GEOTECHNICAL INVESTIGATION REPORT
FOR
DFCCIL PROJECT: NEW KARWANDI TO GANJKHWAJA OF MEGHALSARAI SECTION OF INDIAN RAILWAY

RAIL OVER RAIL BRIDGE

STATE OF BIHAR & UTTAR PRADESH

SUBMITTED TO:

aarvee associates

M/s AARVEE ASSOCIATES
NEW DELHI

NOVEMBER, 2012

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ANNEXURE – I

Following details are attached.....

- Borehole Location Plan
- Consolidated Logs including laboratory test results
- Standard penetration Test Curves
- Liquefaction assessment sheets
- Grain size analysis curves
- Sample Pile capacity calculations.

1.0 INTRODUCTION

The client, **Dedicated freight corridor corporation ltd. (DFCCIL)**, has undertaken the "**Design and Construction of Dedicated Freight Corridor from New Karwandia to Ganjkhwaja on Mughalsarai – Sonenagar Section of Eastern Corridor in the state of Bihar & UP in India**".

DFCCIL Propose to cross the Indian railway tracks through a Rail flyover which is a part of the DFC Eastern Corridor.

The Client appointed, **M/s Aarvee Associates Architects Engineers & consultant Pvt. Ltd.**, as "**Design Consultant**" for the work for preparation of the scheme of arrangement of crossing of the DFC corridor from the North side of the existing railway line to the South side before the approaching the Ghanjkhwja Yard.

The objective of this Detailed Geo-technical Investigation is to interpret the engineering properties of the sub-surface stratum for the purpose of design of the structures. M/s Aarvee Associates Architects Engineers & consultant Pvt. Ltd. have entrusted the work of Geotechnical Investigation to ***M/s INDIAN GEOTECHNICAL SERVICES, Delhi.*** M/s Indian Geo-technical Services carried out the investigations, field tests, sampling and laboratory testing under the instructions of Contractor and Consultant.

Fieldwork including Drilling of bore holes and sample collection was carried out, during October, 2012. Laboratory tests were conducted on selected soil samples to determine the design parameters, confirming to relevant IS specifications and the guidelines received from time to time from Consultant and Client.

This report includes the details of Methodology of Investigation, collection of samples, field test results, and laboratory test results including their interpretation / analysis, recommendations for the properties essential to the design of foundations and recommendations about foundations.

1.1 Scope of This Report

This report contains the following information;

- Introduction
- Planning of geotechnical Investigation programme including scope of work
- Geological Information of the Region
- Methodology of Investigation
- Subsurface Conditions / Geotechnical Assessment
- Foundation support

2.0 PLANNING OF GEOTECHNICAL INVESTIGATION PROGRAMME

On the basis of nature of the project, it was decided to carry out soil exploration in order to:

(i) obtain soil samples, both representative and undisturbed (wherever necessary and possible) for classification tests and other laboratory tests for determining engineering properties;

(ii) obtain soundings of penetration resistance by Standard Penetration test in the boreholes;

(iii) collection of water samples to determine the chemical properties of sub-surface water.

2.1 Scope of Work

To investigate the subsurface conditions bore holes were carried out. Field in-situ tests, like Standard Penetration Test were conducted in the boreholes. Disturbed / undisturbed soil samples and water sample were collected.

Vicinity map, Test Location Plan of borehole locations have been enclosed as **ANNEXURE – I.**

2.1.1 The summary of the fieldwork is given below:

Borehole Details

Works	Borehole No	Borehole Top Elevation	Depth of Borehole
(Description)	(CODE)	(m)	(m)
RAIL OVER RAIL BRIDGE (ROR)	BH-1	75.000	30.00
	BH-2	76.000	30.00
	BH-3	75.500	30.00
	BH-4	77.000	30.00

All locations of boreholes / Ground Elevation were given by M/s JMC.

2.1.2 Conducting Standard Penetration Tests during boring operation.

2.1.3 Collecting disturbed samples / undisturbed soil samples and water sample from the borehole.

2.1.4 Summary of Laboratory Testing program is given below; Laboratory testing was planned on selected disturbed / un-disturbed soil samples / water sample.

Sl. No.	Particulars of Properties	Ref: IS Code	Disturbed Soil Sample	Undisturbed Soil Samples	Water Sample
1.	Sieve Analysis / Hydrometer	IS: 2720 (Part IV)	√	√	
2.	Natural Moisture Content / Bulk / Dry Density	IS: 2720 (Part II)		√	
3.	Specific Gravity	IS: 2720 (Part III)	√	√	
4.	Liquid Limit/Plastic Limit/ Plasticity Index	IS: 2720 (Part V)	√	√	

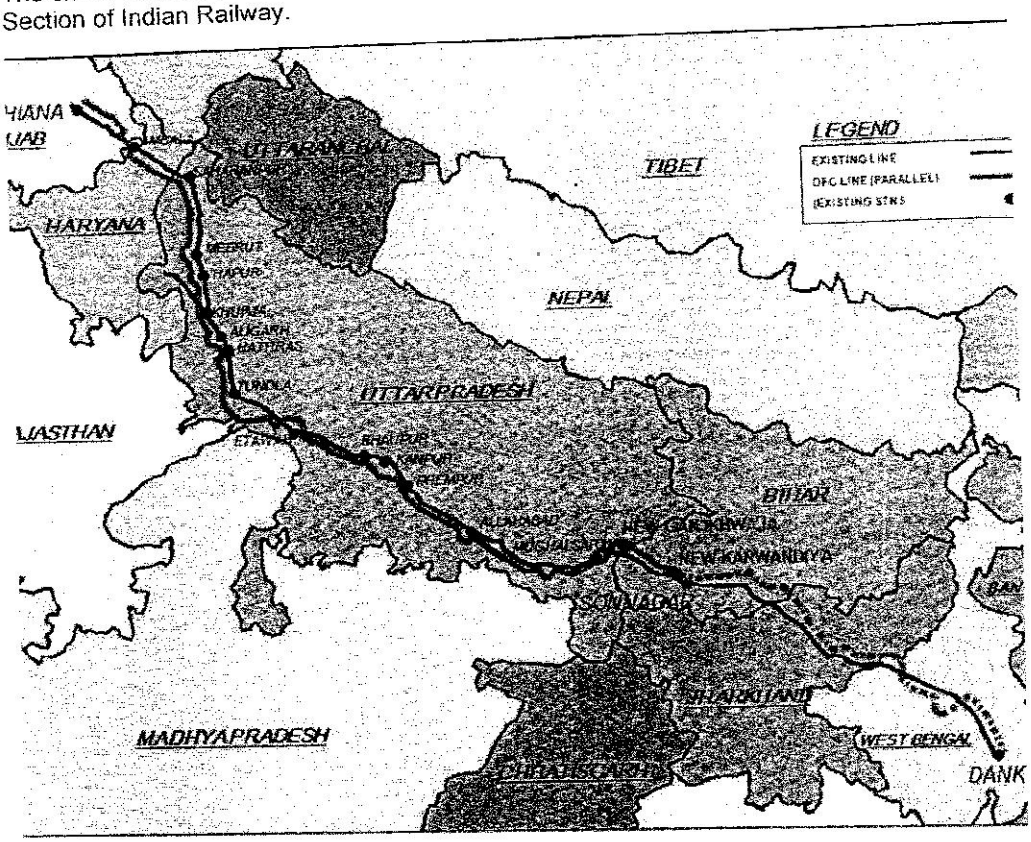
Sl. No.	Particulars of Properties	Ref: IS Code	Disturbed Soil Sample	Undisturbed Soil Samples	Water Sample
5.	Shrinkage Limit	IS: 2720 (Part VI)	√		
6.	Direct Shear Test (for non-cohesive soils)	IS: 2720 (Part XIII)	√	√	
7.	Unconfined Compressive Strength Test	IS: 2720 (Part X)		√	
8.	Unconsolidated Un-drained Tri-axial Test	IS: 2720 (Part XI)		√	
9.	Consolidated Un-drained / Consolidated Drained Tests (for cohesive samples)	IS: 2720 (Part XII)		√	
10.	Free Swell / Swell Pressure (if swelling is critical)	IS: 2720 (Part XL & XLI)	√	√	
11.	Consolidation Tests (Cohesive soils below water table)	IS: 2720 (Part XV)		√	
12.	Chemical Analysis on Soil Samples	IS: 2720 (Part XXVI & XXVII),	√	√	
13.	Chemical Analysis on water samples collected from boreholes	IS: 3025 (Part 11, 24 & 32)			√

All field work, field tests, collection of samples and laboratory Tests were carried out as per relevant IS / Indian Railways specifications.

3.0 GEOLOGICAL INFORMATION OF THE REGION

3.1 Location

The site is referred to as DFCCIL Project – New Karwandia to Ganjkhwaja of Mughalsarai Section of Indian Railway.



3.2 Climate

The **climate of Project Site** is warm subtropical climate with cool, dry winters from December to February and dry, hot summers from April to June. The rainy season is from mid-June to mid-September, gets an average rainfall of 900 - 1000 millimetres from the south-west monsoon winds, and occasionally frontal rainfall in January. In winter the maximum temperature is around 25 °C (77 °F) and the minimum is in the 2 to 3 degrees Celsius range. Fog is quite common from late December to late January. Summers are extremely hot with temperatures rising to the 40 to 45 degree Celsius range, the average highs being in the high 30s.

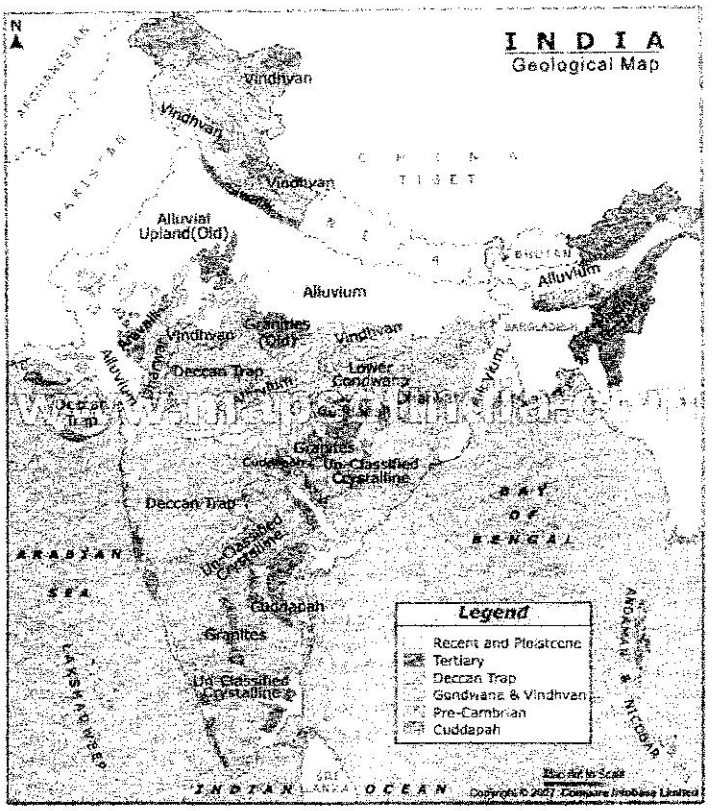
3.3 Topograhy, Geography and General geology

The project site is part of Indo-Gangetic Plain. It is the world's most extensive tract of uninterrupted alluvium. These deep, river-deposited sediments give rise to fertile soils.

Thus Indo-Gangetic plain's soil is the backbone of agricultural and industrial development in Bihar and Uttar Pradesh. The Indo-Gangetic plain in Bihar and Uttar Pradesh consists of a thick alluvial mantle of drift origin overlying in most part. The siwalik and older tertiary rocks. The soil is mainly young loam rejuvenated every year by constant deposition of silt, clay and sand brought by different streams but mainly by floods in Bihar and Uttar Pradesh.

The most common soil in Bihar and Uttar Pradesh is Gangetic alluvium of Indo-Gangetic plain region, Piedmont Swamp Soil which is found in northwestern part of West Champaran district and Terai Soil which is found in northern part of Bihar along the border of Nepal. Clay soil, sand soil and loamy soil are common in Bihar and Uttar Pradesh.

Topographically the plain is homogeneous, with only the floodplain bluffs, changes in river channels and other related features of river erosion forming natural features.



Sediments of the Indo-Gangetic Plain are part of the foredeep of the Himalaya. The Cenozoic succession in these deposits begins with the Eocene – Oligocene 'Nummulitic' Dagshal and Kasauli formations and their equivalents.

3.4 Seismicity

The state of Bihar and Uttar Pradesh lies in the Gangetic Plain. This is a fore-deep, a downwarp of the Himalayan foreland, of variable depth, converted into flat plains by long-vigorous sedimentation. This is known as a geosyncline and the Gangetic Plain is the Indo-Gangetic Geosyncline. The floor of the Gangetic trough (if see without all the sediments) is not an even plain, but shows corrugated inequalities and buried ridges (shelf faults). Western Bihar sits on the sub-surface Faizabad ridge while the eastern sections sit on the Munger-Saharsa Ridge. The central sections of Bihar lie atop the Gandak depression and East Uttar Pradesh shelf.

As per IS: 1893 (Part-1) 2002, the site falls in seismic zone – III. Considering the history of past earthquakes and available seismic data, an earthquake of magnitude 7.0 is considered in the present analysis.

Liquefaction

Liquefaction is the sudden loss of shear strength of the loose fine-grained sands due to earthquake-induced vibration under saturated conditions.

Assessment of liquefaction potential of foundation strata is made by simplified approach proposed by Seed & Idriss (1983 – 1985) from the SPT data and peak ground acceleration likely to occur at the site. In this method, cyclic shear stress likely to be induced in the foundation strata by Design Basis Earthquake (DBE) is first evaluated. Next threshold cyclic shear stress, which is good enough to cause liquefaction is determined from SPT data and the empirical relations. Finally, comparison of these two stresses is used in the estimation of liquefaction susceptibility of the foundation strata.

Cyclic Stress Ratio (CSR)

The equivalent average of shear stress τ_{av} likely to be induced in the foundation material due to an earthquake is calculated by using the equation

$\tau_{av} = 0.65 * \gamma * h * (a_{max} / g) * r_d$

τ_{av} = equivalent average of shear stress likely to be induced by DBE

γ = Unit weight of foundation material

= depth at which cyclic shear stress is calculated

a_{max} = maximum surface acceleration

r_d = Stress reduction factor

= $1.0 - 0.00765 * h$ if $h < 9.15$ m

= $1.174 - 0.0267 * h$ if $h = 9.15$ m to 23 m

= $0.744 - 0.008 * h$ if $h = 23.0$ m to 30.0 m

= 0.50 if $h > 30.0$ m

If the equivalent average of shear stress τ_{av} is normalized with the initial effective overburden pressure (σ_o), the term is called seismic demand of soil layer or cyclic stress ratio (CSR).

$CSR = 0.65 * (\sigma_o / \sigma_o') * (a_{max} / g) * r_d$

Cyclic Resistance Ratio (CRR)

It expresses capacity of soil to resist liquefaction. CRR is determined using correlation between corrected blow count $(N_1)_{60}$ and CRR for earthquake of magnitude 7.5. $(N_1)_{60}$ is

the SPT blow count corrected to an effective overburden pressure of 100 kpa and to hammer energy efficiency of 60 %. The corrected blow count $(N_1)_{60}$ is determined as follows.

$(N_1)_{60} = N_m C_N C_E C_B C_R C_S$

Where,

N_m = uncorrected SPT blow clount

C_E = correction factor for hammer energy ratio

C_B = Correction factor for borehole dia = 1.05 for 150 mm dia borehole

C_R = Correction factor for rod length = 0.75 for 3.0 m to 4.0 m
= 0.85 for 4.0 m to 6.0 m
= 0.95 for 6.0 m to 10.0 m
= 1.0 for 10.0 m to 30.0 m

C_S = correction factor for standard sampler = 1.0

Correction factor for effective overburden pressure (C_N) is given by the following relation.

$C_N = \text{Sqrt}(P_a / \sigma_o')$

Where P_a = Atmospheric pressure

The value of SPT blow count for soil with fines content (FC) can be adjusted to the equivalent clean sand value of $(N_1)_{60CS}$ as follows:

$(N_1)_{60CS} \quad \alpha + \beta (N_1)_{60}$

where α and β can be determined as follows.

$\alpha = 0.0$ and $\beta = 0.0$ for FC <= 5.0 %

$\alpha = \exp[(1.76 - (190/FC^2)]$ for 5.0 % < FC < 35.0 %

$\beta = [0.99 + (FC^{1.5}/1000)]$

$\alpha = 5.0$ and $\beta = 1.20$ for FC >= 35.0 %

$CRR_{M=7.5}$ is given by the following equation.

$$CRR_{M=7.5} = \frac{1}{34 - (N_1)_{60CS}} + \frac{(N_1)_{60CS}}{135} + \frac{50}{[10*(N_1)_{60CS} + 45]^2} - \frac{1}{200}$$

Hence the CRR for a particular earthquake magnitude is determined as

$CRR = CRR_{M=7.5} * MSF * K_\sigma$

The MSF value is 1.44 for earthquake of magnitude 6.5. K_σ is taken as 1.

The factor of safety against liquefaction, FS_L, is given as

$FS_L = CRR/CSR$

The value of CSR and CRR are computed at different depth and depth susceptible to liquefaction is determined. Liquefaction is probable when FS_L is less than 1.0.

Andrews and Martin (2000) have re-evaluated the liquefaction field case histories from the database of Seed et al. (1984, 1985), and have transposed the "Modified Chinese

Criteria" to U.S. conventions (with clay sizes defined as those less than about 0.002mm). Their findings are largely summarized in table below:

	Liquid Limit[1]<32	Liquid Limit > 32
Clay content[2] <10%	Susceptible	Further studies required
Clay content[2] > 10%	Further studies required	Not susceptible

Note: 1. Liquid Limit determined by Casagrande type percussion apparatus.
2. Clay defined as grains finer than 0. 002mm.

4.0 METHODOLOGY OF INVESTIGATION

The investigation was planned to obtain the subsurface stratification in the proposed project site and collect soil samples for laboratory testing to determine the engineering properties such as shear strength, along with basic engineering classification of the subsurface stratum to arrive at the foundation design parameters.

4.1 Boreholes

The Boreholes in soil were progressed by shell & auger boring method as per IS: 1892 – 1979 and approved methodology. Boring was advanced at selected / specified borehole locations. The following steps were adopted during boring operations;

1) Boring rig with power winch was assembled at site and was shifted and erected at the borehole location.
2) Taking out the top soil up to approximately 500 mm.
3) The auger was joined at the end of hollow drill rod, which is rotated manually.
4) After reaching the drill rods attached with the auger attained its full depth another piece (extension rod) was attached and continued the drilling up to the level of water table.
5) Below the water table shell was used instead of auger, casing pipe was lowered as per requirement.
6) Casing was used as per the prevailing soil conditions, to stabilize the borehole.
7) Required field tests i. e, Standard Penetration Tests and collection of undisturbed / disturbed samples was conducted as per requirements at specified depths / levels, the same has been discussed in detail in this document.
8) This process was continued till the achievement of full depth of bore hole as per requirement.

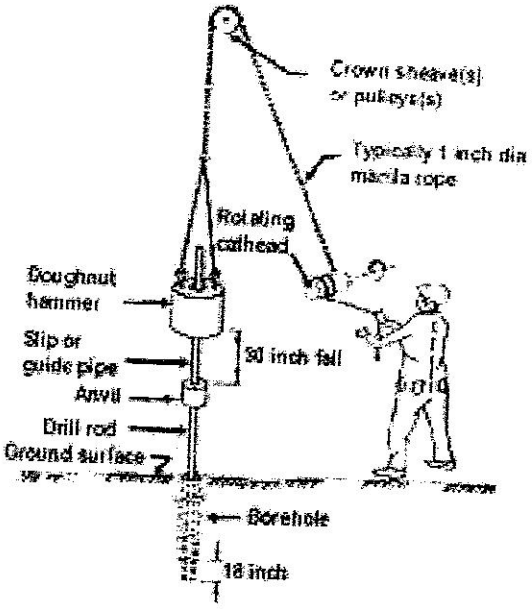
4.2 Standard Penetration Tests (SPT)

Standard Penetration Tests were conducted at 1.5 m interval as per the procedure in IS: 2131 – 1981.

For conducting the test, the bottom of the borehole was properly cleaned and split spoon sampler was properly seated in position in the borehole. The split spoon sampler resting on the bottom of borehole was allowed to sink under its own weight; then the sampler was seated 15 cm with the blows of the hammer of 63.5 Kg weight falling through 75 cm. Thereafter, the split spoon sampler was further driven by 30 cm. The number of blows required to affect each 15 cm of penetration was recorded. The first 15 cm of drive is considered to be seating drive.

The total blows of penetration for the second and third 15 cm of penetration is termed the penetration resistance N. The 'N' values are indicative of the compactness / relative density of cohesion less soils and consistency of cohesive soils.

In case the blow count of SPT in soil (including the number of blows for seating) exceeds 100, the corresponding penetration was recorded and this particular test at that depth stopped. If the total penetration is more than the seating penetration of 15 cm, then breakup of blow count for 15 cm seating penetration and for remaining portion of penetration is also be given.



SPT 'N' values are correlated with relative density of non-cohesive stratum as per BS: 5930 (1999) - for sandy Strata and with consistency of cohesive stratum.

CORRELATION FOR CLAY/PLASTIC SILT		CORRELATION FOR SAND/NON-PLASTIC SILT	
Consistency	Penetration Value	Relative Density	Penetration Value
Very Soft	0 to 2 Blows	Very loose	0 to 4 Blows
Soft	3 to 4 Blows	Loose	5 to 10 Blows
Medium Stiff	5 to 8 Blows	Medium	11 to 30 Blows
Stiff	9 to 16 Blows	Dense	31 to 50 Blows
Very Stiff	17 to 32 Blows	Very Dense	Above 50
Hard	Above 32		

4.3 Disturbed Sampling (Soil) in boreholes

In all boreholes, disturbed soil samples was taken at every 1.5 m interval and at significant change of stratum (or as per specified). Soil from cutting edge of undisturbed samplers and from split spoon sampler used for standard penetration tests was taken as disturbed samples. These samples were placed without delay in adequately sealed polythene bags.

Disturbed Soil Sample from SPT

4.4 Undisturbed Sampling (Soil) in Boreholes

Undisturbed sampling was done in accordance with IS: 2132 – 1986. Undisturbed soil samples (UDS) was obtained at every 3.0 m interval as per approved methodology and sampling schedule.

Undisturbed samples were collected using 100mm dia. and 450mm long MS tubes provided with sampler head with ball check arrangement. Collection of undisturbed samples in very hard cohesive soils / dense granular soils / gravels / cobbles / pebbles / boulders, refusal strata is practically not possible and such collected samples will not truly represent the undisturbed conditions.

Immediately after taking an undisturbed sample in a tube, the adopter head was removed along with the disturbed material. The visible ends of the sample shall each be trimmed off any wet disturbed soil. The ends will then be coated alternately with four layers of just molten wax. More molten wax will then be added to give a total thickness of not less than 25mm.

4.5 Ground Water Table

The depth at which groundwater is struck during boring was carefully noted and the depth of water table was ascertained subsequently in the completed borehole by one of the following methods using electrical dip meter:

The water table in the borehole was allowed to stabilize after depressing the water level adequately by bailing. Stability of the borehole sides and bottom was be ensured at all times.

The borehole was filled with water and then bailed out to various depths. Observations were made at each depth to see if the water level is rising or falling. The depth at which neither a fall nor rise is observed, was considered as the water table depth. This was established by three successive readings of water levels taken at intervals of 2 hour in non-cohesive soils and for 24 hrs in cohesive soils.

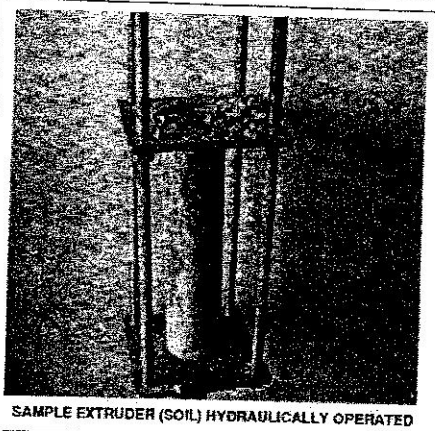
4.6 Laboratory testing

Laboratory tests were carried out as directed by client, consultant in accordance with the procedures described in the relevant Indian Standard Codes (IS: 2720) of practiced.

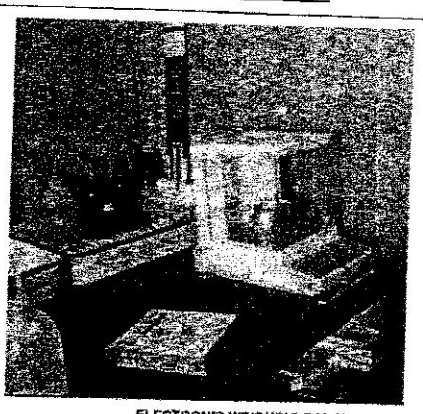
The laboratory testing was done on collected material as per relevant IS codes. The laboratory-testing program consisted of testing the soil index and strength properties, as well as the consolidation characteristics. The index tests were performed to determine the soil moisture content, unit weight, specific gravity, gradation characteristics (gravel, sand and fines content – the silt & clay fractions) and consistency limit. The strength tests were performed to determine the shear parameters (cohesion, friction angle) of soil; the consolidation tests were performed to find out the consolidation properties. The index tests were performed on disturbed split-spoon soil samples or undisturbed samples, except the natural moisture content and dry density tests, which were performed only on

the undisturbed soil samples. The strength tests consisted of the direct shear box and the tri-axial unconsolidated -undrained (UU) test, CU and CD tests. The consolidation characteristics tests were preformed on a one-dimensional consolidometer. The strength and consolidation tests were performed on undisturbed soil samples.

FEW PICTURES SHOWING LABORATORY TESTING IN PROGRESS

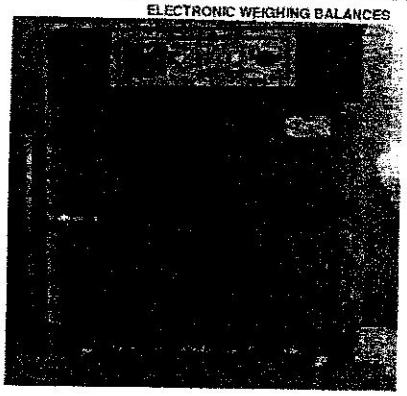


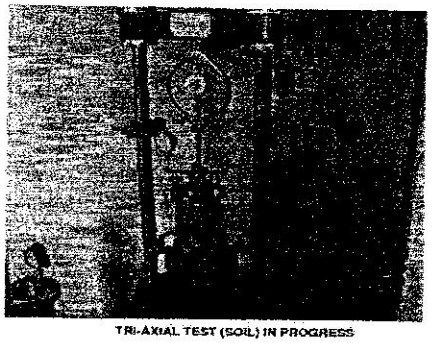
SAMPLE EXTRUDER (SOIL) HYDRAULICALLY OPERATED



ELECTRONIC WEIGHING BALANCES

ATTERBERG'S LIMITTEST (SOIL) IN PROGRESS





TRI-AXIAL TEST (SOIL) IN PROGRESS

SIEVE ANALYSIS IN PROGRESS

4.7 Chemical Analysis

During investigation, soil / ground water samples were collected for chemical analysis to determine their pH and contents of sulphates and chlorides in them. Any precautions for protecting concrete and reinforcement could be decided based on this data.

Sr No	Class	Concentration of Sulphates Expressed as SO_3		
		Soil		Ground Water
		Total SO_3 Percent	SO_3 * g/L	In g/L
I	1	Less Than 0.20	Less Than 1.0	Less Than 0.30
II	2	0.20 to 0.50	1.0 to 1.90	0.30 to 1.20
III	3	0.50 to 1.00	1.90 to 3.10	1.20 to 2.50
IV	4	1.00 to 2.00	3.10 to 5.00	2.50 to 5.00
V	5	More Than 2.00	More Than 5.00	More Than 5.00

* In 2:1 water: soil extract

5.0

SUBSURFACE CONDITIONS / PROPOSED DESIGN PARAMETERS

5.1 Subsurface Conditions

Based on the boring information, the generalized subsurface conditions at the site are as follows.

Stratum 1 **Sandy Silty Gravel (GM)**

Stratum 2 **Clayey Silt / Clayey Silt / Silty Clay of low to medium plasticity (CL/CI)**

Structure	Borehole No.	Stratum – I	Stratum - 2
		Stratum depth (from (m) – to (m))	
RAIL OVER RAIL BRIDGE (ROR)	BH – 1	--	0.00 – 30.00
	BH – 2	--	0.00 – 30.00
	BH – 3	0.00 – 1.00	1.00 – 30.00
	BH – 4	--	0.00 – 30.00

5.2 Standard Penetration Test Resistance (Field SPT values)

Borehole Depth (m)	BH-1	BH-2	BH-3	BH-4
1.50	8	10	14	13
3.00	11	12	16	21
4.50	15	14	20	31
6.00	23	15	20	37
7.50	28	18	24	42
9.00	33	20	29	45
10.50	35	24	31	52
12.00	43	33	40	60
13.50	46	40	50	66
15.00	52	46	52	69
16.50	56	53	56	74
18.00	62	59	50	80
19.50	67	64	64	57
21.00	74	71	68	60
22.50	77	66	71	68
24.00	82	74	73	60
25.50	85	77	77	76
27.00	89	85	78	76
28.50	81	75	80	80
30.00	91	84	82	81

5.3 Penetration Resistance and Proposed Design Parameters (Soil)

In design calculations, the following soil parameters are proposed:

DEPTH (m)	SOIL TYPE	DESIGN 'N' VALUE	DESIGN PARAMETERS			
			$\Upsilon_{bulk\ /\ Sat}$ (T/m^3)	$\Upsilon_{submerged}$ (T/m^3)	Cu, T/m^2	$\phi°$
Location – BH – 1 at Chainage Km 113+300						
0.00 – 2.00	CL	8	1.70	0.80	--	--
2.00 – 5.00	CI	13	1.90	0.90	7.0	0
5.00 – 8.00	CI	25	1.95	0.95	8.5	0
8.00 – 15.00	CI	35	2.00	1.00	13.5	0
15.00 – 20.00	CI	50	2.00	1.00	20.0	0
20.00 – 30.00	CI	>60	2.00	1.00	22.5	0
Location – BH – 2 at Chainage Km 114+150						
0.00 – 2.00	CL	10	1.70	0.80	--	--
2.00 – 5.00	CI	13	1.95	0.95	5.8	0
5.00 – 8.00	CI	16	1.96	0.96	7.6	0
8.00 – 12.00	CI	22	2.00	1.00	9.5	0
12.00 – 15.00	CI	35	2.00	1.00	14.0	0
15.00 – 21.00	CI	50	2.00	1.00	20.0	0
21.00 – 30.00	CI	>60	2.00	1.00	22.5	0
Location – BH – 3 at Chainage Km 114+250						
0.00 – 1.00	GM	--	1.80	0.80	--	--
1.00 – 4.00	CI	15	1.95	0.95	7.0	0
4.00 – 8.00	CI	21	2.00	1.00	9.8	0
8.00 – 12.00	CI	30	2.00	1.00	12.0	0
12.00 – 15.00	CI	40	2.00	1.00	16.0	0
15.00 – 22.00	CI	50	2.00	1.00	20.0	0
22.00 – 30.00	CI	>60	2.00	1.00	22.5	0
Location – BH – 4 at Chainage Km 114+800						
0.00 – 2.00	CL	13	1.90	0.90	--	--
2.00 – 5.00	CI	20	1.97	0.97	8.2	0
5.00 – 7.50	CI	30	2.00	1.00	10.5	0
7.50 – 10.00	CI	40	2.00	1.00	14.0	0
10.00 – 16.00	CI	50	2.00	1.00	20.0	0
16.00 – 30.00	CI	>60	2.00	1.00	22.5	0

Water table was encountered between 1.50m to 1.65m depth below the existing ground level. The ground water table is expected to fluctuate depending upon the climatic factor, drainage conditions and other factors. Water table is considered at ground level for all design purposes.

5.4 Assessment of Liquefaction

Considerations for checking Liquefaction:

Probability of liquefaction has been checked at every borehole location.

Water table Depth	=	at ground Level
Seismic Zone	=	III
Zone Factor	=	0.16
Maximum earthquake magnitude	=	7.0

Subsurface strata below ground level susceptible to liquefaction in earthquake event are tabulated (Filled-up soils are considered as liquefiable);

Location	Down to Depth Below Ground level (m)
BH – 1	Non Susceptible
BH – 2	Non Susceptible
BH – 3	Non Susceptible
BH – 4	Non Susceptible

5.5 Chemical Analysis Test Results

Soil samples and groundwater samples collected from boreholes were analyzed chemically in the laboratory. Following results are reported.

BH NO.	SOIL SAMPLE			WATER SAMPLE			Class
	pH	Chloride	Sulphate	pH	Chloride	Sulphate	
		%	%		mg/l	mg/l	
BH-1-4	6.0 - 7.0	0.02 – 0.22	0.09 – 0.10	7.3	159.94	289.28	1

Results of chemical analysis indicate that the sub-soils and water fall in class-1 classification that means the soil / ground water is not aggressive to concrete and not corrosive to reinforcement steel. Hence, ordinary Portland cement with specified minimum cement content and maximum w/c ratio can be used with clear cover to reinforcement for the concrete as per IS: 456. We also suggest checking the sulphate contents in water sample from nearby tube-well / well at time of construction.

Concrete expert may be referred for advice.

6.0 FOUNDATION SUPPORT

Considering the nature of soil, type of proposed structures, expected heavy loads on foundations of DFCC Corridor, sub-surface strata may undergo excessive settlement due to presence of consolidating clayey layer met down to the final explored depth of 30m. So, open foundation is not a feasible foundation scheme, hence pile foundation is recommended.

6.1 Pile Foundation

We propose the use of RCC bored cast-in-situ piles as foundation system to support the heavy loads on foundations of dedicated freight corridor. Based on soil design parameters and calculations attached in Annexure - I, recommendations are presented below for 1000 mm and 1200 mm diameter bored piles. The cut-off level has been considered as 2.0 m and 2.3m depth below the existing ground level.

Design Consideration:

Sl. No.	Parameter	Value
1.	K (Coefficient of earth pressure)	1.00
2.	Overburden pressure to calculate the shaft resistance and end bearing resistance of pile	Maximum overburden pressure at bottom of pile for calculation of shaft resistance and bearing resistance is limited to overburden pressure at depth equal to 15 times diameter of pile considered from existing ground level.
3.	Depth of water table	Ground water is considered at ground level.
4.	Maximum deflection at Pile cutoff level or at bottom of free length for calculating the lateral load capacity of pile in Normal Condition	5mm at pile cutoff level
5.	Vertical Capacity in Seismic Condition	While calculating the pile load capacity in seismic condition, over burden pressure / friction due to liquefiable strata have been ignored
6.	Other parameters	As per IS:2911 (part1/Sec2) or as per Latest version of IRC: 78

Recommendations: For the purpose of pile capacity analysis, boreholes have been grouped and accordingly Pile capacities are tabulated below:

BOREHOLE NO.	DIAMETER OF PILE (mm)	LENGTH OF PILE BELOW CUTOFF LEVEL (m)	RECOMMENDED SAFE VERTICAL LOAD CAPACITY (Tonnes)		RECOMMENDED SAFE UPLIFT LOAD CAPACITY (Tonnes)		RECOMMENDED SAFE HORIZONTAL LOAD CAPACITY (Tonnes)	RECOMMENDED DEPTH OF FIXITY BELOW CUTOFF LEVEL (m)	
			Normal Condition	**Seismic Condition	Normal Condition	**Seismic Condition	Normal Condition	Normal Condition	Seismic Condition
BH – 1, 2 & 3	1200	24.00	260	260	140	140	20	9.63	9.63
		26.00	280	280	155	155			
		28.00	300	300	170	170			
	1000	24.00	205	205	117	117	15	8.16	8.16
		26.00	220	220	130	130			
		28.00	235	235	140	140			
BH – 4	1200	24.00	280	280	155	155	24	9.20	9.20
		26.00	300	300	170	170			
		28.00	315	315	181	185			
	1000	24.00	220	220	125	125	20	7.70	7.70
		26.00	235	235	140	140			
		28.00	250	250	150	150			

*** - We have not taken into account any enhancement in pile capacities, which is allowed as per codes in seismic condition. The same may be considered as per relevant codes.*

The above pile capacities are based on the static analysis and include a safety factor of 2.5. These capacities may be used as a guide line for design. Final capacities should be confirmed on site by initial pile load test as per IS specification.

for INDIAN GEOTECHNICAL SERVICES

AJAY KUMAR GARG
Geotechnical Consultant / Partner

ANNEXURE – I

Following details are attached.....

- Borehole Location Plan
- Consolidated Logs including laboratory test results
- Standard penetration Test Curves
- Liquefaction assessment sheets
- Grain size analysis curves
- Sample Pile capacity calculations.