ISSN 2229-5518

Cone Penetration Test to Examine Susceptibility of Soil to Liquefaction

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ABSTRACT

Soil liquefaction is the gradual loss of effective strength and development of unrecoverable strain due to induced vibration or repeated loads applied to fine-grained soils. Earthquakes, volcanoes, human activities and construction vibratory works are common sources of liquefaction with consequential negative impacts on human and physical resources in and around neighbourhoods. Knowledge of the liquefaction potential of a soil at the planning and the design stage is a preventive strategy against infrastructure failure and damages. This study aimed at examines the susceptibility of soil to liquefaction in Lagos, Western-Nigeria.

Field tests using Cone Penetrometer were carried out within the study area for eleven (11) locations with thirty-five (35) points. CPT cone resistance q_c for eleven (11) locations with thirty-five (35) points were developed Liquefaction has also been shown to occur if the normalized CPT cone resistance (q_c) is less than 157 tsf (15MP_a) (Idriss and Boulanger, 2006). Generally the cone resistance (q_c) for all the points explored were less than 157 tsf (15MP_a), which indicated that the study area is liquefiable potential.

The pre-knowledge of liquefaction potential of a soil deposit to facilitate the incorporation of provisions to counteract the effects in the structural design of infrastructure for civil engineering and other purposes is strongly desirable in view of the economic and physical benefits derivable.

Key words: *Liquefaction, Cone Penetration Test (CPT)*

1.0 INTRODUCTION

Liquefaction is a phenomenon that occurs when a sudden shock or cyclic loading causes soil pore pressures to temporarily increase until the effective pressure is zero. Residual pore pressure increases on successive stress cycles. Pore pressure also increases with increasing strain. This causes the soil particles to "float", leaving the soil with very low shear strength and allowing the unconfined soil to flow laterally. Another explanation is that when saturated sand is subjected to vibrations, it tends to compact and decrease in volume. If the sand is not allowed to drain, the pore water pressure will increase. If the pore water pressure builds up to equal the overburden pressure, the effective stress becomes zero. The sand loses strength and becomes liquefied.(Juang et al., 2006)

The loading conditions necessary to cause liquefaction exist most commonly during pile driving operations, and under earthquake conditions. Soils most susceptible to liquefaction are saturated, fine to medium-fine grained, loose sands; however, non-saturated clays may also be subject to liquefaction. The safety concern with liquefaction is related to buildings, or other structures bearing on these soils. When soils become liquefied, these structures lose support and could potentially collapse. The entire mass of soil under a structure does not have to be in a state of liquefaction for failure of the foundation to occur. Liquefaction at a single point may cause loads transfer to adjacent soils to become overstressed, resulting in settlement and tilting of the structure.

Sand boils frequently result from the liquefaction of loose, saturated soils during strong ground shaking. The conditions under which sand boils develop play an important part in assessing the effects of liquefaction. Therefore, it is important to have a clear understanding of the mechanics of liquefaction.

The term "liquefaction" is typically used to describe a variety of phenomena that causes soil deformations resulting from monotonic, transient, or repeated disturbance of saturated, cohesionless soils under untrained conditions (Beirill et al. 2009). The generation of excess pore pressures under untrained loading is a key aspect of liquefaction and the formation of sand boils. The evaluation of liquefaction hazards requires that the susceptibility of soils deposits be evaluated. However, not all soils deposits are susceptible to liquefaction. Therefore, several criteria are used by which liquefaction susceptibility can be assessed (Adib et al. 2007). These criteria include historical, geologic, compositional, and state criteria.

2.0 MATERIALS AND METHODS

2.1 Study Area

Lagos state is a metropolitan area that spreads over about 3345 sq km (1292 sq mi) which is located on four principal islands and adjacent mainland. The islands are connected to each other and to the mainland by bridges and landfills. Major sections of the city include (i) the old city, which now serves as the commercial district on western Lagos Island; (ii) Ikoyi Island, situated just east of Lagos Island and joined to it by a landfill; (iii) Apapa, the chief port district, located on the mainland; (iv) the residential Victoria Island; and (v) the industrialized Iddo Island.(vi) Important mainland suburbs, incorporated as part of the city in 1967, include Ebute-Metta, Yaba, Surulere, Ajegunle, Shomolu, Agege, Mushin, and Ikeja which is the state capital of Lagos state. Figure 1 shows the Geographical position of Lagos State as a coastal city in Nigeria.

Figure 1 Geographical position of Lagos State in Nigeria as a coastal city

2.2 Samples and Sample Collection

Field data collection was accomplished through a syndicated arrangement during the geotechnical site investigation for high rise buildings throughout within the study area. CPT cone resistance q_c for eleven (11) locations with thirty-five (35) points and sampling scheme were developed according to according to BS 5930 at these locations, namely Apapa-Badagry, Ojo, Ikeja-Agege, Lagos Island, Ett-Osa, Ibeju-Leki. Alimosho, Oshodi-Isolo, Ifako-Ijaye and Epe

2.2 Cone Penetration Test (CPT)

A CPT device that consists of a cylindrical probe with a cone-shaped tip with different sensors that allows a real time continuous measurement of soil strength and characteristics (model, capacity etc.) was used by pushing it into the ground at a speed of 2 cm/s. The CPT probe measures the normal stress on the tip, the sleeve friction and the pore water pressure. The data was read by a field computer that displays it real-time and stores it at regular depth intervals of 2.5 cm. The Georgia Tech In-Situ group approach was used.

A steel rod with a conical tip (apex angle of 60° and a diameter of 35.7 mm) was used to push at a rate of 2 cm/s into the soil. The steel rod has the same diameter as the cone. The penetration resistance at the tip and along a section of the shaft (friction sleeve) was measured. The friction sleeve is located immediately above the cone and has a surface area of 150 cm^2. The electric CPT is provided with transducers to record the cone resistance and the local friction sleeve. The CPT is standardized and the measurements are less operator-dependent than the SPT, thus giving more reproduce able results.

2.3 Recommended Screening Criteria for Liquefaction Susceptible Soil

Ohio EPA recommends using the fire screening criteria included in the U.S. EPA guidance document titled "RCRA subtitle D(258) Seismic Design Guidance for Municipal solid waste landfill facilities, EPA/600/ R-95/05/ April 1995 for completing a liquefaction evaluation:

Soil penetration Resistance: Hryciw (2003), states that soil layers with a normalized SPT blow-count $(N_1)_{60}$ less than 22 have been known to liquefy. Holzer et al. (2002), suggest an SPT value of $(N_1)_{60}$ less than 30 as the threshold to use for suspecting liquefaction potential.

Liquefaction has also been shown to occur if the normalized CPT cone resistance (q_c) is less than 157 tsf(15MP_a) (Idriss and Boulanger, 2006).

3.0 RESULTS AND DISCUSSION

3.1 Cone Penetration Test Values

CPT cone resistances q_c for eleven (11) locations with thirty-five (35) points were developed for clarity of the results the summary of these CPT result values are shown in the Table 1. Liquefaction has also been shown to occur if the normalized CPT cone resistance (q_c) is less than 157 tsf (15MP_a) (Idriss and Boulanger, 2006). Generally the cone resistance (q_c) for all the points explored were less than 157 tsf (15MP_a), which indicated that the soils within study area are susceptible to liquefaction.

Table 1 Summary of CPT Results

S/N	Location	CPT (Mpa)	Max. Depth (m)	Remark
1	Connal Street off Herberty Marculy Way,Yaba.			
	Point 1	< 15	4.20	Yes
	Point 2	<15	4.00	Yes
	Point 3	< 15	3.20	Yes
	Point 4	< 15	5.40	Yes
	Point 5	< 15	4.80	Yes
	Point 6	< 15	3.60	yes
2	Buildindg Development Lekkil;phase I			
	Point 7	<15	7.00	yes
3	Residential Development,Plot 1A,Block A8, Magodo			
	Point 8	<15	2.85	Yes
	Point 9	<15	4.50	Yes
4	Development at PHCN site, 7th Avenue FESTAC, Amuwa			
	Point 10	<15	6.00	Yes
	Point 11	<15	2.00	Yes

Table 1 Summary of CPT Results Contd.

S/N	Location	CPT (Mpa)	Max. Depth (m)	Remark
5	Development at PHCH Office, IBA-LASUS.			
	Point 12	<15	5.00	Yes
	Point 13	<15	10.00	Yes
6	Suberu Close, Ketu-Alapere			
	Point 14	<15	15.00	Yes
	Point 15	<15	12.25	Yes
	Point 16	<15	11.00	Yes
	Point 17	<15	12.00	Yes
7	Adeniji Adele			
	Point 18	<15	11.50	Yes
	Point 19	<15	11.00	Yes
	Point 20	<15	10.75	Yes
	Point 21	<15	12.00	Yes
8	Alaba-Rago			
	Point 22	<15	5.75	Yes
	Point 23	<15	5.00	Yes
9	Ikeja			
	Point 24	<15	20.00	Yes
	Point 25	<15	27.00	yes

ISSN 2229-5518

Table 1Summary of CPT Results Contd.

S/N	Location	CPT (Mpa)	Max. Depth (m)	Remark
10	Ebute-Metta			
	Point 26	<15	4.70	Yes
	Point 27	<15	11.80	Yes
11	Pako Market, Oshodi			
	Point 28	<15	3.75	Yes
	Point 29	<15	3.00	Yes
	Point 30	<15	3.00	Yes
	Point 31	<15	4.00	Yes
	Point 32	<15	3.00	Yes
	Point 33	<15	3.75	Yes
	Point 34	<15	3.75	Yes
	Point 35	<15	3.25	Yes

3.2 Cone Penetration Test (CPT) Approach

Based on one of the screening criteria for liquefaction of soils susceptibility according to Shibata, and Taparaska, (1988), liquefaction occurs if normalized CPT cone resistance (q_c) is less than 157tsf (I5MPa). It is obvious from the Table 1 coupled with the curves presented in Figures 2 to 7 that values for cone resistance (q_c) for all the points considered for the test are less than 15Mpa which means the zone could be susceptible to liquefaction.

ISSN 2229-5518

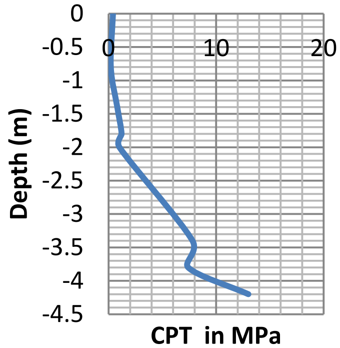

Figure 2a Connal Street off Herberty Marculy Way

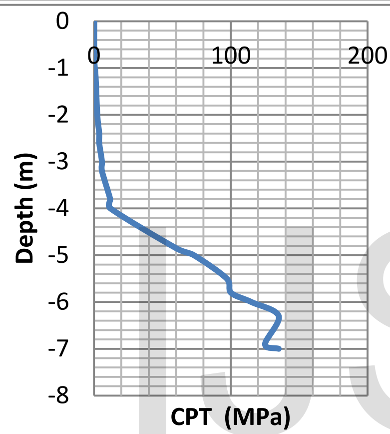

Figure 2b Connal Street off Herberty Marculy Way

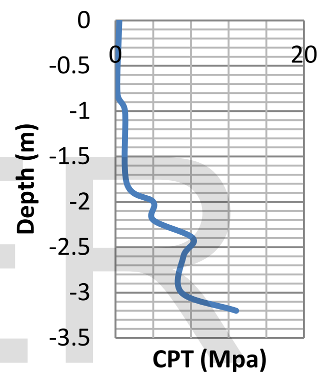

Figure 2c Connal Street off Herberty Marculy Way

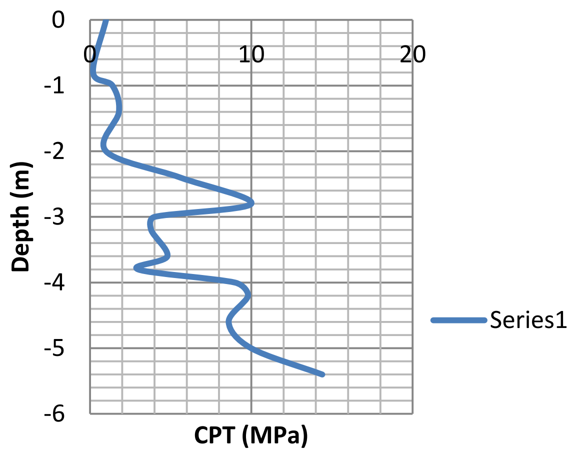

Figure 2d Connal Street off Herberty Marculy Way

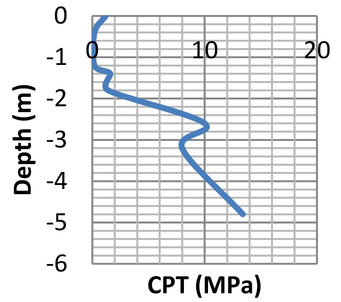

Figure 2e Connal Street off Herberty Marculy Way

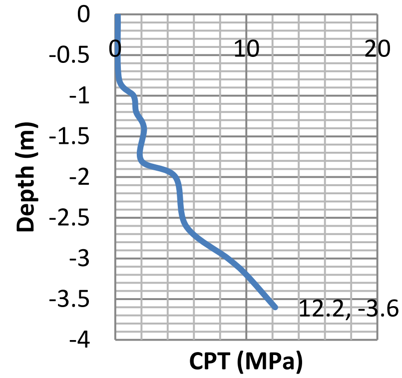

Fig ure 2f Connal Street off Herberty Marculy Way

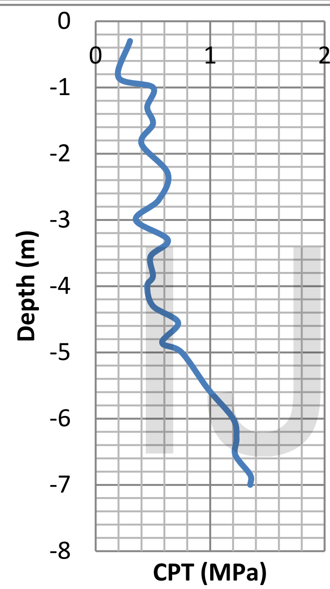

Figure 3 Building Development,Lekki Phase I

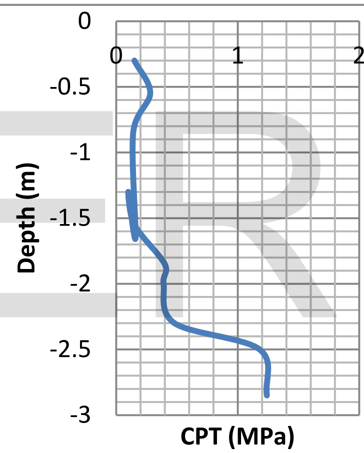

Figure 4a Residential Development,polt 1A,BlockA8,Aigbokan Drive,Magodo

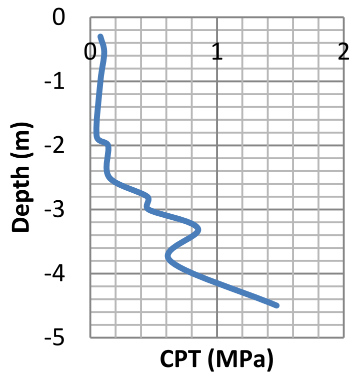

Figure 4b Residential Development,polt 1A,BlockA8,Aigbokan Drive,Magodo

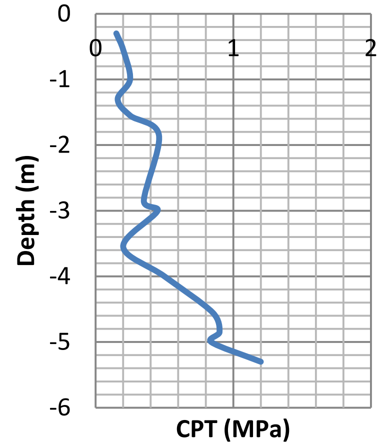

Figure 5a Development at PHCN site,7th Avenue FESTAC Town,Amuwa.

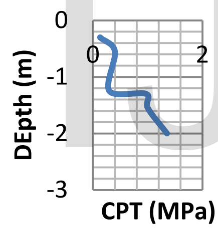

Figure 5b Development at PHCN site,7th Avenue FESTAC Town,Amuwa

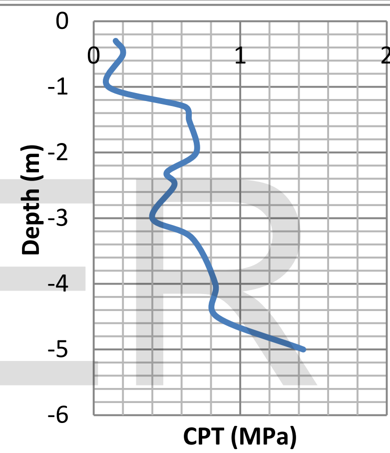

Figure 6a Development at PHCN Office IBA-LASU Road.

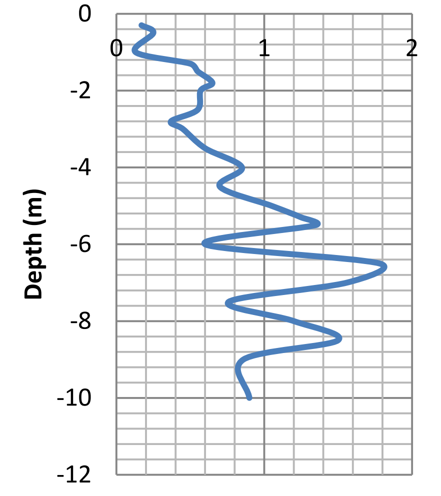

Figure 6b Development at PHCN Office IBA-LASU Road.

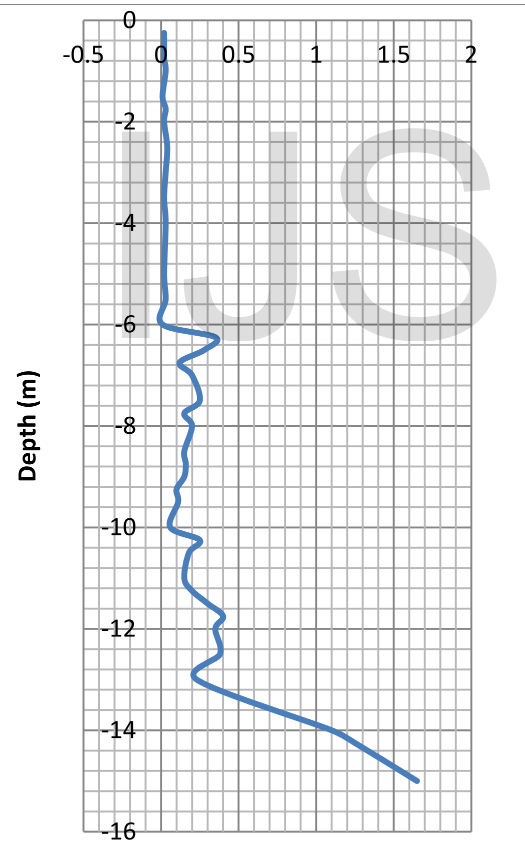

Figure 7a Suberu close Off Bakare Street, Fatai Area, Ketu-Alapere

4.0 CONCLUSION

From the analysis of CPT data with the soil liquefaction susceptibility bench marks, conducted at state wide locations in Lagos Western-Nigeria, the following conclusions were made:-

(i) The entire area of Lagos Metropolitan city is characterised with high water table.

(ii) It was highly probable that the subsoil in the entire region would experience liquefaction in the case of any catalyst incidence, thereby necessitating the incorporation of ameliorating strategies in place without necessarily waiting for the occurrence,

5.0 REFERENCES

1. Adib, M., Villet, W.C.B. and Nisar, A. (2007). "Prest ressed concrete piles under seismic loading: case history." Proc. 3rd intl. conf on Recent Advances in Geotechniquke Earthquake Engineering and soil Dynamics.

2. Beirill, J.B. Christensen, S.A., Keenan, R.J., and Okada, W. (2009). "Lateral- spreading loads on a pile bridge foundation". Seismic Behaviour of Ground and Geotechnical Structures, Seco ePinto (ed.) Balkema, Rotterdam, 173-183.

3. Holzer, T.M., Bennett, M.J., Noce, T.E., Padovani, A.C., Tinsley, J.C. (2002), III Liquefaction hazard and shaking amplification maps of Alameda, Berkeley, Emeryville, Oakland, and Piedmont: A digital database. U.S. Geological Survey Open-file Report 02-296 http://geopubs.wr.usas.gov/open-file/Qffl2-296

4. Idriss, I, M. and Boulanger, R. W., (2006). "Semi-empirical procedures for evaluating liquefaction potential during earthquakes," Soil Dynamics and Earthquake engineering, Vol. 26, pp. 115-130

5. Juang, C. H., Fang, S. Y., and Khor, E. H. (2006)., "First order reliability method for probabilistic liquefaction triggering analysis using CPT" Journal of Geotechnical and Geoenvironmental Engineering, ASCE, Vol. 132, No. 3, pp. 337-350

6. Shibata, T., and Taparaska, W., (1988), "Evaluation of Liquefaction Potentials of Soils Using Cone Penetration Tests," Soils and Foundations, Vol. 28, No. 2, pp. 49 - 60. United States EPA, Office of Research and Development, 1995, EPA/600/R-95/051, RCRA Subtitle D (258) Seismic Design Guidance for Municipal Solid Waste Landfill Facilities. Available as of thewriting of this policy at www.epa.gov/clhtml/pubtitle.html on the U.S. EPA Web site.