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Bearing Capacity and Settlement Response of PMS Tanks on Cohesionless Soil Lithology in Lekki, Lagos of Nigeria

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ABSTRACT

Vehicular petrol tank (TAC) foundations founded on medium-dense, slightly silt SAND formation in Lekki area of Lagos State, Nigeria have been evaluated for bearing capacity and settlement. The study involved field boring of holes (BH), standard penetration tests, laboratory tests and analysis of soil samples on TAC-1 and TAC-2. The net allowable bearing capacity, $q_{n(a)}$, of both tanks increased with foundation depth, but in BH4, $q_{n(a)}$ of TAC-1 decreased with depth up to 3m, attaining a value of about 110 kN/m^2; beyond which it increased with depth. Higher values were attained on TAC-2 but $q_{n(a)}$ decreased noticeably in BH4 from 5m depth. Higher immediate settlement generally occurred on TAC-2 in Harr's approach but with Burland and Burbidge, TAC-1 showed higher immediate settlement. Total settlement was generally higher in TAC-1 than TAC-2 and the ***i****nduced vertical stress distribution with depth at tank centers were lower than allowable bearing capacity.*

Key words: Induced vertical stress, Poisson ratio, Elastic modulus, Flexible foundation.

INTRODUCTION

Foundations of vehicular petrol (PMS)/crude oil tanks are commonly designed as flexible foundation and imposed load from the petroleum product is transmitted through metal plates on granular overburden layer to the underlying soil formation. Most often, the elevated tank metal sheets rest on concrete ring beam. Two storage tanks under study were designed to have a floating roof type and are scheduled for rehabilitation by increasing Tank (TAC-1) diameter from 32.9m diameter to about 48.8m diameter and 14.4metres height, while Tank (TAC-2) had a diameter of 32.9m and 14.4m height, after several decades of operation. When fully operational, the PMS generates a bearing pressure of about 107kPa on the metal plates - soil interface for vehicular PMS with unit weight of 7.37kN/m^3. The subsurface soil lithology beneath the tanks site generally consists of medium-dense, slightly silty SAND. Hence, the magnitude of tolerable settlement the super structure can sustain controls the foundation design and this makes settlement prediction very vital. Ola [1] had reported on the settlement of two oil tanks in Kaduna, Nigeria where rate of settlement showed improved agreement with measured rates of settlement. In the Niger Delta region of Rivers State, bearing capacity and settlement evaluation on crude oil tanks foundations founded on compacted granular soils that are underlain by cohesive soils have also been reported [2,3]. This paper attempts to evaluate both the stability and deformation characteristics of two PMS tanks placed on sand formation.

MATERIALS AND METHODS

Field Exploration/ Laboratory Analysis

Material and methods adopted in this investigation involved ground borings, laboratory tests and analysis of results. Subsurface conditions at the site were studied through ground borings to depths of 15m using a percussion boring rig in addition to in-situ tests; cone penetration tests, standard penetration test (SPT) and resistivity tests, with test points shown in Figure 1. Both disturbed and undisturbed samples were collected for identification, laboratory testing and classification. The static water table varied from about 1.7-1.8m depth below the existing ground level at the time of this investigation.

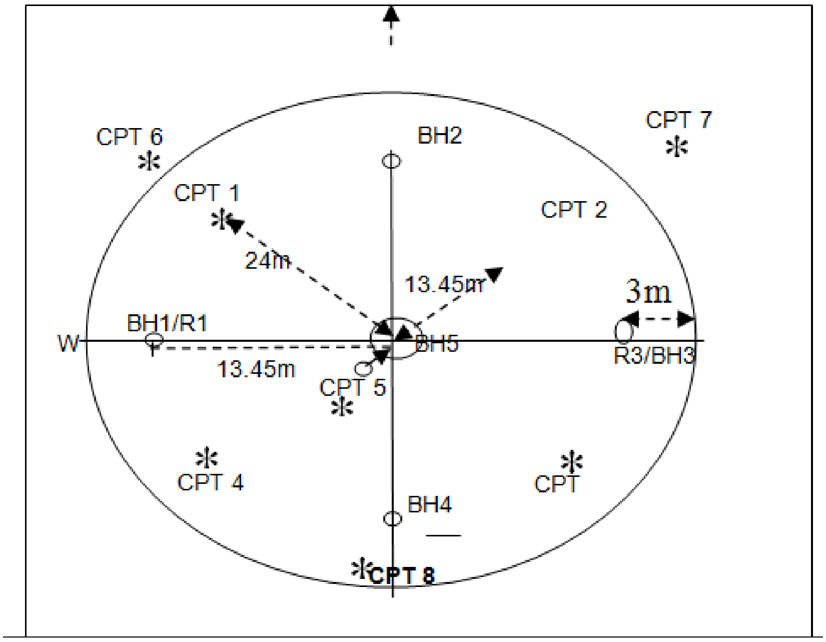

Figure 1: Typical boring, CPT and Resistivity points on each PMS Tank Vicinity

Bearing Capacity

SPT Approach on Shallow Foundation

Two modes of tank foundation failures have been observed in practice, namely, base and edge shear failures. In base shear failure, the entire tank act as a unit, while in edge shear failure, local failure of a portion of the tank perimeter and contiguous portion of tank base occur [4]. The subsurface formation of tanks site consists of medium-dense, slightly silty SAND formation, which necessitated the adoption of modified Meyerhof [5] correlation in evaluating bearing capacity using Standard Penetration Resistance approach. The method presented by Bowles [6] was used to analysis the 32.9m and 48.8m diameter by 14.m height PMS circular tank foundation. The modified Meyerhof method was adopted as it gives middle bound values compared to that of Parry [7] which gives higher bound values and Meyerhof [5] which gives lower bound values of bearing capacity[8] The modified Meyerhof expressions are given by;

$$q_{n(a)} = 19.16NF_d\left(\frac{s}{25.4}\right) \qquad for\ \ B \leq 1.2m \qquad (1)$$

$$q_{n(a)} = 11.98N\left(\frac{3.28B+1}{3.28B}\right)^2 F_d\left(\frac{s}{25.4}\right) \qquad for\ \ B > 1.2m \qquad (2)$$

where F_d = depth factor = 1+ 0.33 (D_f/ B) $\leq$ 1.33 (3)

S = tolerable settlement
N = average penetration number

Settlement Analysis:
This was evaluated based on the following;

Stress Analysis
The induced vertical stress ($\Delta\sigma_z$) with depth from the PMS load is obtained from the expression [9];

$$\Delta\sigma_z = q\left\{1 - \frac{1}{\left[1+\left(\frac{a}{z}\right)^2\right]} 3/2\right\} \quad (4)$$

where $\Delta\sigma_z$ = induced vertical stress
q = applied stress
a = radius of circular area
z = depth of interest

For vehicular petrol, a unit weight of 7.37kN/m^3 was adopted for stress analysis and at full capacity under static load, generates a bearing pressure of approximately 107kN/m^2 that is transmitted to the ground through the metal plate.

Immediate Settlement
Immediate settlement at corner of flexible foundation with diameters of 32.9m and 48.8m having equivalent breadth of 29.15m and 43.24m respectively placed on sand were obtained from the expression proposed by Harr [10] and reported in Braja [11] as follows;

$$s_i = \frac{q_n}{E_o} B(1-\mu^2) I_p \quad (5)$$

where S_i is immediate settlement, B is equivalent breadth of foundation at a corner, q_n is net foundation pressure, E_o is modulus of elasticity, μ is Poisson ratio and I_p is influence factor.

Based on SPT values, E_o can be obtained from the expression;

$$E_o = 0.478N + 7.17\text{MPa} \quad (6)$$

and for cohesionless soils, Poisson ratio, μ can be evaluated from;

$$\mu = \frac{1-\sin\phi}{2-\sin\phi} \quad (7)$$

where ϕ is angle of internal friction of sand and N is average SPT blow count for sand stratum. The values of influence factor, I_p, for various length to breadth (L/B) ratios were obtained from standard curves [11]. For normally consolidated sand, the average settlement has been expressed in terms of net foundation pressure, foundation breadth and compressibility index [12] as;

$$s_i = \frac{q_n B^{0.7}}{3}\left(\frac{1.71}{N^{1.4}}\right) \quad (8)$$

where q_n is the net foundation pressure, B is foundation breadth and N is average value of standard penetration resistance.

Consolidation Settlement:
Coefficient of volume compressibility
The coefficient of volume compressibility, m_v, is obtained from the following expression;

$$m_v = \frac{(1+\mu)(1-2\mu)}{E_o(1-\mu)} \quad (9)$$

And the consolidation settlement was evaluated from the expression [13] presented as follows:

$$\rho_c = \frac{\Delta e}{1+e_o}\left(\frac{1}{\Delta p}\right)\Delta\sigma_z H$$

$$= \frac{\Delta e}{1+e_o}\left(\frac{1}{\Delta p}\right)\frac{q_{nBL}}{(B+Z)(L+Z)}H, \text{ or} \qquad (10)$$

$$= m_v \frac{q_n B^2}{(B+Z)^2}H \qquad (11)$$

where ρ_c is consolidation settlement, e_o is initial void ratio, $\Delta\sigma_z$ is induced vertical stress and $\frac{\Delta e}{1+e_o}\left(\frac{1}{\Delta p}\right)$ is coefficient of volume compressibility, m_v, q_n is net foundation pressure, B is foundation breadth, Δp is change in pressure and Δe is change in void ratio. Substituting Equation (9) into Equation (11) gives consolidation settlement in the form;

$$\rho_c = \frac{(1+\mu)(1-2\mu)}{E_o(1-\mu)}\frac{q_n B^2}{(B+Z)^2}H \qquad (12)$$

Total settlement of circular foundation with equivalent breadth, B, can then be written as;

$$\rho_t = \frac{q_{nB}}{E_o}(1-\mu^2)I_p + \frac{(1+\mu)(1-2\mu)}{E_o(1-\mu)}\frac{q_n B^2}{(B+Z)^2}H \qquad (13)$$

Total settlement can also be written for case of normally consolidated sand incorporating Burland and Burbidge [11] expression as;

$$\rho_t = \frac{q_n B^{0.7}}{3}\left(\frac{1.71}{N^{1.4}}\right) + \frac{(1+\mu)(1-2\mu)}{E_o(1-\mu)}\frac{q_n B^2}{(B+Z)^2}H \qquad (14)$$

Limiting values for allowable settlement of different structures founded on either clay or sand have been specified by scholars[14, 15 and 16]

RESULTS AND DISCUSSION

Soil Classification/Stratification

The granular soil samples of both tanks were analysed by dry sieving and generally, the soil consists of medium-dense, brown, slightly silty SAND.

Stress Analysis

The induced vertical stress distribution from PMS product with depth at centre of each tank foundation is found to be within the net allowable bearing capacity of the soil and the predictive model representing the induced vertical stress variation is given in Equation (15).

$$\Delta\sigma_z/q = 0.285(z/a)^3 - 0.800(z/a)^2 + 0.16\,z/a + 0.991 \qquad (15)$$

where $\Delta\sigma_z$= induced vertical stress, a= radius of tank, z = depth and q = net foundation pressure.

Shear Strength Parameters

The shear strength parameter ϕ, of the cohesionless soil formations were evaluated from in-situ values of Standard Penetration Test (SPT) of the respective stratum or layer of interest. Details on SPT and ϕ values are presented in Table 1.

Table 1: Variation of SPT values with Depth

Borehole No.	Depth (m)	SPT Values (N)	
		Tank 1	Tank 2
1	1	12	16
	3	17	23
	5	19	29
	7	23	34
	9	28	10
2	1	13	20
	3	16	23
	5	20	28
	7	26	33
	9	30	1
3	1	11	25
	3	17	28
	5	19	30
	7	23	33
	9	27	5
4	1	16	17
	3	2	27
	5	10	32
	7	13	11
	9	20	4
5	1	11	18
	3	17	21
	5	17	23
	7	21	22
	9	22	32

Bearing Capacity:

SPT Approach Shallow Foundation

The allowable bearing capacity of tanks TAC-1 and TAC-2 are shown in Table 2 and Figures 2a and 2b. Its noticed that $q_{n(a)}$ increased with foundation depth and the induced vertical stress due to imposed PMS load are generally lower than the allowable bearing capacity of the soil in tanks sites. In Figure 2a, allowable bearing capacity increased with foundation depth, but in BH4, net allowable bearing capacity, $q_{n(a)}$, decreased with depth up to 3m, attaining a value of about 110 kN/m^2; beyond which allowable bearing capacity increased with depth. Higher values were attained on TAC-2 site (Figure 2b) but $q_{n(a)}$ decreased noticeably in BH4 from 5m depth.

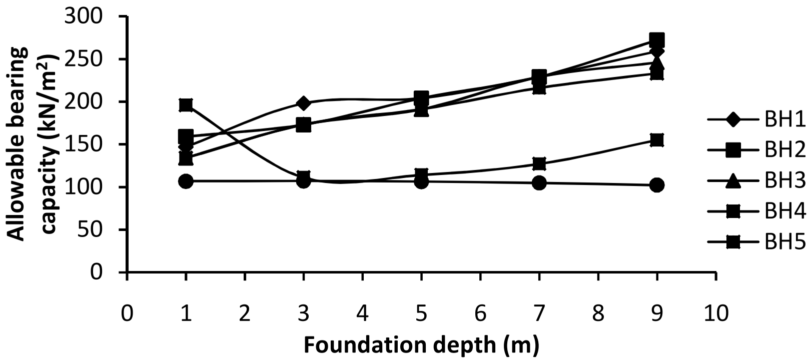

Figure 2a: Variation of $q_{n(a)}$, induced vertical stress with foundation depth on TAC-1

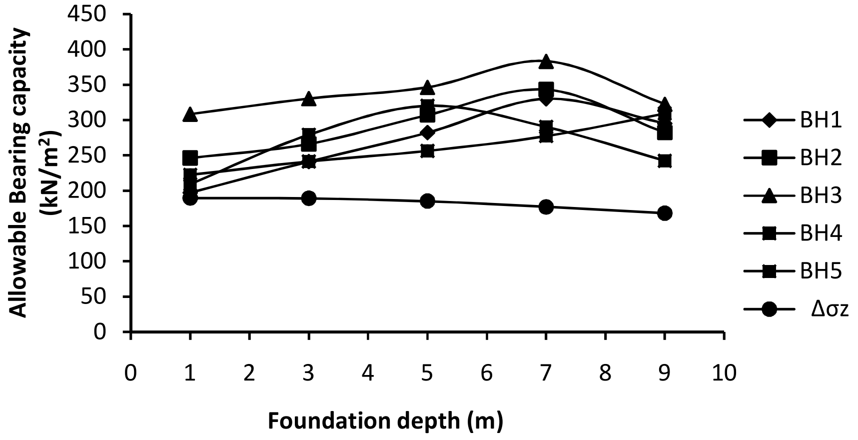

Figure 2b: Variation of $q_{n(a)}$, induced vertical stress with foundation depth on TAC-2

Settlement Analysis:

Immediate Settlement on Sand

The magnitude of immediate settlement at centre of TAC-1 and TAC-2 are presented in Table 3, while variations of immediate settlement with depth using Harr's approach are shown in Figure 3, but that of Burland and Burbidge approach are presented in Figure 4. In Harr's approach a reduction in immediate settlement with foundation depth was evident on both tanks, but in TAC-1 soils in BH4 had higher immediate settlement. Higher immediate settlement generally occurred in TAC-2 in Harr's approach but with Burland and Burbidge, TAC-1 showed higher immediate settlement.

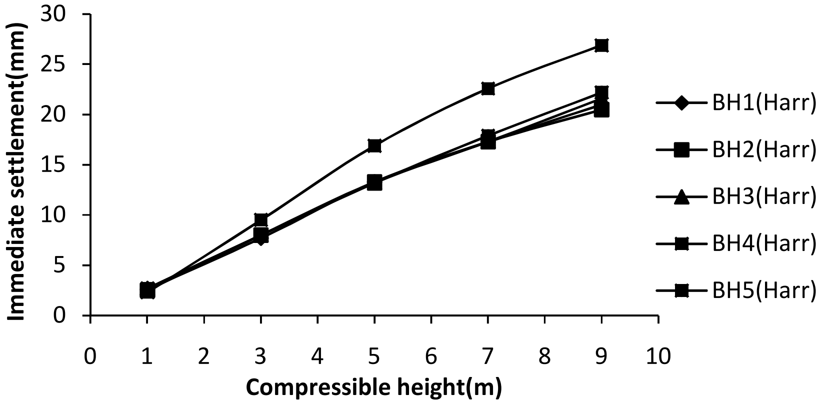

Figure 3a: Immediate settlement with foundation depth on TAC-1(Harr's Approach)

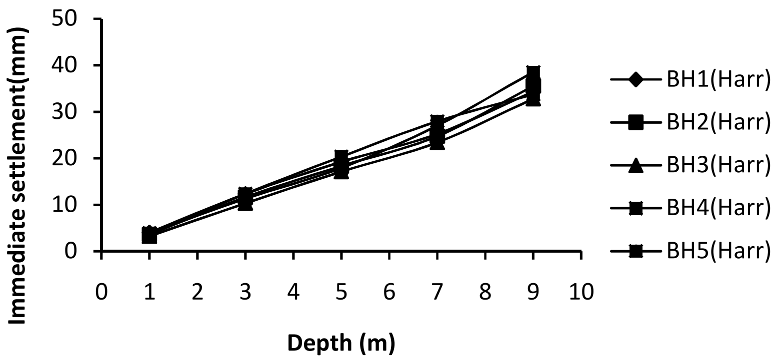

Figure 3b: Immediate settlement with foundation depth on TAC-2 (Harr's Approach)

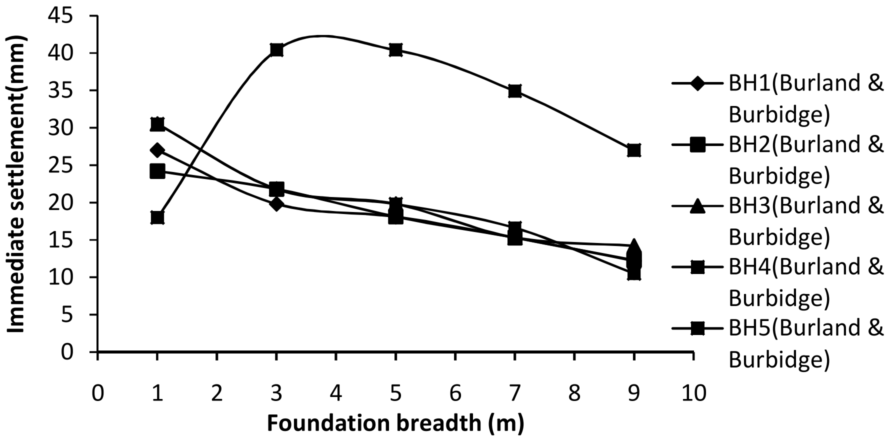

Figure 4a: Immediate settlement with foundation depth on TAC-1 (Burland & Burbidge Approach)

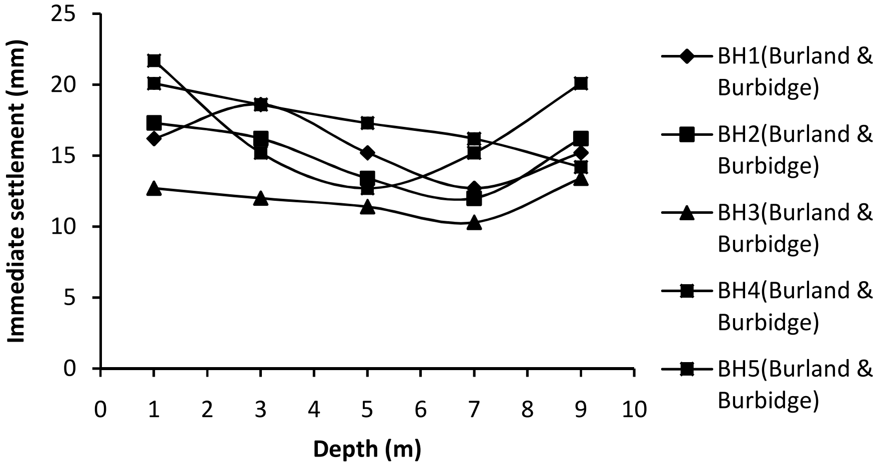

Figure 4b: Immediate settlement with foundation depth on TAC-2 (Burland & Burbidge Approach)

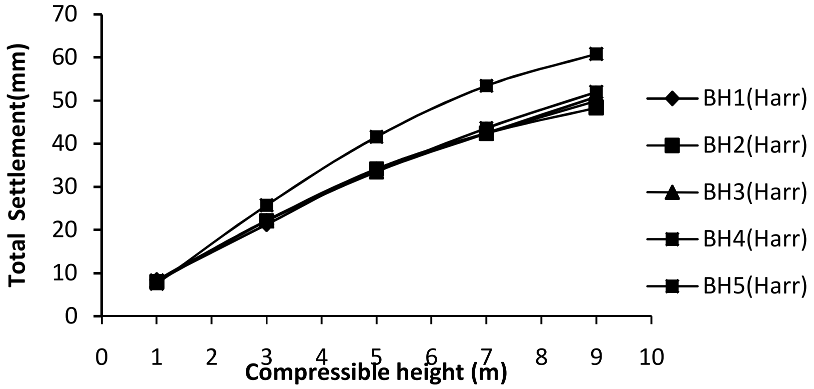

Figure 5a: Total settlement with foundation depth on TAC-1(Harr's Approach)

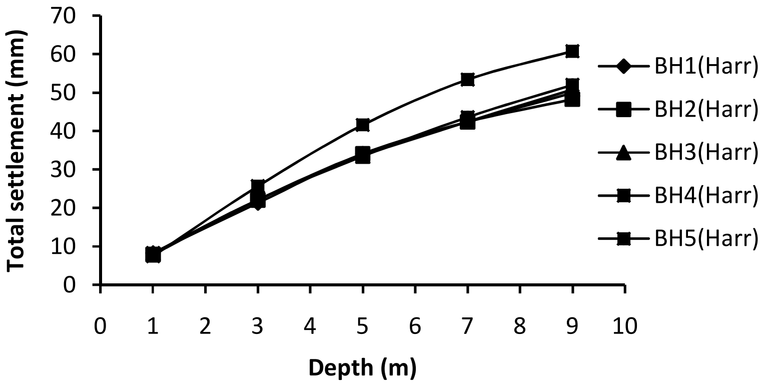

Figure 5b: total settlement with foundation depth on TAC-2 (Harr's Approach)

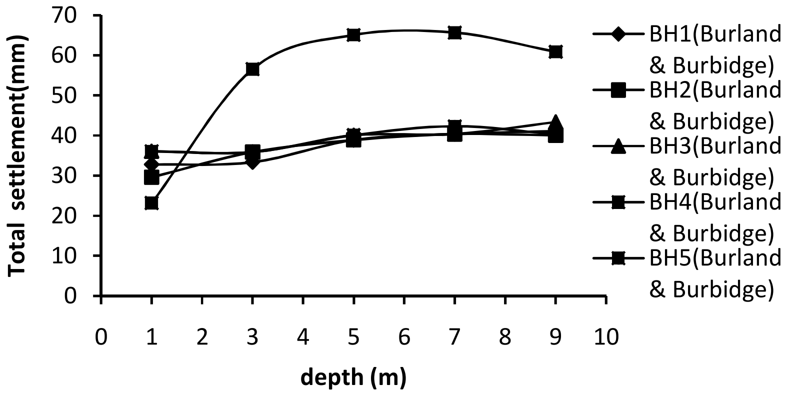

Figure 6a: Total settlement with foundation depth on TAC-1 (Burland & Burbidge)

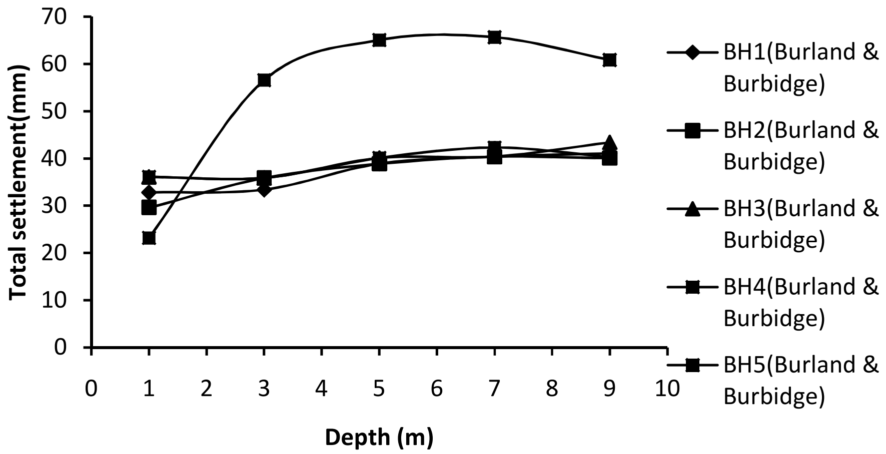

Figure 6b: Total settlement with foundation depth onTAC-2 (Burland & Burbidge Approach)

Total Settlement on Sand

The maximum total settlement (p_t) given by the expression;

$$\rho_t = \rho_i + \rho_c \qquad (16)$$

Is obtained from Table 3, while variation of total settlement with depth on both tanks are depicted in Figures 6 and 7. Harr's approach, and Burland and Burbidge approach showed progressive increase in total settlement with foundation depth, but soils around BH 4 had higher total settlement values compared to other sections within tanks vicinity.

Table 2: Bearing Capacity (SPT Approach)

	BH No	Depth of Fdn (m)	Foundation Equivalent Breadth, B (m)	D_f / B	Average SPT value (N)	Depth Factor F_d	Allowable bearing capacity q_a (kN/m^2)
TAC-1	1	1	43.24	0.023	12	1.01	147
		3		0.069	15	1.02	198
		5		0.115	16	1.05	204
		7		0.161	18	1.05	229
		9		0.208	20	1.07	259
	2	1	43.24	0.023	13	1.01	159
		3		0.069	14	1.02	173
		5		0.115	16	1.05	204
		7		0.161	18	1.05	229
		9		0.208	21	1.07	272
	3	1	43.24	0.023	11	1.01	134
		3		0.069	14	1.02	173
		5		0.115	15	1.05	191
		7		0.161	18	1.05	229
		9		0.208	19	1.07	246
	4	1	43.24	0.023	16	1.01	196
		3		0.069	9	1.02	111
		5		0.115	9	1.05	114
		7		0.161	10	1.05	127
		9		0.208	12	1.07	155
	5	1	43.24	0.023	11	1.01	134
		3		0.069	14	1.02	173
		5		0.115	15	1.05	191
		7		0.161	17	1.05	216
		9		0.208	18	1.07	233
TAC- 2	1	1	29.15	0.034	16	1.01	197
		3		0.103	19	1.02	241
		5		0.172	22	1.05	282
		7		0.240	25	1.08	330
		9		0.308	22	1.10	295
	2	1	29.15	0.034	20	1.01	246
		3		0.103	21	1.02	266
		5		0.172	24	1.05	307
		7		0.240	26	1.08	343
		9		0.308	21	1.10	282
	3	1	29.15	0.034	25	1.01	308
		3		0.103	26	1.02	330
		5		0.172	27	1.05	346
		7		0.204	29	1.08	383
		9		0.308	24	1.10	322
	4	1	29.15	0.034	17	1.01	209
		3		0.103	22	1.02	279
		5		0.172	25	1.05	320
		7		0.204	22	1.08	290
		9		0.308	18	1.10	242
	5	1	29.15	0.034	18	1.01	222
		3		0.103	19	1.02	241
		5		0.172	20	1.05	256
		7		0.204	21	1.08	277
		9		0.308	23	1.10	309

Table 3: Settlement Analysis on Sand

Tank	BH No.	Depth z(m)	SPT $\bar{N}$	Poisson ratio, μ	Angle of friction (φ)	Elastic Modulus E(Mpa)	Coefficient of volume compressibility m_v (m^2/MN)	Immediate settlement ρ_i (mm) Harr's Approach	Immediate settlement ρ_i (mm) Burland & Burbidge Approach	Consolidation settlement, ρ_c (mm)
TAC-1	1	1	12	0.333	30	12.09	0.055	2.5	27.0	5.8
		3	15	0.326	31	14.34	0.047	7.7	19.8	13.6
		5	16	0.319	32	14.81	0.047	13.3	18.1	20.8
		7	18	0.319	32	15.77	0.044	17.3	15.3	25.1
		9	20	0.312	33	16.73	0.042	21.0	12.2	28.9
	2	1	13	0.326	31	13.38	0.051	2.5	24.2	5.4
		3	14	0.326	31	13.86	0.049	8.0	21.8	14.1
		5	16	0.319	32	14.81	0.047	13.3	18.1	20.8
		7	18	0.319	32	15.77	0.044	17.3	15.3	25.1
		9	21	0.312	33	17.20	0.041	20.5	12.3	27.8
	3	1	11	0.333	30	12.42	0.053	2.7	30.5	5.6
		3	14	0.326	31	13.86	0.049	8.0	21.8	14.1
		5	15	0.326	31	14.81	0.046	13.3	19.8	20.3
		7	18	0.319	32	15.77	0.044	17.3	15.3	25.1
		9	19	0.319	32	16.25	0.043	21.6	14.2	29.2
	4	1	16	0.319	32	14.81	0.047	2.3	18.0	5.2
		3	9	0.340	29	11.47	0.056	9.5	40.4	16.2
		5	9	0.340	29	11.47	0.056	16.9	40.4	24.7
		7	10	0.333	30	11.95	0.054	22.6	34.9	30.8
		9	12	0.333	30	12.90	0.050	26.9	27.0	33.9
	5	1	11	0.333	30	12.42	0.053	2.7	30.5	5.6
		3	14	0.326	31	13.86	0.049	8.0	21.8	14.1
		5	15	0.326	31	14.81	0.046	13.2	19.8	20.3
		7	17	0.319	32	15.29	0.045	17.9	16.6	25.7
		9	18	0.319	32	15.77	0.044	22.2	10.5	29.8
TAC-2	1	1	16	0.319	32	14.82	0.047	4.0	16.2	7.5
		3	19	0.319	32	16.25	0.042	12.3	18.6	19.2
		5	22	0.312	33	17.68	0.040	19.2	15.2	27.0
		7	25	0.306	34	19.12	0.038	25.2	12.7	32.9
		9	22	0.312	33	17.78	0.040	34.3	15.2	41.9
	2	1		0.312	33	16.73	0.042	3.6	17.3	7.5
		3	20	0.312	33	17.20	0.041	11.6	16.2	19.2
		5	21	0.305	34	18.64	0.039	18.3	13.4	27.0
		7	24	0.299	35	19.60	0.038	24.7	12.0	32.9
		9	26	0.312	33	17.21	0.042	35.5	16.2	41.9
			21							
	3	1		0.306	34	19.12	0.038	3.2	12.7	6.7
		3	25	0.299	35	19.59	0.038	10.3	12.0	17.8
		5	26	0.298	35	20.07	0.037	17.1	11.4	25.6
		7	27	0.298	35	21.03	0.035	23.4	10.3	30.3
		9	29	0.306	34	18.64	0.039	32.8	13.4	33.7
			24							
	4	1		0.319	32	15.29	0.045	3.9	21.7	8.0
		3	17	0.312	33	17.68	0.040	11.3	15.2	18.7
		5	22	0.306	34	19.12	0.039	17.9	12.7	27.0
		7	25	0.312	33	17.78	0.040	27.0	15.2	34.6
		9	22	0.319	32	15.77	0.040	38.5	20.1	43.9
			18							
	5	1	18	0.319	32	15.74	0.044	3.8	20.1	7.8
		3	19	0.319	32	16.25	0.044	12.3	18.6	20.6
		5	20	0.312	33	16.73	0.042	20.3	17.3	29.1
		7	21	0.312	33	17.21	0.042	27.9	16.2	36.3
		9	23	0.306	34	18.16	0.040	33.7	14.2	40.0

CONCLUSION

The following conclusions can be drawn based on the findings;

i. The induced vertical stress distribution with depth from PMS product at centre of tanks is generally found to be within the net allowable bearing capacity of the soil.

ii. Allowable bearing capacity generally increased with foundation depth, but at BH4, $q_{n(a)}$ decreased with depth up to 3m, attaining a value of about 110 kN/m^2 for TAC-1. Beyond which allowable bearing capacity increased with depth.
iii. Higher bearing capacity values were attained on TAC-2 site (Figure 2b) but $q_{n(a)}$ decreased noticeably in BH4 from 5m depth.
iv. Both Harr's approach and Burland and Burbidge approach showed increase in immediate settlement with foundation depth.
v. Total settlement was generally higher in TAC-1 than TAC-2

REFERENCES

[1] S A Ola. *Q.J. Eng. Geol. London*, **1982**, 15, 317-324.
[2] S B Akpila. *Inter-World Journal of Science and Technology*, **2007**, 3(4), 600-607.
[3] S B Akpila and O ThankGod. *International Journal of Physical Sciences*, **2008**, 3(1), 51-58.
[4] S K Kong and D Q Yang. Behaviour of Cylindrical Welded Steel Tanks Supported on Pad Foundation over Reclaimed Land. Proceedings of 5th International Symposium on Field Measurements in Geomechanics, Singapore, **1993**, 169-175.
[5] G G Meyerhof. *Journal of the Soil Mechanics and Foundation Division*, ASCE, **1956**, 82(1), 1-19.
[6] J E Bowles. Foundation Analysis and Design, 5th Edition, McGraw-Hill, New York, **1997**; pp 263-266.
[7] R H G Parry. *Journal of Geotechnical Engineering Division, ASCE*, **1977**, 103(9), 1014-1019.
[8] S B Akpila. *Scientific Journal of Pure and Applied Sciences*, **2013**, 2(2), 72-78.
[9] R F Craig. Soil Mechanics, 4th Edition, ELBS Edition, Great Britain, **1987**.
[10] M E Harr. Fundamentals of Theoretical Soil Mechanics, McGrey-Hill, New York, **1966**.
[11] M D Braja. Principle of Foundation Engineering, 4th Edition, PWE Publishing Company, USA, **1999**; p 243.
[12] J B Burland and M C Burbidge. Settlement of Foundations on Sand and Gravel. *Proceedings of Institution of Civil Engineers*, **1985**, 78(1), 1325-1381.
[13] A W Skempton and L Bjeruum. *Geotechnique*, **1957**, 1, 168-178.
[14] A W Skempton and MacDonald. The Allowable Settlement of Buildings, Proceedings, Institute of Civil Engineers, **1956**, 5(III), 727-784.
[15] D E Polshin and R A Tokar. Maximum Non Uniform Settlement of Structures. Proc. of the 4th International Conference of Soil Mechanics and Foundation Engineering, London, **1957**, 1, 402-405.
[16] H E Wahls. *Journal of the Geotechnical Division*, **1981**, ASCE, 107 (11), 1489-1504.