

Ggeotechnical Investigations and Designs of Horizontal LPG Tanks Foundations at an Oil and Gas Depot in the Marginal Lands of Niger Delta Sub-Region of Nigeria

Teme, S.C., Morrison, T.; Nwankwoala H.
Department of Geology, Rivers State University
Port Harcourt

Abstract

Due to the need to found a large horizontal Liquefied Petroleum Gas (LPG) Tank, a detailed geotechnical investigation was carried out to determine the geological nature of the subsoils at the site. The location is within the marginal lands of the Nigerian Niger Delta subregion. This was with a view to determining soil properties and conditions of subsoils regarding (i) the bearing capacity of the subsoil (ii) the foundation types and rates of settlements that are appropriate for the proposed project site. The field investigations included a detailed surface geological mapping, hydrological assessment and subsurface geotechnical investigation involving detailed SPT drill tests at X3 Nos points down to the depth of 30.00m. The geotechnical investigations reveal the following subsurface lithology: (1) Engineered Fill (SP), (2) Reddish-Brown Stiff Silty Clay layer (CL), (3) Reddish-Brown Clayey Sand Clay layer (SC), (4) Reddish Brown Silty-Clay Layer (CL), (5) Reddish-Grey Sands-Silts Layer (SM) and (6) Milky- Light Grey, Poorly Graded Sand layer (SP). The geotechnical characteristics of the subsurface materials include (a) Soil friction angles of $(\phi) = 8-34^{\circ}$, cohesion (c) of 0.00 - 45 kPa, Bearing capacity values of between 141.64 and 221.89 kPa. Settlement values ranged from 0.60 to 1.163 which is within limits. This paper presents the details of the study and the results.

Key Words: Engineering Geology & Geotechnics; Horizontal Tank Foundations Designs; Geotechnical Properties; Foundations Bearing Capacities, Settlement of Foundation.

I. INTRODUCTION

Site investigation is fundamental requirement for designing and constructing foundations for sustainable structure. It involves obtaining information about subsurface conditions at the site of proposed construction (Arora, 2004). It is the essential step for having a productive, efficient and safe construction environment (Abija *et al*, 2020). Geotechnical site investigation, defined as the study of the physical properties of soil and rock, to evaluate and identify potential foundation problem, enables the assessing of the suitability of the soil material to bear the imposed load. It provides vital data for informed site development decision-making and planning. However, most times this important aspect of development planning is often neglected (Akhter, 2021).

The sustainability of any civil construction project largely depends on the adequate knowledge of the surface soil conditions, and designing and constructing such structure in line with the prevailing soil conditions. Insufficient knowledge of the subsoil geotechnical conditions of the leads to inappropriate designs, environmental damage to the site and other related issues (Teme, 2022; Abam, 2023); Morrison & Esonanor, 2023).

It is in line with the above observation that an investigation of the subsoil condition at the proposed building site for Horizontal LPG Tank at Department site was carried out with a view to determining:

- a) To Determine The Subsoil Conditions At The Site To Depth Commensurate Foundation Types Such As Heavy Weight (>20 – 50 Tons) Horizontal LPG Tanks.
- b) To Evaluate By The Performance Of Laboratory And Field Testing, The Physical Properties And Strength Characteristics Of The Subsoils That Will Influence Both The Choice Of Foundation And Design Consideration.
- c) To Determine And Recommend The Foundation Type Options That May Be Commensurate With The Observed Subsoil Characteristic.

- d) To Provide And/Or Recommend Construction Technique That May Be Needed According To The Dictates Of The Subsurface Conditions.

II. DESCRIPTION OF PROJECT SITE

The project site is situated between Latitude $04^{\circ}47'59.81''\text{N}$ and $04^{\circ}48'0.26''\text{N}$ of the Equator and Longitudes $006^{\circ}56'21.02''\text{E}$ of the Greenwich Meridian as shown by the coordinates between the Boring point No. 1 and Boring point No. 6 at the project site on Table 4 and as shown on Figure 3 below.

Table 1: Drilled/boring points at the proposed horizontal LPG tank site

Boring Points	Coordinates		Percussion Drilling Depth (m)
	Northing (N)	Easting (E)	
BH #1	$04^{\circ}48'0.26''$	$006^{\circ}56'21.02''$	40
BH #2	$04^{\circ}47'59.96''$	$006^{\circ}56'20.41''$	40
BH #3	$04^{\circ}47'59.81''$	$006^{\circ}56'20.61''$	40

Generally, the project area is a flat-lying hydraulically sand-filled area of parts of the Niger Delta Marginal Lands. (Figure 1 below).



Figure 1: Satellite imagery showing the location of the proposed horizontal LPG tank site

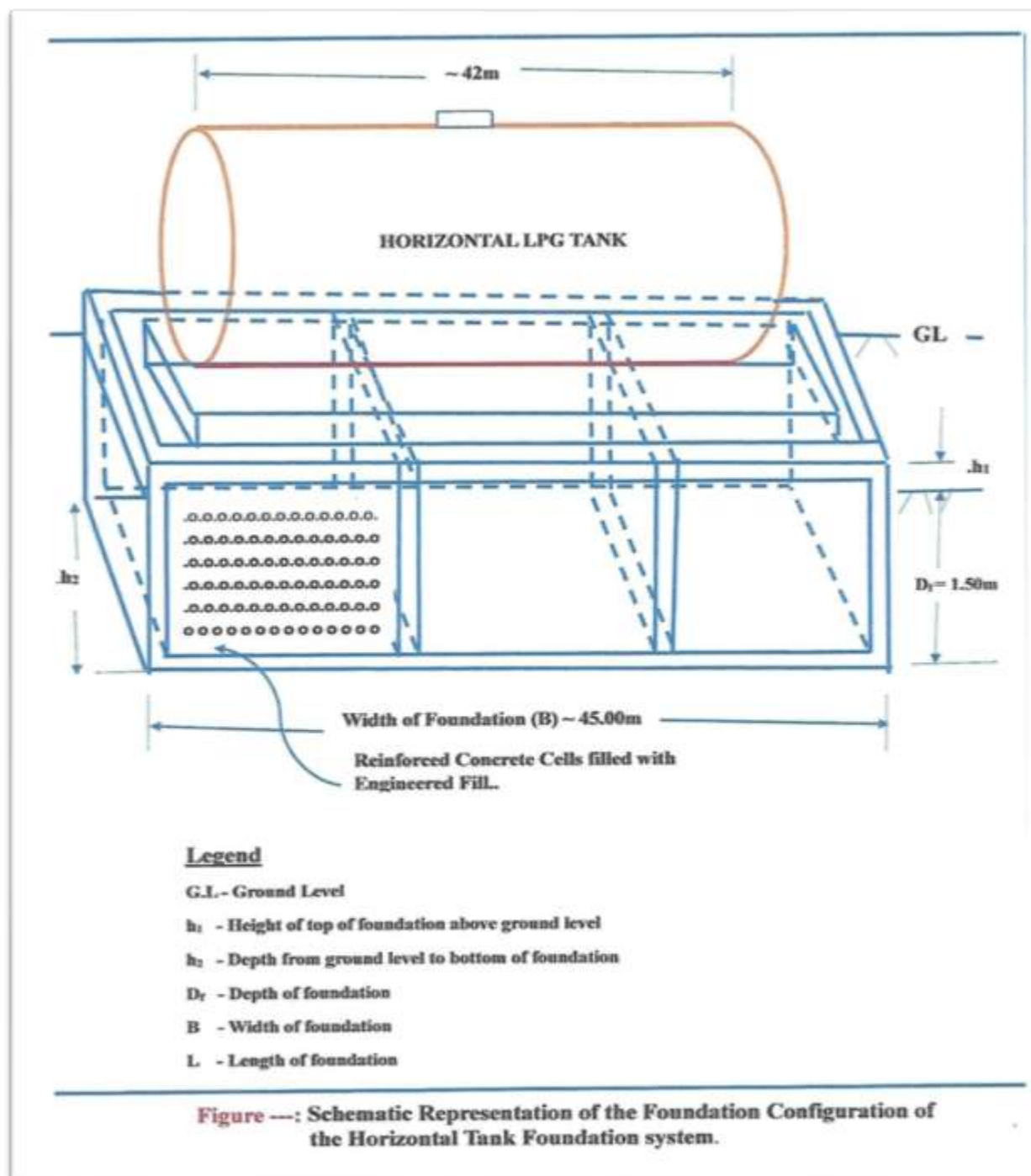


Figure 2: The schematic representation of the heavy weight horizontal LPG tank site

III. METHODOLOGY

SPT sounding, soil sampling and U4 sampling. In all a total of 3 deep boarding were made to final depth of 30.00m each.

A Visual inspection based on the following points contained in Table 2 below was used.

S/No.	Items to be determined	Remarks
1.	Is Site Below Water Table?	No
2.	Does the In-Situ Material appear to have recently been placed there?	No
3.	Does the In-Situ Material have any clay content?	Yes
4.	Does the In-Situ Material have a fair amount of moisture?	Yes
5.	Is In-Situ Material non-cohesive?	No

In using this system developed by the Andrew-SatCom Africa group, a series of eliminations based on a chart is carried out to find the appropriate Sub-Soil Test (SST) required for each particular site. The Chart is shown in Figure 3. below.



During the percussion Rig (Shell and Auger) drilling exercise, soil samplings were carried at appropriate depth interval at 1.50m in all sampling boreholes. Both disturbed and undisturbed soil samples were obtained during the drilling process. The received soil samples were subjected to both field and laboratory visual examination as well as detailed laboratory testing.

The Standard Penetration Tests (SPT) were carried out according to the methods of Terzaghi & Peck (1974); Peck, Hanson & Thorburn (1974); Holtz & Kovacs (2018), and carried out only in soils having Cohesion (C) and Friction (ϕ), and not purely cohesive soils.

3.3.Laboratory Tests

- a) The laboratory tests carried out included the following; .
- b) Gradation (wet sieving) as per BS 1377, Part 2, CI9.2.
- c) Atterberg Limits: BS 1377, Part 2, C1 4& 5.
- d) Dry Density/Moisture Content Relationship: BS 1377, Part 4, C13.
- e) Unconfined Compression Test on Soil: ASTM D 2938 – 1995.
- f) Modulus of Elasticity Method: ASTM D 2938 – 1995
- g) Oedometer Consolidation Test on recovered undisturbed samples.
- h) Quick Undrained Triaxial Test on recovered undisturbed samples
- i) Proctor Compaction Test on disturbed soil samples.

IV. RESULTS

4.1.Lithology

Details of the various lithologies encountered during the sub-surface exploration programme are presented in the borehole logs shown in Figure 4 below.

Generally, the soils at the projects site as observed during the field boring exercises, can be categorized on the basis of consistency, gradation and strength into Six types.

These are as follows:

- i. Engineered Sandfill Layer (SP) (Top Soil)
- ii. Brownish – to- Reddish Brown Stiff Silty Clays Layer (CL).
- iii. Reddish-Brown Clayey Sands Layer [SC]
- iv. Reddish-Brown loose – to stiff Silty Clays Layer (CL)
- v. Reddish-Grey Silt-Sand Mixtures Layer (SM), and
- vi. Milky-Grey Poorly Graded Sands Layer (SP)

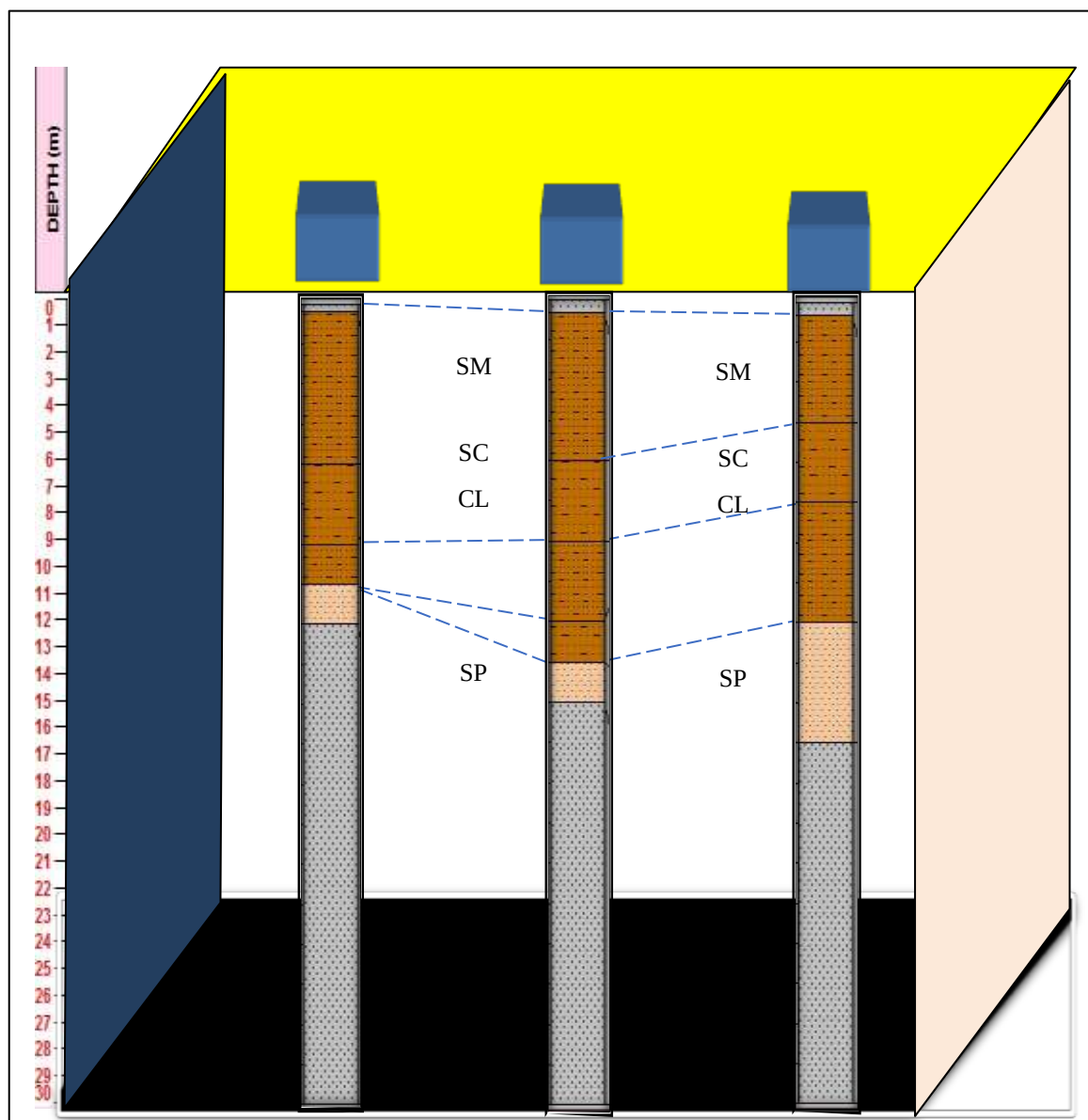
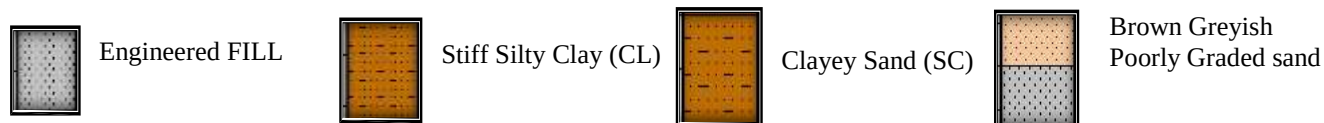


Figure 4: Fence diagram for 30-m percussion drilling at the proposed

4.2.Geotechnical Subsoil Characteristics

Table 3: A: Summary of the geotechnical properties for the subsoils at the proposed horizontal LPG tank si 04°48'.26"N; 006°56'21.02"E

	Sam. No.	Depth (M)	USC Class	Soil Consistency			Sat. Unit Wt	U-Triaxial Tests		Oedometer Consolidation Tests				AASHTO Compaction		Sous. Din gs	Grain (%)
				Wn (%)	LL (%)	PI (%)		ϕ (°)	Cu Kpa	Mv (M ² /MN) X 10 ⁴		Cv (M ² /Yr.)		OM C	MDD		
										50.00 Kpa	400.00 Kpa	50.00 Kpa	400.00 Kpa				
Neered Fill	1/0.3	Top	SM	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mdfill)		Soil															
F Silty Clay	1/1.5	1.50	CL	35.5	25.5	10.0	25.5	8.0	45	7.0	9.0	1.24	1.35	38	26	-	100
-	1/3.0	3.00	CL	35.8	25.8	10.0	28.0	8.0	45	7.0	9.0	1.24	1.35	40	31		100
Brown Silty	1/4.5	4.50	CI	-	-	-	-	-	-	-	-	-	-	-	-	-	-
R (CL)	1/6.0	6.00	CL	33.5	24.0	9.5	25.0	8.0	40	6.0	8.0	1.20	1.29	34	28	-	100
Brown Clayey	1/7.5	7.50	Sc	28.5	22.5	6.2	20.4	12	32	1.35	1.76	0.75	0.91	25	18	-	100
>Er(SC)	1/9.0	9.00	SC	-	-	-	-	-	-	-	-	-	-	-	-		-
Trown Stiff	1/10.5	10.5	CL	35.0	25.8	12.5	25.3	8.0	45	7.0	9.0	1.22	1.31	37	25		100
'Layer (CL)	1/12.0	12.0	CL	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Grey Sand-Silt	1/13.5	13.5	Sm	22.5	Np	Np	14.5	28	0.0	0.85	0.98	0.39	0.48	25	15		78
Vi)	1/15.0	15.0	Sm	-	-	-	-	-	-	-	-	-	-	-	-		-
.lght Grey	1/16.5	16.5	SP	17.0	NP	NP	13.5	33	0.0	0.70	0.89	0.38	0.45	22	12	12	63
Raded Sand	1/18.0	18.0	SP	-	-	-	-	-	-	-	-	-	-	-	-	16	-
Q)	1/19.5	19.5	SP	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	1/21.0	21.0	SP	-	-	-	-	-	-	-	-	-	-	-	-	16	-
	1/22.5	22.5	SP	14.0	NP	NP	12.5	33	0.0	0.69	0.88	0.39	0.44	20	10	-	60
	1/24.0	24.0	SP	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	1/25.5	25.5	SP	-	-	-	-	-	-	-	-	-	-	-	-	18	-
	1/27.0	27.0	SP	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	1/28.5	28.5	SP	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	1/30.0	30.0	SP	14.0	NP	NP	11.5	34	0.0	0.69	0.88	0.39	0.44	18	12	19	58
	1/31.5	31.5	SP	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	1/33.0	33.0	SP	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	1/34.5	34.5	SP	-	-	-	-	-	-	-	-	-	-	-	-	25	-
	1/36.0	36.0	SP	12.0	NP	NP	11.5	34	0.0	0.65	0.88	0.39	0.45	18	12	-	58
	1/37.5	37.5	SP	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	1/39.0	39.0	SP	-	-	-	-	-	-	-	-	-	-	-	-	28	-
	1/40.5	40.5	SP	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Water Table (WT) = 4.50 Meter																	

**Table 4: Summary of the geotechnical properties for the subsoils at the proposed horizontal LPG tank site
04°47'.59.96"N; 006°56'20.41"E**

	Sam No.	Depth (M)	USC Class	Soil Consistency			Sat. Unit Wt Kn/M³	U-Utriaxial Tests		Oedometer Consolidation Tests				AASHTO Compaction		Soun Dings	Grai n (%)
				.Wn (%)	LL (%)	PI (%)		ϕu (°)	Cu Kpa	Mv (M² /MN) X 10⁴		Cv (M²/Yr.)		OM C	MOD		
							50.00 Kpa			400.00 Kpa	50.00 Kpa	400. Kpa					
Neered Fill Ind Fill)	2/0.5	Top Soil	SM	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Wn Stiff Silty R (CL)	2/1.5	1.50	CL	40.0	35.5	13.5	30.5	9.0	42	7.0	9.0	1.25	1.35	40	30	.	100
	2/3.0	3.00	CL	40.0	32.5	15.5	25.5	9.0	43	7.5	9.0	1.28	1.35	40	29	-	98
	2/4.5	4.50	CL	35.5	33.5	12.5	25.3	9.0	43	7.0	9.0	1.25	1.33	30	24	-	99
Wn Soil Plant Eat) (PT)	2/6.0	6.00	PT	33.5	-	-	-	-	-	-	-	-	-	-	-	-	-
\-Reddish-Wse- Stiff Layer (CL)	2/7.5	7.50	CL	39.5	34.2	10.5	30.6	8.0	42	7.0	8.0	1.25	1.33	38	26	-	98
	2/9.0	9.00	CL	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2/10.5	10.5	CL	33.0	30.5	15.5	25.0	9.0	44	7.5	9.0	1.28	1.35	30	22	-	96
	2/12.0	12.0	CL	30.5	30.5	15.0	26.8	9.0	44	7.5	9.0	1.28	1.35	30	22	-	98
Grey Clayey	2/13.5	13.5	SC	33.0	25.2	7.5	23.0	14	32	1.32	1.75	0.72	0.88	25	17	-	88
	2/15.0	15.0	SC	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ey Poorly And Layer	2/16.5	16.5	SP	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2/18.0	18.0	SP	-	-	-	-	-	-	-	-	-	-	-	-	25	-
	2/19.5	19.5	SP	16.5	NP	NP	14.5	33	0.0	0.68	0.89	0.37	0.53	21	14	-	66
	2/21.0	21.0	SP	.	.	-	.	.	-	-	-	-	-	-	-	-	-
	2/22.5	22.5	SP	-	-	-	-	-	-	-	-	-	-	-	-	27	-
	2/24.0	24.0	SP	.	.	-	.	-	.	.	.	.	.	-	.	-	-
	2/25.5	25.5	SP	16.0	NP	«NP	14.5	33	0.0	0.68	0.89	0.37	0.53	19	12	-	62
	2/27.0	27.0	SP	-	-	-	-	-	-	-	-	-	-	-	-	26	-
	2/28.5	28.5	SP	.	-	-	-	-	.	-	.	.	-	-	-	-	-
	2/30.0	30.0	SP	.	.	.	.	-	-	-	.	-	-	-	-	-	-
	2/31.5	31.5	SP	16.0	NP	NP	15.0	33	0.0	0.60	0.89	0.38	0.49	18	12	.	58
	2/33.0	33.0	SP	.	.	.	-	.	-	-	.	-	-	-	-	30	-
	2/34.5	34.5	SP	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2/36.0	36.0	SP	-	-	-	-	-	-	-	-	.	-	-	-	-	-
	2/37.5	37.5	SP	-	-	-	-	.	-	.	.	-	.	-	-	30	-
	2/39.0	39.0	SP	16.5	NP	NP	15.0	35	0.0	0.58	0.88	0.37	0.50	20	14	-	58
	2/40.5	40.5	SP	-	-	.	-	-	-	-	-	-	-	-	-	-	-
Water Table (WT) = 4.38 Meter																	

Water Table (WT) = 4.38 Meter

**Table 5: Summary of the geotechnical properties for the subsoils at the proposed horizontal LPG tank site
04°47'59.81"N; 006°56'20.61"E**

	Sam No.	Depth (m)	USC Class	Soil Consistency			Sat. Unit Wt kN/m³	U-Utrialxial Tests		Oedometer Consolidation Tests				AASHTO Compaction		Sounding? SPT (N)	Grain Patte (%) >2mm
				.wn (%)	LL (%)	PI (%)		ϕu (°)	Cu Kpa	Mv (m² /MN)xI(^(		Cv (m³/yr.)		O M C	MDD		
										50.00 kPa	400.00 kPa	50.00 kPa	400. kPa				
Neered Fill Sand Fill)	3/0.5	0.00	SP	.		-	-	-	.	-	.	-	.	-	-	.	-
	3/1.5	1.50	SP	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3/3.0	3.00	SP	14.0	NP	NP	13.5	33	0.0	0.52	0.88	0.33	0.43	18	12	-	65
Brown Silty Clay	3/4.5	4.50	CL	39.5	27.5	11.5	28.5	8.0	46	7.5	9.0	1.26	1.36	36	25	-	100
Brown Soil /Plant Eat) (PT)	3/6.0	6.00	PT	32.0	.	-	-	-	-	-	-	-	-	.	-	.	-
Reddish-Ose –Stiff Layer (CL)	3/7.5	7.50	CL	35.3	22.5	10.5	30.0	7.5	44	7.0	9.0	1.24	1.36	38	29	.	100
	3/9.0	9.00	CL	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3/10.5	10.5	CL	35.5	25.5	12.0	25.5	7.5	45	7.0	9.0	1.25	1.36	36	24	-	100
Grey Sand-Silt (Sm)	3/12.0	12.0	SM	21.0	NP	NP	18.0	28	0.0	1.22	1.56	0.78	0.89	26	18	-	7
	3/13.5	13.5	SM	-	-	-	-	-	-	-	-	-	-	-	-	-	-
,ight Grey Mdred Sand (°)	3/15.0	15.0	SP	17.0	NP	NP	14.0	33	0.0	0.59	0.90	0.42	0.56	20	12	.	7
	3/16.5	16.5	SP	.	.	-	.	-	-	-	-	-	-	-	-	.	-
	3/18.0	18.0	SP	-	-	-	-	-	-	-	-	-	-	-	-	15	-
	3/19.5	19.5	SP	.	-	.	.	-	-	-	-	-	-	-	-	-	-
	3/21.0	21.0	SP	16.5	NP	NP	13.0	33	0.0	0.58	0.88	0.38	0.54	18	12	-	6
	3/22.5	22.5	SP	-	-	-	-	-	-	-	-	-	-	-	-	26	-
	3/24.0	24.0	SP	.	-	-	-	-	-	-	-	-	-	-	-	.	-
	3/25.5	25.5	SP	-	-	.	.	-	-	-	.	-	-	.	-	.	-
	3/27.0	27.0	SP	15.0	NP	NP	12.5	33	0.0	0.58	0.88	0.38	0.55	18	12	26	58
	3/28.5	28.5	SP	-	-	.	-	-	-	.	-	.	.	.	-	.	-
	3/30.0	30.0	SP	.	.	.	.	.	-	-	.	.	.	-	.	.	-
	3/31.5	31.5	SP	-	.	-	.	.	-	.	-	.	.	.	.	28-	-
	3/33.0	33.0	SP	15.0	NP	NP	12.5	34	0.0	0.58	0.86	0.38	0.56	16	10	-	69
	3/34.5	34.5	SP	-	-	.	-	-	-	.	-	.	-	.	.	-	-
	3/36.0	36.0	SP	-	-	-	-	-	.	.	.	-	-	.	-	-	-
	3/37.5	37.5	SP	-	-	-	-	-	-	-	-	-	-	.	-	29	-
	3/39.0	39.0	SP	.	.	-	.	-	-	-	-	.	.	-	-	.	-
	3/40.5	40.5	SP	15.0	NP	NP	11.5	34	0.0	0.58	0.86	0.38	0.56	16	10	-	70
Water Table (WT) = 3.85 meter																	

Water Table (WT) = 3.85 meter

Table 6: Consolidation and drainage characteristics of the materials at the project site N/A = Non Applicable in this case

Lithology	Depth Range (M)	Coefficient Of Compressibility	Coefficient Of Consolidation C_v	Coefficient Of Permeability	Remarks
		M_v (m^2/MN)	($m^2/yr.$)	K (Cm/Sec)	
		(Average Values)	(Average Values)	(Average Values)	
Silty Clay	2.00	0.207	118.27	8.04×10^{-7}	High to medium
And	3.40	0.102	117.15	3.7×10^{-7}	compressibility
Sandy Clay	4.25	0.110	112.23	4.05×10^{-7}	practically
	6.30	0.095	140.00	4.58×10^{-7}	impermeable
Coarse Sands	6.50				Low
And	To	N/A	N/A	$> \times 10^{-4}$	compressibility,
Gravelly	12.70				Highly Previous
Sands					(good drainage)
Greyish	12.7and	N/A	N/A	$< 1 \times 10^{-7}$	High
Sandy Clays	Below				Compressibility
					very impermeable

4.3 Bearing Capacity Computations of the Foundation Soils at the Project Sites.**Table 7: Summary of computed bearing capacities of subsoil layers at the proposed horizontal LPG tank site**

S/No.	Soil Layer	Depth (M)	FieldSpt-N Values	AverageField SPT-N Values	Bearing Capacity of Soil Layers (kPa)@ Factor-Of-Safety = 3.0
BH1	Engineered Fill (Sand Fill)	0.00 – 1.50	-	-	-
	Reddish Silty Clay Layer (CL)	1.5 – 6.0	-	-	-
	Reddish-Brown Clayey sand Layer(SC)	6.0 – 9.0	-	-	-
	Reddish-Brown Stiff Silty Clay Layer (CL)	9.0 – 12.0	-	-	-
	Reddish-Grey Sands-Silts Layer (SM)	12.0 – 15.0	-	-	-
	Milky-Light Grey, Poorly-Graded Sands Layer (SP)	15.0 – 40.0	12,16,16, 18,19,25,28	16.86	397.997
BH2	Engineered Fill (Sand Fill)	0.5 – 6.0	-	-	-
	Dark-Brown Stiff Silty Clay Layer (CL)	6.0 – 9.0	-	-	-
	Dark-Brown Organic Peaty Soil Layer (Pt)	6.0 – 7.5	-	-	-
	Brownish-Red Stiff Silty-Clay Layer (CL)	7.5 – 12.0	-	-	-
	Reddish-Grey Clayey Sands-Silts Layer (SC)	12.0 – 15.0	-	-	-
	Milky-Grey, Poorly-Graded Sands Layer (SP)	15.0 – 40.0	28,27, 26,30,30	28.2	665.6892
BH3	Engineered Fill (Sand Fill)	0.0 – 3.0	-	-	-
	Dark-Brown Silty Clay Layer (CL)	3.0 – 6.0	-	-	-
	Dark-Brown Organic Peaty Soil Layer (Pt)	6.0 – 7.5	-	-	-
	Brownish-Red Stiff Silty-Clay Layer (CL)	7.5 - 12.0	-	-	-
	Reddish-Grey Sand-Silt Mixture (SM)	12.9 – 15.0	-	-	-
	Milky-Light Grey, Poorly-Graded Sands Layer (SP)	15.0 – 40.0	15,26, 26,28,29	248	585.4288

Table 8: Summary of computed bearing capacity values of subsoil layers at the proposed horizontal LPG site (based on the various standard methods and on depth of foundations $d_f = 1.50\text{m}$. (Based on F.S = 3.0)

P Project Site	SPT N-value (at desired depth)	Depth of Foundation	Computational Methods (kPa)				Field Methods (kPa)	Average Values kPa
			Meyerhof (1974)	Bowles (1988)	Terzaghi & Peck (1967)	Brinch Hansen	SPT Method	
Horizontal LPG Tanks Site	1 8	1.50	73.0495	76.991	285.48	70.167.	141.636	129.4647
RR Remarks.			Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable

These values are however, below the upper values for bearing capacity (380 to 470 kPa) cautioned for use by Bowles (1977). Settlement considerations are by the virtue of the inherent use of these equations limited to 25.4mm. The use of the Factor of Safety of 3.0 takes care of any unexpected high settlement values that may likely be obtained for this site.

From the above, it could be observed that the Range Of Soil Bearing Capacity Values useable at the proposed Horizontal LPG Tanks Foundation at the project site based on a foundation depth (D_f) of 1.50 meters for a B value = 42.00 meters = 70.167 to 285.48 kPa with an average of 129.4647 kPa.

The above values of bearing capacity are based on the empirical methods of Bowles (1988), Meyerhof (1974), Terzaghi and Peck (1967); Hansen (1978) and proven field methods using the SPT techniques of Peck, Hansen and Thornburn, (1974).

4.4 Estimation of Average Settlements, Rates of Consolidation Settlements and the Incremental Settlements of Loaded Areas

Table 9: Results of the estimated average settlements of the horizontal LPG tank foundations sites: Method "A" - Christian & Cartier's Method (. $q_n = A \sim 120.00\text{ kPa}$)**

S/No	μ_0	μ_1	$q_n = A$ (kPa)	B (m)	Ave. mv (m2/MN)	Ed =	$\rho_i = (1/mv) \{(\mu_0)(\mu_1)(B)\} / Ed$ where:
					$\times 10^{-4}$		[Ed = (1/mv)]
							(mm)
BH# 1	0.95	0.05	120.00**	42.00	0.000700	1,428.6	0.001396
BH# 2	0.95	0.05	120.00	42.00	0.000750	1,333.33	0.001496
BH# 3	0.95	0.05	120.00	42.00	0.0007500	1,333.33	0.001496

Table 10: Results of the estimated incremental settlements of the proposed horizontal LPG tank sit(BH #1)

DEPT H	Σ H	H_d 4.0	γ 28.	ΣH_y 56.6	ΔP 56.6	M_v 0.000700	ΔH 0.15848
2-4	2	4.0	30.	60.4	117.0	0.000700	0.32760
4-6	2	4.0	28. 0	56.0	173.0	0.000700	0.48440
(BH#2)							
DEPT	Σ	H_d	γ	ΣH_y	ΔP	M_v	ΔH
0-2	2	4.0	33.	67.0	67.0	0.000750	0.20100
2-4	2	4.0	30.	61.0	128.0	0.000750	0.38400
4-6	2	4.0	28. 5	57.0	185.0	0.000750	0.55500
(BH#3)							
DEPT	Σ	H_d	γ	ΣH_y	ΔP	M_v	ΔH
0-2	2	2.5	30.	60.4	60.4	0.000800	0.12080
2-4.5	2.	2.5	28.	71.3	131.7	0.000800	0.26340

Table 11: Results of the estimated Immediate Settlements at the Horizontal LPG Tank Foundations sites Based on Skempton and Bjerrum Method (1957):

S/No.	Boring Site	Incremental Settlements	Remarks.
1.	BH #1.	0.056mm	Acceptable
2.	BH #2.	0.06mm	Acceptable
3.	BH #3.	<u>0.04</u>	Acceptable.

Table 12: Results of rates of consolidation settlements at the horizontal LPG tank foundations sites

S/N	Items		Boring BH#1	Nos. BH#2	BH#3
1.	Thickness of Layer (.d = Ho)(m)		4	4	2.5
2.	d2		16	16	6.25
3.	Coeff. of Consolidation (Cv)	T10 (yrs.)	1.23 0.104065	1.28 0.100000	1.25 0.04
		[0.008] T20 (yrs.)	0.040325	0.3875	0.155
	Estimated	[0.031] T30 (yrs.)	0.92357	0.8875	0.355
4.	Time Rate of	[0.071] T40 (yrs.)	1.63902	1.5750	0.630
	Consol- idation:	[0.126] T50 (yrs.)	2.56260	2.4625	0.985

	[t(ys) = [T.d2/Cv]]	[0.197] T60 (ys.)	3.73333	3.5875	1.435
		[0.287] T70 (ys.)	5.24227	5.0375	2.015
		[0.403] T80 (ys.)	7.37561	7.0875	2.835
		[0.567] T90 (ys.)	11.0309	10.600	4.240
		[0.848] T95 (ys.)	15.1285	14.5375	5.815
		[1.163]			

V. DISCUSSION

The study which involved 3 Nos field boring and laboratory analysis carried out on the soil samples obtained from the project site revealed basically six (6), identifiable soil horizons namely;

- Engineered Sandfill Layer (SP) – Top Soil
- Brownish-To-Reddish Brown Stiff Clay Layer (CL)
- Reddish-Brown Clayey Sands Layer (SC)
- Reddish-Brown Loose To Stiff Silty Clays Layer (CL)
- Reddish-Grey Silt-Sand Mixtures Layer (SM), And
- Milky-Grey Poorly Graded Sands Layer (SP)

The moisture content (W_n) is variable, ranging from 28-40% in the clayey soil to between 12-17% in the sandy strata, with liquid limits from 22.5 – 35.5% and plasticity index (PI) of 6.2 – 15.5% for the clays. Summary of geotechnical parameter values are presented in Tables 3 to 5. The moisture content is moderate, ranging from 15.0% in the grey sand to 39.5% in the silty clay. The soils are of low consistencies. With liquid limit between 25.5 and 27.5%, plastic limit in the range of 12.0 to 16.0%

Results of Triaxial Tests indicate average frictional angle of 33° and 8° for the sand and clays respectively. The SPT on the granular section of the subsoil have N-values in the range of 15-30 which when converted to bearing capacity give values between 397.99 and 585.42kPa. Detail in Table 6. However, values of bearing capacity from empirical computation gives 73.049kPa for Terzaghi's method as presented in Table 7. The computed settlement data indicates immediate settlement values to be 0.056mm (BH#1), 0.06mm (BH#2) and 0.04 (BH#3). This is the settlement expected to occur during the construction phase of the project. Longterm (consolidated) settlement values for the site is estimated to be about 0.756m (BH#1); 0.09m (BH#2) and 0.9m (BH#3). About 50% of the settlement must have taken place between 22.2 – 40.6years after construction as indicated in Table 12.

Foundation Consideration

Based on the results of both field and laboratory analysis of the proposed project site, a raft footing (Rectangular Cellular Raft) is most appropriate.

- The range of values obtained for the bearing capacities for the recommended raft footing at the project site, based on a foundation depth (D_f) of 1.50m for a B value = 42.00m and the range of bearing capacity values applicable for this site based on the various computational methods adopted is between 70.167 and 258.48kPa with an average of 129.465kPa as given in Table 7.
- The Raft Footing should be borne at depth of 1.50m comprising the engineered fill (sand fill) layer and/or the 1.50m of reddish-brown silty clay layer below the ground surface. (see Figure 3b). This will necessitate the removal of about 1.50m of the overburden at the site during the foundation construction phase of the project.
- The width of the Raft Foundation in all cases should be taken as (B+X)m where: B = width of the base of the Tank (42.00m), and X = 1.00m as allowance around the perimeter of the excavation.

- iv. In view of the terrain, foundation concrete should be dense and impermeable for protection against sulphate attack especially in the areas likely to be in contact with rain or surface or groundwater.

REFERENCES

- [1]. Abam, T.K.S (2017). Exploring ground conditions for sustainable building foundation design. Proceedings of the 2nd International Conference of the Nigeria Association for Engineering Geology & the Environmental Laos, (1), 32-41.
- [2]. Abija, F.A., Oborie, E. & Obolio, E.O. (2019). Site investigations studies for the design of raft-on-pile foundation for elevated water tank in the coastal area of Opnama, Warri North Western Niger Delta, Nigeria. Journal of Mechanical and Civil Engineering (IOSR-JMCE), 19(6), 58-66.
- [3]. Akhter, S. (2021). "Shallow foundation – definition, types, uses and diagrams" Proceeding of Civil Engineers, 3((5), 727-784.
- [4]. Bowles, J.E. (1977). Foundation analysis and design. 2nd Edition. McGraw-Hill Book Company, New York., 750 pages.
- [5]. Christian J.T. & Carrier, W.D. (1978). Janbu, Bjerrum and Kjaernsli's chart Re-interpreted. Canadian Geotechnical Journal, 15: 123-128.
- [6]. Hansbo, S. (1994), Foundation Engineering Developments in Geotechnical Series No. 75. Elsevier Amsterdam. 519 pages.
- [7]. Hansen, J.B., (1968). A revised extended formular for bearing capacity. Danish Geotechnical Institute Bulletin, No. 28.
- [8]. Janbu, N., Bjerrum, L. & Kjaernsli, B (1956) Norwegian Geotechnical Institute Publication No. 16. Meyerhof, G.G., (1963), Some recent research on bearing capacity of foundations. Canadian Geotechnical Journal, 1:16 – 26.
- [9]. Peck, R. B., Hanson, W. E & Thornburn, T. H. (1974). Foundation engineering. Second edition; John Wiley and Sons Inc. New York, 514 pages.
- [10]. Skempton, A.W. & MacDonald, H.H. (1956), The allowable settlement of buildings. Proc. of Civil Engineers, 3(5),727 – 784.
- [11]. Smith, I. (2013). Smith's elements of soil mechanics (8th edition), John Wiley and Sons, Inc. ISBN 978-1-405-13370-8.
- [12]. Teme, S.C., (2022). Report on geotechnical investigations for the foundation design for a residential building at Amassoma, Southern Ijaw Local Government Area, Bayelsa State, Nigeria. Technical report submitted to HFP Engineering Nigeria Limited, Ahoda Industrial Estate, Rivers State, 29 pages.
- [13]. Teme, S.C., (2023). Report on geotechnical investigations for the foundation design of the Nal Merchant Bank PLC Building Complex, Trans-Amadi Industrial Area, Port Harcourt. Technical Report submitted to NAL Merchant Bank Plc, Port Harcourt, 95 pages.
- [14]. Teme, S.C., (2022). Report on geotechnical investigations for the foundation design of a residential building complex at the Naval Base, Onura-Onne, Rivers State. Technical report submitted to Echikwa Phillips Partnership, 32 Trans-Amadi Industrial Layout, Port Harcourt, 52 pages.
- [15]. Terzaghi, K and Peck, R.B. (1967). Soil mechanics in engineering practice. 2nd Ed. John Wiley, New York, 271-276.
- [16]. Tomlinson, M.J. (1980). Foundation design and construction. pitman Advanced Publishing Programme, London 4th Edition 793 pages.