESS OF LAYER	MATERIALS DESCRIPTION	LOG	FIELD TEST SPT (15 / 15 / 15 / 15 / N)	Sample Type	Sample No.	RECOVERY %	RQD %	Remarks
	19	-------	up to end of boring (8.00m)	Moderately weathered greyish Volcanic Tuffs				55-58	93	93	
	20							59-63	93	93	
	21							64-67	86	86	
	22							68-74	99	89	
	23							75-77	90	90	
	24	-------		END OF LOG							
	25										
	26										
	27										

RECOVERY % scale: 25 50 75 100 — RQD % scale: 25 50 75 100

LEGEND

- Silty Clay Soil
- Sand with Gravels
- Moorum with Boulders
- Yellowish Basalt
- Completely Weathered Rock
- Fractured Basalt
- Greyish Basalt
- Volcanic Tuff

ABBRV

DS	: DISTURBED SAMPLE
WS	: WASH SAMPLE
WO	: DISTURBED SAMPLE
UDS	: UNDISTURBED SAMPLE
C.P	: CORE PIECES
SP	: SMALL PIECES
SPT	: STANDARD PENETRATION TEST
VST	: VANE SHEAR TEST

SCALE:- V 1:100
H N.T.S
DATE:- 29-12-2017
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Civil Globe Consultants
Email:- info@civilglobe.in
mahesh.han@gmail.com
Contact-09561420336

Appendix- II

BH Location Plan

BOREHOLE LOCATION PLAN

Appendix- III

Laboratory Test Results

Project: CProject: Construction of River Bridge across Senapati Bapat marg to Western express highway Bandra, Mumbai

Summary of Rock test Results

Sr. No.	BH NO.	Depth (m)	PC. NO.	Specific Gravity	Water Absorption	Porosity	Unconfined Comp. Strength	Corrected Unconfined Comp. Strength	Remark
					%	%	(T/m^2)	(T/m^2)	
1	3	7.0-8.0	7	2.29	6.14	14.05	458.68	459.68	
2		8.0-9.0	17	2.14	6.27	13.43	421.55	422.45	
3		10.0-11.0	24	2.15	7.75	16.67	872.83	874.74	
4		13.0-14.0	35	2.19	8.70	19.05	944.41	946.43	
5		14.0-15.0	38	2.24	5.63	12.60	1167.63	1175.05	
6		17.0-18.0	46	2.06	7.01	14.42	971.69	973.82	
7		21.0-21.5	58	2.13	2.01	4.29	910.70	916.59	
8	4	8.0-9.0	2	2.00	5.30	10.61	529.93	471.25	
9		9.0-10.0	5	1.97	6.11	12.03	325.08	326.14	
10		12.0-13.0	21	1.79	9.20	16.48	587.82	549.07	
11		13.0-14.0	26	2.12	8.33	17.65	1038.85	1041.08	
12		14.0-15.0	31	2.10	6.95	14.61	1171.20	1114.87	
13		17.0-17.5	41	2.04	7.58	15.44	1340.42	1344.78	
14	2	9.0-10.0	21	1.87	7.41	13.85	272.16	260.44	
15		10.0-11.0	27	1.94	9.03	17.55	536.17	537.91	
16		11.0-12.0	34	1.90	9.06	17.21	136.71	137.16	
17		12.0-13.0	43	2.00	7.24	14.48	431.42	431.42	
18		15.0-16.0	68	1.93	7.29	14.09	731.91	731.91	
19		17.0-18.0	84	2.03	7.35	14.93	1068.77	1072.25	
20		18.0-19.0	88	2.05	6.71	13.73	1650.36	1655.73	
21		19.0-20.0	94	2.02	11.48	23.18	1377.12	1378.61	
22	6	15.0-16.0	33	1.92	9.75	18.75	894.21	897.12	
23		16.0-17.0	45	2.05	8.71	17.83	982.82	986.02	
24		20.0-21.0	61	2.07	9.49	19.67	1205.49	1208.12	
25		22.0-23.0	74	1.90	11.63	22.06	1517.21	1522.15	
26		23.0-24.0	77	1.97	9.23	18.18	848.78	851.54	

Project: Construction of River Bridge across Senapati Bapat marg to Western express highway Bandra, Mumbai

Summary of Soil test Results

Sr No	BH No	Sample type	Depth of sample	Moisture content	Differential free swell	Gravel	Sand	Silt & Clay	Liquid Limit	Plastic Limit	Plasticity Index
			M	%	%	%	%	%	%	%	%
1	BH-02	SPT	3-3.6	37.97	100.00	0.00	3.60	96.40	82.11	52.99	29.12
2	BH-02	SPT	4.5-5.1	47.17	80.00	0.00	9.78	90.22	77.71	50.15	27.56
3	BH-02	SPT	6.0-6.6	43.49	50.00	0.00	44.02	55.98	64.32	43.33	20.99
5	BH-03	SPT	1.5-2.1	31.74	80.00	0.00	29.80	70.40	72.11	43.00	29.11
6	BH-03	SPT	3.0-3.6	36.42	70.00	0.00	32.24	67.76	69.94	43.23	26.71

Appendix- IV

Photographs

BH 02 Corebox I

BH 02 Corebox II

BH 03 Corebox I

BH 03 Corebox II

BH 04 Corebox I

BH 06 Corebox I

BH 06 Corebox II

BH 06 Corebox III