Evaluation of Liquefaction Potential of Soils Using Standard Penetration Method

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ABSTRACT

The liquefaction potential of soils of metropolitan Lagos, Nigeria was assessed as a component of routine geotechnical site evaluation for assurance of pre-emptive provision against failure of infrastructure in the megacity.

A syndicated geotechnical evaluation of sites for high-rise buildings (i.e. not less than 5 storeys) throughout the entire Lagos state was conducted for 12 months. Standard Penetration Test (SPT) number (N) and Cone Penetration Test (CPT) data and accompanying soil sampling scheme were conducted in accordance with BS 5930 for 18 exploratory boreholes spread across Lagos. The soil samples collected were further tested in the laboratory in accordance with BS 1377,(BSI 2000), as modified, to reflect the liquefaction evaluation objectives and procedures for particle size gradation, normalized SPT blow counts$(N_1)_{60,}$ Cone resistance (C_N) and cyclic resistance ratio. The outcomes were compared with respective standard soil liquefaction bench marks. The locations of the 18 boreholes are namely Apapa-Bagagry axis, Ojo, Ikeja-Agege axis, Lagos Island, Eti-Osa axis, Ibeju-Leki axis, Alimosho, Oshodi-Isolo axis, Ifako-Ijaye axis and Epe.

The results revealed that the:(i) larger percentage of Lagos metropolitan city of about 75% of area(km^2) is characterised with high water table; fine to medium sands, silt sands and weak clays / peat with low $(N_1)_{60,}$ (ii) loose soils (N < 5) at shallow depth of about 10m and water saturation condition are more likely susceptible to liquefaction near costal shelf with normalized SPT blow count $(N_1)_{60}$ of less than 22 and normalized CPT cone resistance (q_c) of less than 15MPa, (iii) Cyclic Resistance Ratio limits plotted on standard liquefaction susceptibility charts were within the liquefiable zones, and evaluation based on the particle size characteristics also proved that almost 100% of soils considered were within the established liquefiable boundaries,

Key words: Standard Penetration Test (SPT), Liquefaction

1.0 INTRODUCTION

Soil liquefaction describes the behaviour of soil that, when loaded, suddenly suffers a transition from a solid state to a liquefied state, manifesting the properties of heavy liquid, which is more likely to occur in loose and or moderately saturated granular soils, such as silty sands, sands and gravels with poor drainage capped or containing seams of impermeable sediments (Abdohun, 2010). Most of the soils with the enumerated characteristic features and located in the coastal region in respective continents exhibited the liquefaction process. Also during cyclic undrained loading, (e.g., earth movement and loadings imposing vibration), loose sands tend to decrease in volume, which produces an increase in pore water pressures and consequently a decrease in effective strength and shear strength (Sanchez, 2002). It has been discovered that deposits most susceptible to liquefaction are young (Holocene-age deposited within the last 10,000 years), sands and silts of similar grain size (well-sorted), in beds of at least five meters thick, and saturated with water. Such deposits are often found along river-beds, beaches, dunes, and areas where windblown silt and sand have accumulated. Some examples of indication of liquefaction include quick sand, quick clay, turbidity currents, and earthquake liquefaction. Further through 1999 Kocaeli earthquake (www.google.com), and the statistical record of soil liquefaction due to earthquake, flood, and or landslides etc, in Asia and in the USA and the little effects in some parts of European countries (Matlock et al., 2008). It was discovered that much disaster is eminent due to soils susceptibility to liquefaction.

A number of failures of embankments, natural slopes, earth structures and foundations have been attributed to the liquefaction of sands caused by either static or seismic loading. Many case histories of landslides or flow failures due to liquefaction have also been cataloged to have being occurring since early twenties the century and have destroyed hundreds of bridges, caused massive landslides and a number of buildings, houses and other infrastructures. To date and after about 30 years of intensive research, much progress has been made in understanding the liquefaction phenomena of cohesionless soils under static and seismic loading. The enormity of the probable damages due to liquefaction therefore deserves more robust studies and as a proactive and preventable strategy. At least, the reduction of the damages should be possible if the probability of likelihood were known during the planning stage of any infrastructural development, variety of methods for evaluating the liquefaction potential of soils to go along with the geotechnical site evaluation were examined consequently in this study.

2.0 MATERIALS AND METHODS

This involved the activities to develop the necessary data and field investigation by using Standard Penetration Test (SPT) method.

2.1 Field Investigation

Field invetigation was accomplished through a syndicated arrangement during the geotechnical site investigation for high rise buildings throughout the entire Lagos state. Standard Penetration Test (SPT) and soil sampling scheme were developed according to BS 5930 for 18 exploratory boreholes at ten main locations, namely Apapa-Badagry, Ojo, Ikeja-Agege, Lagos Island, Ett-Osa, Ibeju-Leki. Alimosho, Oshodi-Isolo, Ifako-Ijaye and Epe.

2.2 Evaluation of Liquefaction Potential using SPT Resistance Method for Cohesionless Soils

Investigations based upon in-depth theoretical study and extensive review of field performance of sands and silty sands during actual earthquakes in the Western United States, Alaska, South America, Japan and China, show that a high correlation exists between soil liquefaction resistance under earthquake shaking and soil SPT resistance (Lam and Kapuskar 2002), Based on this correlation, a design procedure for evaluating the liquefaction potential in this research work was developed as discussed below

(a) Field investigation/Laboratory Testing Data base: The number of blows (i.e. N-value) required for different layers at various depth of soil, were noted and corresponding collection of the disturbed soil sample taken for laboratory analysis. The parameters relevant include the particle size distribution, Atterberg limits, and moisture content and compared to the criteria/liquefaction bench mark given by Yam et al., (1991)

(b) Corrected N-value $(N_1)_{60}$ determinations: Using the formula.

$$(N_1)_{60} = 1\text{-}29\ C_N\ ER_m\ N_{SPT}/60 \qquad (1)$$

where $(N_1)_{60}$ = normalized standard penetration resistance under an effective overburden pressure of 1 tsf (95.76kN/m^2) for an SPT test performed with a hammer providing 60% of the theoretical free-fall energy, C_N = and overburden correction factor, equal to $\left(\sigma_0'/_{2000}\right)^{-1/2}$ but not greater than 2.0, where σ_0' is in psf, or $\left(\sigma_0'/_{95.76}\right)^{-1/2}$ where σ_0' is in kN/m^2 (Tokida *e tal*,1992; Tokimatsuand Asaka 1998). ER_m = energy ratio defined as the percent of theoretical free-fall energy delivered to the drill rods.

(c) Comparison of the computed $(N_1)_{60}$ to references given by (Hryciw. 2003), (Holzer et al., 2002), (Hu et al., 2002).

(i) Normalized SPT blow count $(N_1)_{60} < 22$ is potentially liquefiable

(ii) Normalized SPT blow count $(N_1)_{60} < 30$ is potentially liquefiable

(iii) Normalized SPT blow count $(N_1)_{60} > 30$ is not potentially liquefiable

(d) By indication, it could be seen that two of the criteria stated above i.e. (ii) and (iii) are the same in terms of soils liquefaction potential in relation to normalized SPT blow count $(N_1)_{60}$. It should also be noted that all results from the field investigation and laboratory testing were used summarily to form a base map for potentially liquefiable soils for different locations in Lagos State

2.3 Cyclic Resistance Ratio (CRR)

Cyclic Resistance Ratio (CRR) curves were positioned to separate regions with data indicative of liquefaction from regions with data indicative of non liquefaction.

If three or more of the above criteria indicate that liquefaction is not likely; the potential for liquefaction can be dismissed. Otherwise, a more rigorous analysis of the liquefaction potential of soil is required. However, it is possible that other information, especially historical evidence of past liquefaction or sample testing data collected during the subsurface investigation, may raise enough of a concern that a full liquefaction analysis would be appropriate even if three or more of the liquefaction evaluation criteria indicate that liquefaction is unlikely,

3.0 RESULTS AND DISCUSSION

3.1 Standard Penetration Test Values

N_{SPT}-log

The N_{SPT} - log eventually developed equation 1 at different depth and the various locations were compiled. Soil samples were collected. The corrected normalized N-value $(N_1)_{60}$ were determined using the formula expressed in equation 1. The results of the evaluation are summarized in Tables 1, 2 and 3 for the three classified location with respect to proximity to the coast, in respectively most northerly and further away from the ocean and water table measurement also taken, so as to determine other important geotechnical parameters necessary for the correction of the N - values.

Table 1 Liquefaction Evaluation for group 1 sub soils- northern most from coast.

S/N	Location	Borehole and geotechnical characteristics						$(N_1)_{60}$	Remark
		BH	D (m)	WL(m)	(kN/m^2)	N_{SPT}	C_N		
1	Ikeja Agege Axis	BH1	6.0	2.0	70.3	50	1.17	57	Not
			12.0	2.0	125.3	21	0.87	18	Yes
			15.0	2.0	153.1	33	0.79	25	Not
		BH2	1.0	2.0	19.0	28	2.24	54	Not
			6.0	2.0	74.8	50	1.13	55	Not
			9.0	2.0	107.65	50	0.94	45	Not
			12.0	2.0	135.25	50	0.84	41	Not
			15.0	2.0	162.5	50	0.77	37	Not
2	Lagos Mainland	BH1	3.0	0.70	28.46	6	1.83	11	Yes
			6.0	0.70	50.06	14	1.38	19	Yes
			7.5	0.70	69.86	34	1.17	38	Not
			9.0	0.70	89.66	28	1.03	28	Not
			12.0	0.70	124.76	32	0.88	27	Not
			15.0	0.70	164.36	45	0.76	33	Not
3	Alimosho	BH1	9.0	1.00	46.60	4	1.43	6	Yes
4	Oshodi Isolo	BH1	1.5	3.75	28.50	5	1.83	22	Yes
			3.0	3.75	57.00	11	1.30	21	Yes
			4.5	3.75	78.15	26	1.11	9	Yes
			6.0	3.75	91.95	20	1.02	14	Yes
			9.0	3.75	119.55	23	0.89	28	Not
			12.0	3.75	147.90	63	0.80	20	Yes
			15.0	3.75	179.63	16	0.73	20	Yes

Depth of probable occurrence: 1.5m – 15.0m

Table 2 liquefaction evaluation for group II sub soils intermediate distance from coast.

S/N	Location	Borehole and geotechnical characteristics						$(N_1)_{60}$	Remark
		BH	D (m)	WL(m)	(kN/m2)	N_{SPT}	C_N		
1	Festac Town Axis	BH1	3.0	2.5	47.6	10	1.42	14	Yes
			6.0	2.5	78.2	22	1.11	24	No
			12.0	2.5	145.4	28	0.81	22	Yes
2	Ojoo	BH1	3.0	0.75	35.7	15	1.64	24	No
			8.0	0.75	94.2	22	1.01	22	Yes
			15.0	0.75	176.1	30	0.74	21	Yes

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Depth of probable occurrence: 3.0m – 15.0m

Table 3 liquefaction evaluations for group III sub soils- southernmost and nearest to coast.

S/N	Location	Borehole and geotechnical characteristics BH D (m) W_L(m) (kN/m^2) N_{SPT} C_N	$(N_1)_{60}$	Remark

1	Apapa Badagry	BH1	2.0	4.8	38.0	11	1.59	17	yes
	Axis		3.5	4.8	66.5	12	1.20	17	Yes
			5.0	4.8	93.4	13	1.01	13	Yes
		BH2	1.5	5.79	25.5	8	1.94	15	Yes
			3.0	5.79	51.0	8	1.37	11	Yes
			4.50	5.79	76.5	5	1.12	5	Yes
			15.0	5.79	181.27	21	0.73	15	Yes
		BH3	2.0	5.22	34.0	8	1.68	13	Yes
			3.5	5.22	59.5	12	1.27	15	Yes
			5.0	5.22	85.0	14	1.06	14	Yes
	Lagos Island		6.5	5.22	101.8	15	0.97	14	Yes
2	(Dolphin Estate)	BH1	3.0	0.50	34.00	13	1.68	21	Yes
			6.0	0.50	69.10	17	1.18	19	
			12.0	0.50	125.8	23	0.87	19	Not
		BH2	3.0	0.50	38.75	6	1.57	9	Not
			14.0	0.50	76.20	21	1.12	23	Not
			15.0	0.50	83.40	25	1.07	26	Not
		BH3	3.0	0.50	38.75	15	1.57	23	Not
			7.5	0.50	73.50	19	1.14	21	Yes
			12.0	0.50	105.8	23	0.95	21	Yes
3	Eti Osa	BH1	1.5	0.70	19.71	6	2.20	12	yes
			3.0	0.70	32.01	7	1.73	12	yes
			5.0	0.70	51.66	6	1.36	8	yes
			6.5	0.70	67.71	9	1.19	10	yes
			8.0	0.70	81.51	9	1.08	9	Yes
			10.0	0.70	103.40	4	0.96	4	Yes
			11.5	0.70	119.34	3	0.90	3	Yes
			13.0	0.70	135.93	18	0.84	15	Yes
			15.0	0.70	156.79	16	0.78	12	Yes
		BH2	1.5	0.55	20.07	20	2.18	39	No
			3.0	0.55	36.12	4	1.63	6	Yes
			8.0	0.55	89.12	6	1.04	6	Yes
			13.0	0.55	141.87	15	0.82	12	Yes
			15.0	0.55	163.27	13	0.77	13	Yes
		BH3	1.5	0.43	18.01	3	2.61	6	Yes
			3.0	0.43	33.31	4	1.70	7	Yes
			6.5	0.43	69.01	12	1.18	14	Yes
			11.5	0.43	121.51	10	0.89	9	Yes
			15.0	0.43	158.96	18	0.76	14	Yes
4	Ibeju – Lekki	BH1	1.5	0.00	15.30	8	2.50	15	Yes
			4.5	0.00	49.65	14	1.39	19	Yes.

Depth of probable occurrence: 2.0 m – 6.5m

3.2 Cyclic Resistance Ratio (CRR)

Seed et al., (1985) t established several charts for estimating SPT-based CRR using the corrected penetration resistance $(N_1)_{60}$. Due to the limitation of the charts in the computation efficiency and probabilistic analysis, Youd, et al., (2001) formulated the CRR curve established by Seed et al. (1985). Later, the CRR curve was further modified as;

$$CRR = 1/34 - (N_1)_{60} + (N_1)_{60}/135 + 50/\{10*(N_1)_{60} + 45\}^2 - 1/200 \qquad \text{(equ 2)}$$

Cyclic Resistance Ratio (CRR) curves were positioned to separate regions with data indicative of liquefaction from regions with data indicative of non liquefaction. Figure 1 was developed by plotting corrected SPT $(N_1)_{60}$ against Cyclic Resistance Ratio (CRR). Cyclic resistance ratio (CRR) were determined for all the locations chosen for Standard Penetration Test (SPT) and the results were illustrated in Figures 2-10. However using Seed et al (1985) and Youd (2001) the liquefaction limit curve as shown in Figures 2- 10 indicated that the upper and lower parts of the chart (curve) indicates the liquefaction and non-liquefaction points respectively.

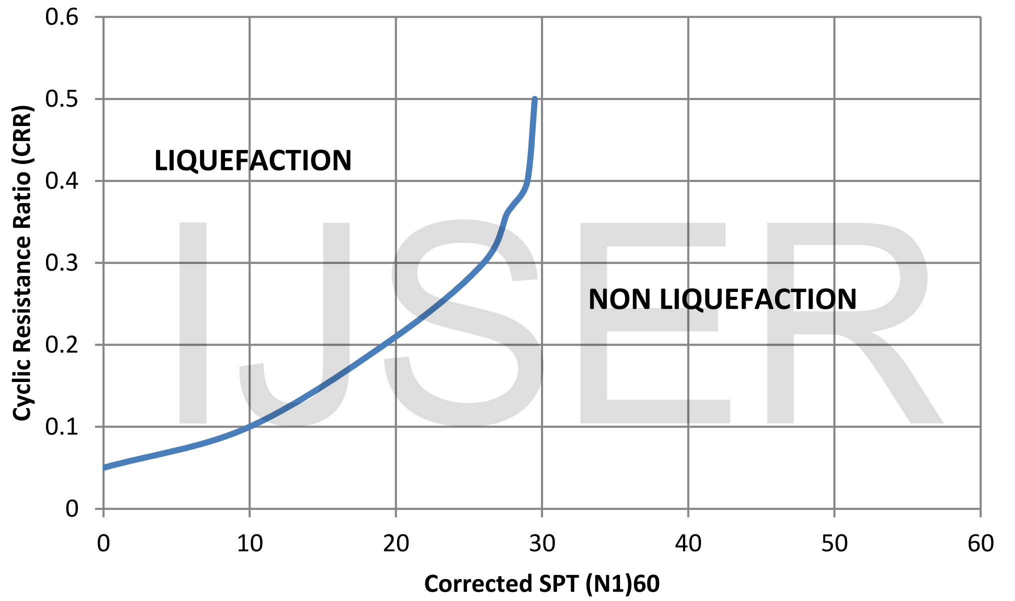
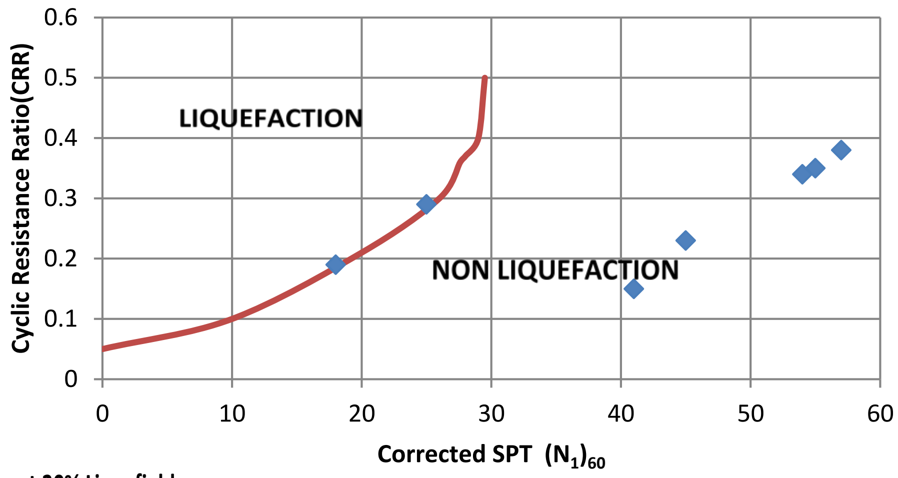
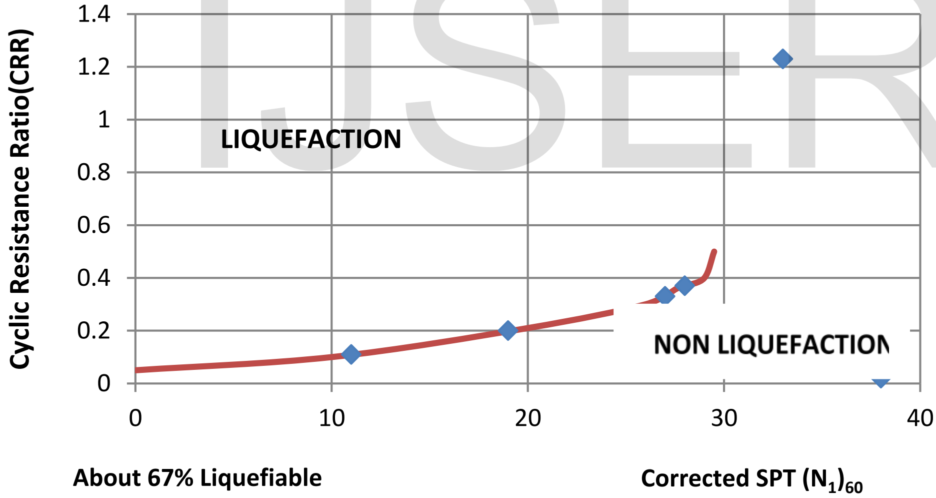


Figure 1 Modified Seed et al (1985), Youd (2001) Liquefaction Limit Curve Used for Evaluation of Liquefaction Probabilty



About 30% Liquefiable

Figure 2 Relationships between CRR and Corrected SPT-Ikeja-Agege Axis



About 67% Liquefiable

Figure 3 Relationships between CRR and SPT- Lagos Mainland

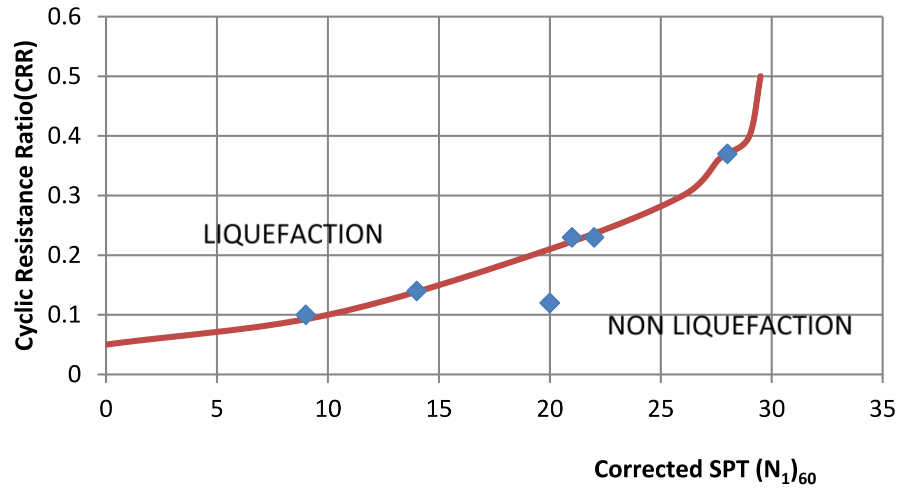


Figure 4 Relationships between CRR and Corrected SPT- Oshodi-Isolo Axis

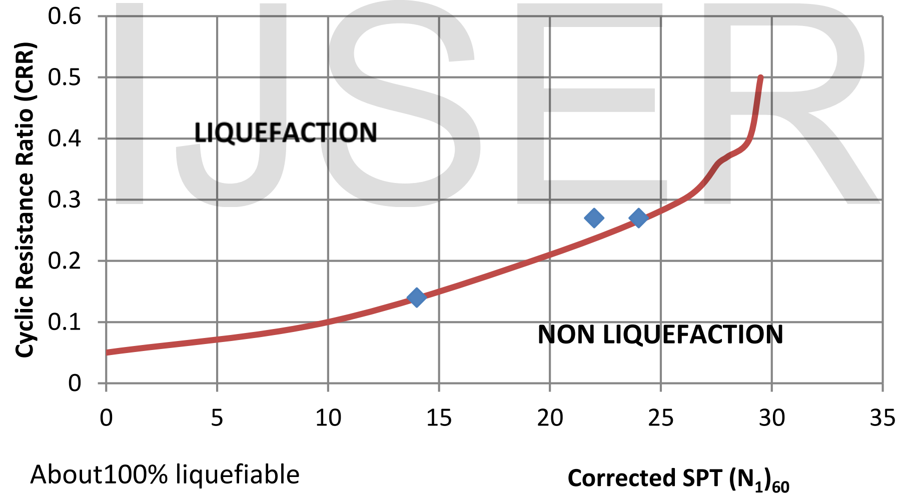


Figure 5 Relationships between CRR and Corrected SPT- Festac Town Axis

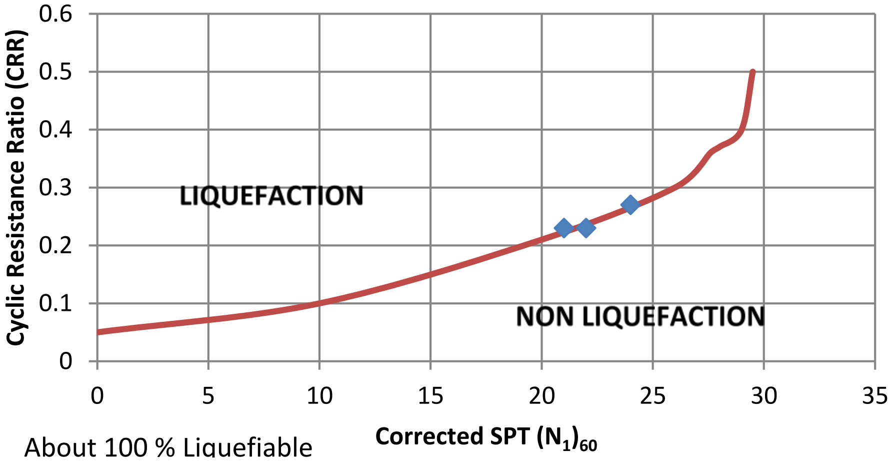


Figure 6 Relationships between CRR and Corrected SPT- Oojo

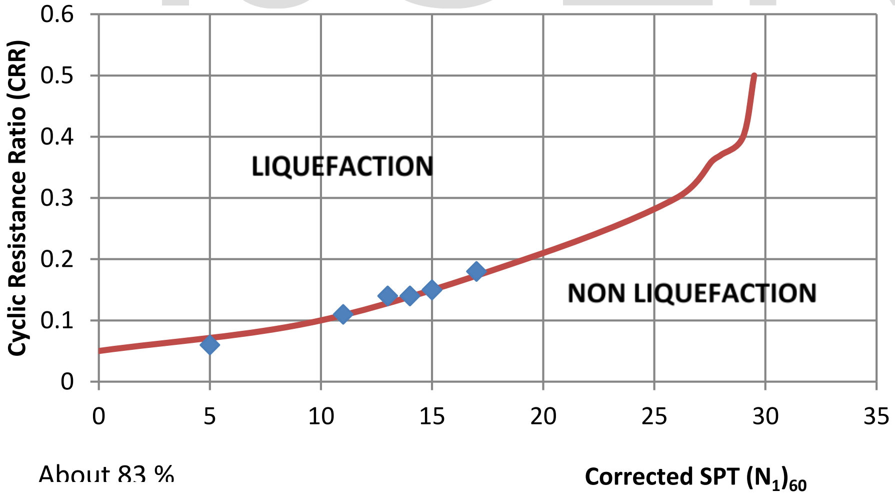


Figure 7 Relationships between CRR and Corrected SPT- Apapa Badagry

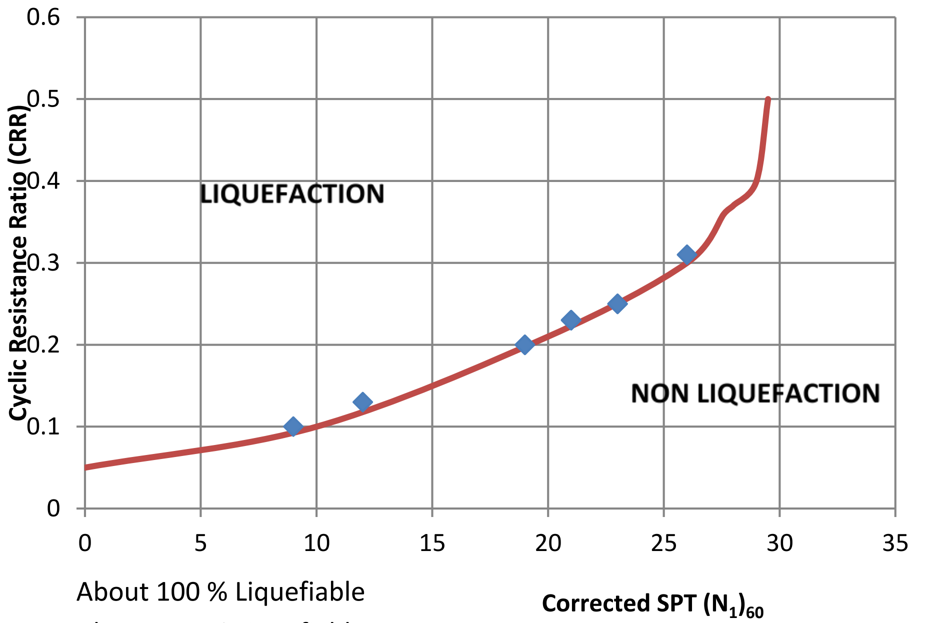


Figure 8 Relationships between CRR and Corrected SPT- Lagos Island-Dolpin Estate

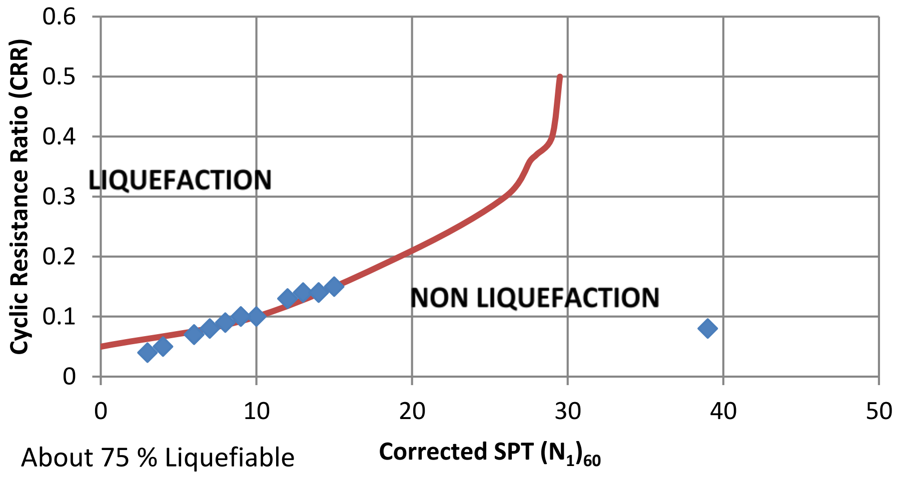
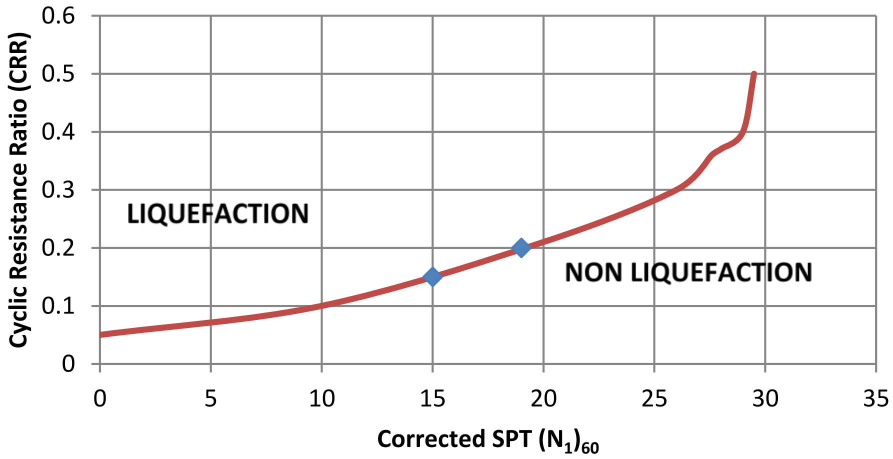


Figure 9 Relationships between CRR and Corrected SPT- Eti-Osa



About 100 %

Figure 10 Relationships between CRR and Corrected SPT-Eti-Osa

3.3 Summary and Facts from Standard Penetration Test (SPT)

Generally the soil shows increase in the N-value with depth in all locations, which is an indication of an increase in shear strength of the soil with depth. However, at the locations where clay soils were encountered during the site investigation, there was indication of more plasticity at deeper layer. Also in the areas where peat was observed, it could be as a result of decomposition of organic debris transported by water because there was evidence of regular water logging in that vicinity. The entire area is characterized with high water table. From the N-values obtained it could be seen that higher percentage of Lagos state soils are loose (N< 5) and likely fine to medium sands, silt sands and weak clays / peat.

Based on the corrected N - values, the entire study area can be grouped in to three distinct classes respectively reflecting relative geographical position in the metropolitan Lagos and the coast. Tables 1, 2 and 3 give the summary of evaluation respectively for the location in north most, the transition and the south most and nearest to the coast. In other words, Ikeja -Agege, Oshodi - Isolo and the larger mainland belong to one Class; Festac Town and Ojoo, the second while the areas such as Apapa Badagry, Eti - Osa and the Island of Lagos constitute the third. From the inspection of the results of the evaluation exercise, it is apparent that the sub soils of the first group, the Mainland, Ikeja, Agege etc are not likely susceptible to liquefaction to considerable depth .

The N_{60} values are greater than 30, the bench mark value (Seed et al.) whereas the region in between are not also vulnerable, but to a lesser extent. However, the sub soils in the third group, Apapa - Badagry, Eti -Osa, Lekki, etc and other waterlogged areas; and which are nearest to the coasts or big bodies of water, indicate the most vulnerable to liquefaction. The corrected N values are less than 22 in all the boreholes and the depths explored in these areas. Even in some locations, the values are less than 10. At an earthquake driven loading, loose sands tend to decrease in volume, which produces an increase in their pore water pressure and consequently decrease in shear strength. The reduction in effective stresses cannot definitely prevent, deformation during cyclic loading, which would depend on the density of the soil, the magnitude and duration of the cyclic loading, and amount of shear stress reversal. The most common type of soil in Lagos state is silty sand and well graded sand which is as a result of water depositional processes. While the little clay that were found are located in the mainland where a large number of industries that uses heavy machinery with high level of vibration are situated. As noted earlier, this geology causes the level of susceptibility of the soils in Lagos state to liquefaction as a result of ground water movements, vibration of moving vehicles and locomotives, industrial and commercial activities of the populace in the state.

It might well be known that there has never been a case of earthquake of significant magnitude around the Lagos metropolis, or even entire country, Nigeria could not be ruled out for potential soil liquefaction. The possibility should not be ruled out and hence the necessity to prepare for the eventuality. It can prove to be a worthwhile proactive strategy and schism for reduction of consequences of collapse of infrastructure, if perchance an earth quake were to occur in the densely populated and industrialized Lagos megacity. Thus the evaluation of soils in some area that are seen as liquefaction susceptible based on the hypothesis set out at the study concept. Generally, fine-grained soils are susceptible to potential liquefaction if they satisfy the criteria of (i) Normalized SPT blow count $(N_1)_{60} < 22$ (Hryciw, 2003) and (ii) Normalized SPT blow count $(N_1)_{60} < 30$ (Holzer et al., 2002). Incidentally, the first criterion can be taken as dominating for conservative geotechnical engineering practice. For the evaluation of the susceptibility of soil to liquefaction, computed $(N_1)_{60}$ values were compared with the preferred criterion for fine medium sands, (quoted earlier); $(N_1)_{60}$ less than or equal to 22, (Hryciw, 2003).

4.0 CONCLUSION

From the SPT test data with the soil liquefaction susceptibility bench marks, conducted at state wide locations in Lagos Metropolitan, Nigeria, the following conclusions were made:

(i) From the N-values obtained it could be seen that higher percentage of Lagos state soils are loose (N< 5) and likely fine to medium sands, silt sands and weak clays / peat. In the areas where peat was observed, it could be as result of decomposition of organic debris transported by water because there was evidence of regular water logging in that vicinity.

(ii) A liquefaction susceptibility ranking with respect to the coastal shelf was established with nearness to the pool of water more pronounced.

(iii) The soils at shallow depth and by the coast would liquefy before those in the farther main land.

(iv) Some of the steps to ameliorate include control of extraction of underground water and rigorous and periodic enlightenment on the dangers and consequences of liquefaction provision in the structural design.

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