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PRELIMINARY ASSESSMENT OF LIQUEFACTION AND LANDSLIDE POTENTIALS IN SOILS FROM THREE MAJOR SUSCEPTIBLE AREAS IN NIGERIA

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Abstract
Landslide is one of the most ravaging natural disasters in the world and recent occurrences in Nigeria require urgent technical assessment of susceptible zones. In this study, three major susceptible areas in Nigeria were accessed for potentials for liquefaction and sliding. The areas are Oko (Anambra State), Agbaja (Kogi State), Enyenkorin and Asa Dam (Kwara State). Reconstructed samples were collected from each locality for the purpose of determining and comparing their susceptibilities to landslide and liquefaction. Grain size analyses and Atterberg consistency limits were used to investigate the liquefaction potential while the slope conditions were deduced using SLOPE/W software. Grain size distribution revealed that the soils contain 0-7% gravel, 63-96% sand and 2-18% fines for Oko and Agbaja compared to 4-12% gravel, 30-36% sand and 18-39% fines for Asa Dam and Enyenkorin. These values and plots of plasticity index against liquid limit, dry density against moisture content and coefficient of permeability show that samples from Oko and Agbaja are potentially liquefiable when compared with the control sample. The shear strength parameters have values ranging 40-80 kPa and 24-35^o while the Coefficient of permeability varies between 1.71×10^{-5} and 1.18×10^{-3}. The factor of safety (FOS) values for soils from Oko, Agbaja and Asa Dam are 1.452, 1.946 and 2.488 respectively. Though these values indicate stability, caution must be applied as the condition at the area revealed that the slope are in their state of impending failure. The FOS for dry slope was higher when compared to those of wet slope. This was due to the effect of pore water pressure on the soil as it reduced the shear strength of the soil. A reduced value of FOS was observed in the model under loading conditions, which indicates loading as a contributing factor to the slope failure. It is recommended that proper and efficient drainage system should be employed in these areas to reduce the influence of pore water pressure in the soils. Also surface terracing is recommended to reduce the effect of toe failure.

Keywords: *Liquefaction, landslide, slope stability, geotechnical analyses, Nigeria*

Introduction

The effect of natural disaster in the world cannot be over-emphasized, as a number of failures of embankments, natural slopes, earth structures and foundations have been attributed to the liquefaction of sands, landslides and slope instability [13]. The 1937 Zeeland coast of Holland slides involving 7 million cubic meters of alluvial sands and the 1944 Mississippi River slide near Baton Rouge containing about 4 million cubic meters of fine sands are limited case studies.

In Nigeria, landslide has caused serious destructions to physical structures and loss of lives and properties. For instance, a landslide, which occurred in Oko Community of Anambra State, rendered more than 150 people homeless according to the information provided by the State Emergency Management Agency (SEMA). There is need to understand the mechanism of these natural disasters and hence this study is aimed at carrying out preliminary assessment of liquefaction and landslide potentials in soils from some parts of Nigeria using geotechnical method and software modelling (SLOPE/W) from Geostudio 2012. Three localities were adopted in this research work with the aim of having widespread variation in the geotechnical properties of the study areas.

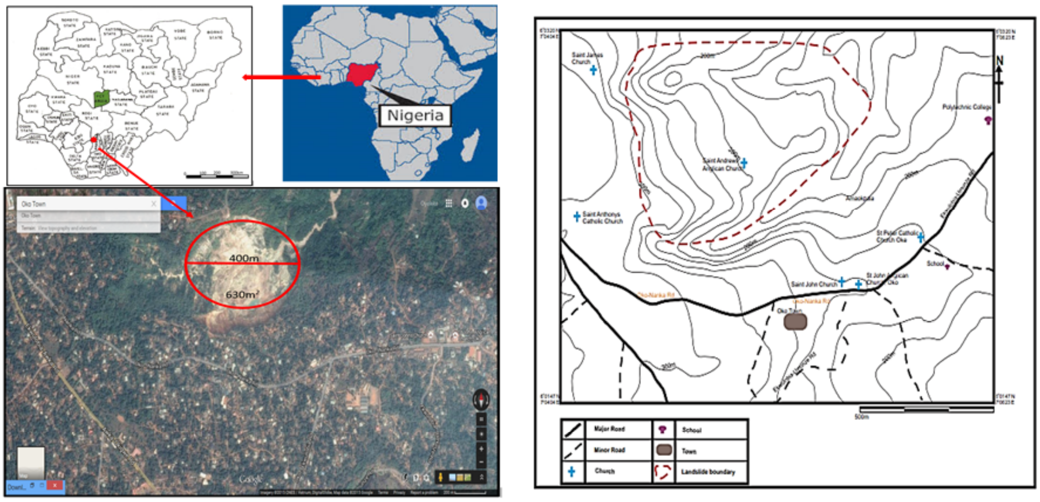
Nigeria is a part of Africa that forms the continental crust and lies in the Pan-African mobile belt that has been affected by Pan- African events during the ages of orogenic, epiorogenetic, tectonic and metamorphic cycles [17]. The Nigerian Basement Complex forms part of the Pan-African mobile belt and lies between the West African and Congo Cratons and to the south of Tuareg Shield [10]. It consists of gneiss migmatite complex, schist belt and granitoids (older granites) of the Archean, Paleoproterozoic and Neoproterozoic [9]. About 50% of the total landmass of Nigeria is covered by sedimentary basins. These basins generally develop over the Precambrian basement and dominated by clastic deposit and in places, ironstone and organic coal-bearing sediments [14].

The study area falls in both the Basement Complex and sedimentary areas. The areas under sedimentary part of Nigeria are Oko in Anambra State and Agbaja in Kogi State, while those in the Basement Complex are Eyenkorin and Asa Dam in Ilorin, Kwara State. Oko area of Anambra State was chosen because of incessant occurrence of landslide. Agbaja area of Lokoja was also considered because of the slope failure observed in the study area while Ilorin was added to the study area so as to check the stability of the embankment slopes in the study area.

Location of the Study Area

Oko, Anambra State

Oko is situated in Orumba North Local Government Area of Anambra State. It is geographically situated between latitudes 6^{o}01'47"N and 6^{o}03'20" N and longitudes 7^{o}04'04"E to 7^{o}06'23E and has humid climatic condition (Fig. 1). The average annual rainfall in Oko is about 1386mm. Rainfall is heavy between April to October, typically resulting in high intensity storms and often causes flooding and erosion leading to the development of gullies. It is a rain forest area and is characterized by vast undulating landscape and of alluvial plain. Greater part of its vegetation is made up of forest (tropical vegetation). The area is underlain by the Nanka Sand (Eocene). The sandy units are morphologically occurring as intercalation. Groundwater is intercepted through borehole at depths range from 5.7 to 21m. Geotechnically, the soils grade from 3.0 to 9.0%, mean value of 7.4% for gravel, 84.0 to 90.0%, mean value of 86.0% for sand and 2.0 to 11.0%, mean value of 5% for fines, depending on the local conditions of weathering and deposition [16].



a

b

Fig. 1: Map showing Oko area and landslide region in Anambra State (a) Red circle in Satellite image shows Landslide affected area

Agbaja, Kogi State

Agbaja is geographically situated between latitudes 7^{o}45’06"N and 7^{o}50’20"N and longitude 6^{o}38’33"E and 6^{o}48’32"E (Fig. 2). The land rises from about 300 m along rivers Niger-Benue confluence, to the heights of about 500 m above sea level in the uplands. Agbaja Plateau, which ranges from 335-366m above sea level, is one of the predominant landforms in the state. The stratigraphic units of Agbaja are such that the sandy units are morphologically occurring as inter-beds of varying thicknesses [15]. Groundwater bodies are intercepted through borehole at depths range from 11.2 to 28.3m. Geotechnically, the soils grade from 2.0 to 11.0% for gravel; 63.0 to 87.3% for sand and 5.0 to 9.5% for fines [15].

Ilorin, Kwara State

The sample localities are located on Basement Complex terrain. The area is well drained by river Asa that divides the town into two equal halves (Fig. 2b). Geologically, Ilorin is underlain by igneous and metamorphic rocks of Precambrian age [12]. It is largely undifferentiated and constitutes about 50 % of the bedrock in Nigeria. Large outcrops of granite and gneisses with cross-cutting pegmatites are common [1]. The general trend of the outcrops in the area is SW-NE with a west dip. The rocks are relatively stable, less susceptible to mass movement, when compare with other localities.

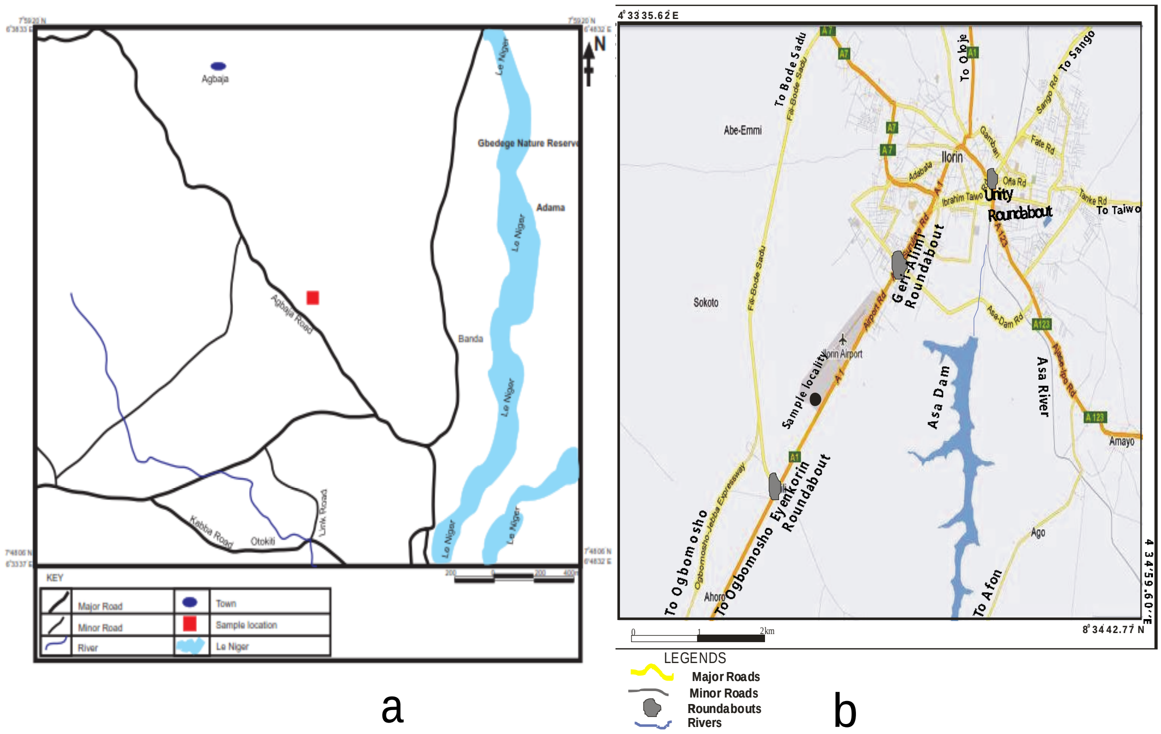


Fig. 2a: Location Map of sampling areas (a) Agbaja Hill (Kogi State) (b) Eyenkorin (Kwara State)

Materials and Methods

Nine undisturbed soil samples were collected from exposed sections of the study areas at depth of 1.0m, 1.5m, for the samples from Asa Dam and Eyenkorin and 2.5m and 3.0m from Agbaja area and Oko area respectively. The stained surfaces were removed before soil auger was inserted horizontally. The sampled depths, coordinates and field photos were also documented. However, in areas where landslides had occurred, the samples were collected from scar. The collected fresh soil samples were transported to the soil laboratory, Civil Engineering Department, University of Ilorin, Nigeria for geotechnical tests. Series of geotechnical tests were carried out on the samples among which are grain size analysis, Atterberg consistency limit, compaction test, permeability test etc. Then, the analyses were carried out according to the widely accepted procedure contained in British Standard Institute [11].

Method of slices using SLOPE/W software

The slope model was analysed using SLOPE/W and SEEP/W software with the aim to report the state of the slopes and their factors of safety using Limit Equilibrium Method (LEM). The software computes the factor of safety (FOS) for various shear surfaces (SS). The method of slices was considered because of its application to SLOPE/W. The method is widely used by much computer software because it can accommodate geometry of complex slope, different soil conditions and influence of external boundary loads [2]. Conventionally, the weight of soil lying at a particular point should influence the stress acting normal to that point on sliding surface.

Theoretically, the basic principle of slices method is the potential slide mass, which is subdivided into several vertical slices and the equilibrium of individual slice can be evaluated in terms of forces and moments. This would allow easy estimation of the allowable safety factor of a slide mass. In this study, shear strength parameters obtained from soil layers, with different strength parameters were used for slope stability analyses. These parameters were used in both dry and wet conditions. Similarly, two unit weight of soils, one above the groundwater table (GWT) and the other below the GWT were also considered. The three different conditions considered for slope stability analyses are dry slope, wet slope and dry slope with external loads. The analysed load conditions were defined as:

i. Case 1: Completely dry slope, i.e. no GWT inside the model,
ii. Case 2: Completely saturated slope, i.e. GWT on the surface (hydrostatic pore pressure),
iii. Case 3: Dry slope with external forces, i.e. q = 40 and 50 kPa.

The stability of the dry slope was first analysed in SLOPE/W. The minimum factor of safety (FOS), critical slip surfaces (CSS) were searched by entry and exit option as well as groundwater table (GWT) level shown in the model using limit equilibrium (LM) principle. The CSS was searched from thousands of possible SS by defining the input of 15 slices, 1500 iterations, 15 increments for entry, 10 increments for exit and 5 increments for radius. In addition to the limit equilibrium methods (LEM), the Bishop's and Janbu's simplified methods as well as the Spencer and Morgenstern-Price (M-P) factors of safety were used for rotational and irregular surface failure mechanisms.

Results and Discussion

Grain size distribution and soil classification

The results of grain size analysis are shown in Fig.3 and Table 1. The grain size distribution curves show that the soil samples consist of all fractions ranging from grave to clay. The clay content ranges between 2-34% across the soil samples. The soil sample from Asa Dam road in Ilorin, which is plastic in nature has the highest clay content of about 34%. Soil samples from Agbaja and Oko areas have very low fine content ranging from 2-12 % and are non-plastic in nature. The sand fraction dominated the samples area about 70-80% especially those obtained from Agbaja and Oko areas. Similarly, the uniformity coefficient varies from 5-275, except for the sample from the Asa Dam and Eyenkorin representing the basement complex part of the country with uniformity coefficient of 2000 (Fig. 3 and Table 1) according to USCS [4, 5].

Atterberg limit

The summary of results obtained from moisture content, liquid limit, plastic limit and plasticity index analyses are presented in Table 2. The plasticity chart was used to classify the samples and most of the samples fall below A zone (Fig. 4). Samples from Eyenkorin and Asa Dam are in the region with symbol CL, thus they were classified as inorganic clays of medium compressibility. Anambra and Lokoja fall in the CL-ML region and are classified as cohesionless and inorganic silts of low compressibility. The predominance of sand in the soil type indicates abrasion process which could trigger liquefaction.

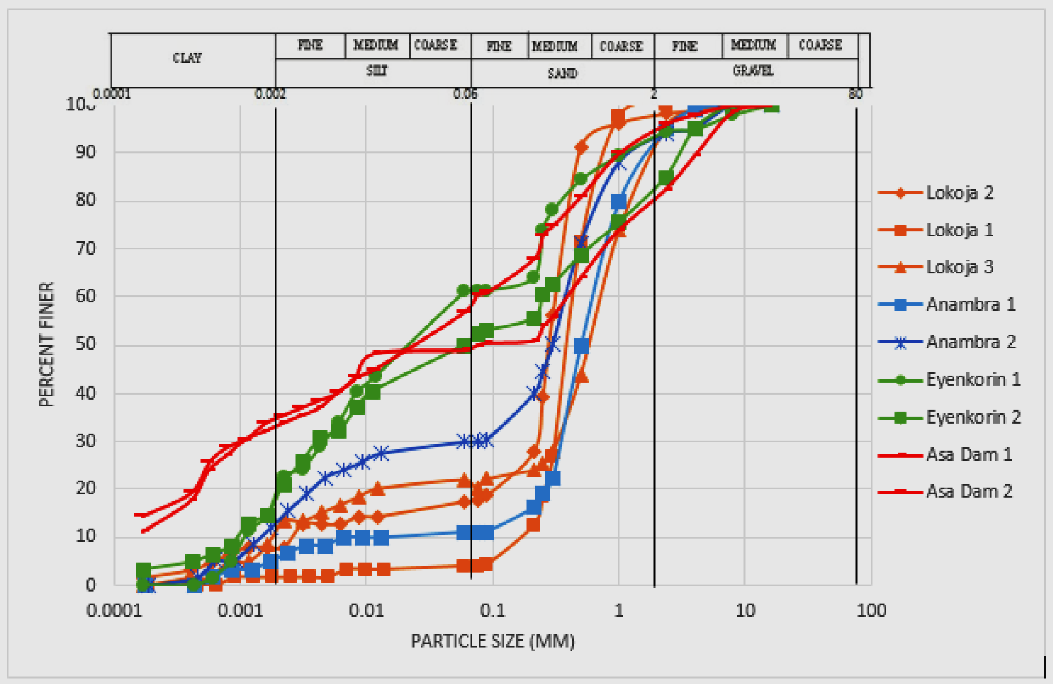


Fig. 3: Grain size distribution curves for the soil samples.

Table 1: Summary of the grain size analysis and soil classification

Sample ID	S.G	% clay	% silt	% fine	% sand	% gravel	Cu	Cc	Group symbol
Lokoja 1	2.5 3	2	2	4	96	0	5	1.19	SW
Lokoja 2	2.78	8	10	18	80	2	12	0.0005	SM
Lokoja 3	2.56	12	8	20	72	2	389	81	SM
Anambra 1	2.58	6	5	11	83	6	86	38	SM
Anambra 2	2.47	12	18	30	63	7	267	6	SM
Eyenkorin 1	2.67	18	35	55	31	16	220	7	CL
Eyenkorin 2	2.68	22	39	61	31	8	33	0.42	CL
Asa Dam 1	2.65	32	18	50	30	20	2000	0.035	CL
Asa Dam 2	2.65	34	26	60	36	4	275	0.074	CL

Key: SW and SM = Poorly Graded Sand, CL= Well Graded Sandy silt.

Compaction test

The compaction test at standard state condition yielded maximum dry densities (MDD) of 1.84g/cm^3 and 1.88g/cm^3 for Eyenkorin, respectively. The optimum moisture content (OMC) for Eyenkorin (in Kwara State) ranges from 13.0-14.0%. Samples from Lokoja (Kogi State) and Oko (Anambra State) have lower values of Maximum Dry Density and Optimum Moisture Content, ranging between 1.64-1.80g/cm^3 and 8.0-12.3%, respectively (Table 3). These values show that the samples can be described as granular material with soil having anticipated embankments performance as poor to fair, value as subgrade material as fair to good and value as a base course as good to poor (Table 3).

Table 2: Plasticity values of the soil samples.

Sample ID	Depth (m)	Moisture content (%)	Liquid limit (%)	Plastic limit (%)	Plasticity index (%)
Lokoja 1	8.6	1.6	23.0	15.0	8.0
Lokoja 2	12.5	0.8	28.0	24.0	4.0
Lokoja 3	17.0	9.8	27.0	18.0	9.0
Anambra 1	10.2	0.8	21.0	16.5	4.5
Anambra 2	12.0	0.8	23.0	19.45	3.55
Eyenkorin 1	2.3	1.3	41.0	21.3	19.7
Eyenkorin 2	3.0	1.8	44.5	15.5	29.0
Asa Dam 1	2.5	2.5	40.0	17.5	22.5
Asa Dam 2	3.4	3.3	43.0	22.5	19.5

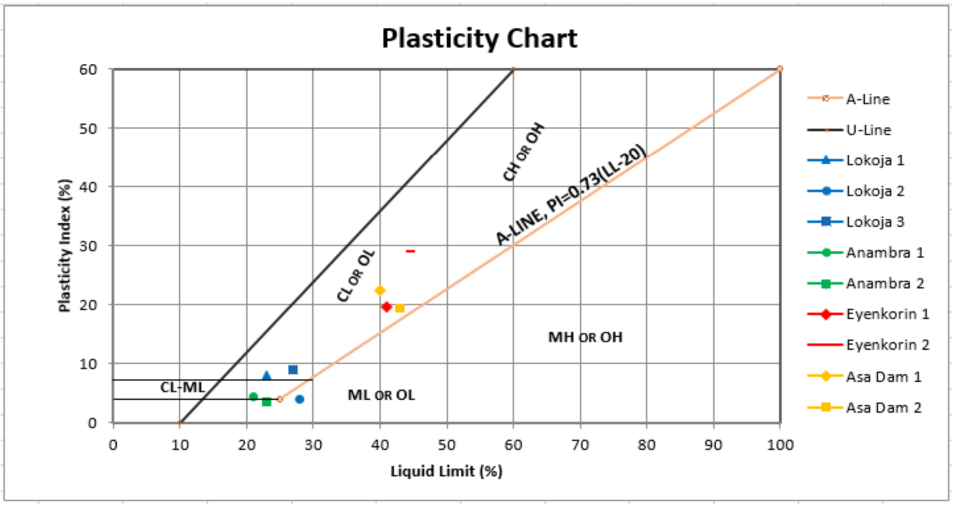


Fig.4: Plasticity chart plot for fine grained soil and fine fraction in coarse grained soil.

Table 3: Compaction characteristics and ratings of the soil samples based on the unified soil classification classes for soil construction (ASTM, 1557-91).

Sample ID	MDD (g/cm^3)	OMC (%)	Anticipated Embankment Performance	Value as Subgrade material	Value as Base Course
Lokoja 1	1.73	8.5	Poor	Fair	Good
Lokoja 2	1.80	8.0	Fair	Good	Poor
Lokoja 3	1.76	12.3	Fair	Good	Poor
Anambra 1	1.76	10.1	Fair	Good	Poor
Anambra 2	1.64	8.8	Poor	Good	Fair
Eyenkorin 1	1.84	14.0	Fair	Good	Fair
Eyenkorin 2	1.88	13.0	Fair	Good	Fair
Asa Dam 1	1.85	13.4	Fair	Good	Fair
Asa Dam 2	1.87	12.2	Fair	Good	Fair

Shear strength and permeability

The summary of shear strength and permeability results, as well as their interpretations is tabulated in Tables 4. The direct shear strength test on the soil samples show that the cohesion and angle of internal friction varies between 40-80 kPa and 24-35^{o}. The Coefficient of permeability of the soil samples vary between 8.71 × 10^{-5} and 1.18 × 10^{-3}. Table 4 shows that permeability is highest in Oko area.

Liquefaction susceptibility

The results of liquefaction studies after [18] are presented in Fig. 5. Liquefaction involves the temporary loss of internal cohesion of material, such that it behaves as a viscous fluid rather than as a soil [3]. Soils containing a high percentage of sand and silt will deform more quickly than those containing high percentage of clay. Due to their cohesive strength, clays adjust more slowly to increased pore-water pressure than unconsolidated soils. The plot of plasticity index against Liquid limit after [18] shows that the soil samples from Anambra and Lokoja are potentially liquefiable. The liquefaction screening criteria after [8] also shows that Oko, Eyenkorin and Lokoja are potentially susceptible to liquefaction, whereas samples from Asa Dam are not susceptible to liquefaction (Fig. 6).

Boundaries in the gradation curves for soils were used to determine liquefaction susceptibility of the soil samples. Boundary most susceptible to liquefaction is in the sand region, with about 60-80 % of sand, whereas boundary for potentially liquefiable soil is in the region of 20-40 % sand [19]. Soils with a higher percentage of gravels tend to mobilize higher strength during shearing, and to dissipate excess pore pressures more rapidly than sands. However, there are case histories indicating that liquefaction has occurred in loose gravelly soils [7] during severe ground shaking or when the gravel layer is confined by an impervious layer. Based on [19] classification, it can be deduced that soil samples from Anambra and Lokoja having sand portion ranging from 72-96 %, and as such are liquefiable (Fig. 7 and Table 5). Anambra 2 has 63 % of sand which is potentially liquefiable, based on the classification proposed by Tsuchiba (1970). Some of the soil samples fall outside Tsuchida's boundaries, but non-plastic and low plasticity silts, despite having their grain size distribution curves outside of Tsuchida's boundaries for soils susceptible to liquefaction, have potential for liquefaction similar to that of sands [20]. In addition, they further stated that increased plasticity will reduce the level of pore pressure response in silts. This reduction, however, is not significant enough to resist liquefaction for soils with plasticity indices of ≤ 5.

Table 4: The summary of the shear strength parameters and interpretation

Sample ID	Cohesion, c (kPa)	Angle of internal friction, φ	Interpretation	***k* (cm/sec)**	**Interpretation**
Lokoja 1	48	28.5^0	Loose sand: rounded grains	1.18×10^{-4}	Clean sand and gravel mixtures
Lokoja 2	70	29^0	Loose sand: rounded grains	9.77×10^{-5}	Very fine sand
Lokoja 3	65	24^0	Loose sand: rounded grains	3.61×10^{-5}	Very fine sand
Anambra 1	50	29^0	Loose sand: rounded grains	8.71×10^{-5}	Very fine sand
Anambra 2	55	28^0	Loose sand: rounded grains	7.80×10^{-5}	Very fine sand
Eyenkorin 1	60	23^0	Loose sand: rounded grains	1.18×10^{-3}	Clean sand and gravel mixtures
Eyenkorin 2	80	26^0	Loose sand: rounded grains	1.18×10^{-3}	Clean sand and gravel mixtures
Asa Dam 1	40	35^0	Medium sand: rounded grains	1.18×10^{-3}	Clean sand and gravel mixtures
Asa Dam 2	60	32^0	Medium sand: rounded grains	1.18×10^{-3}	Clean sand and gravel mixtures

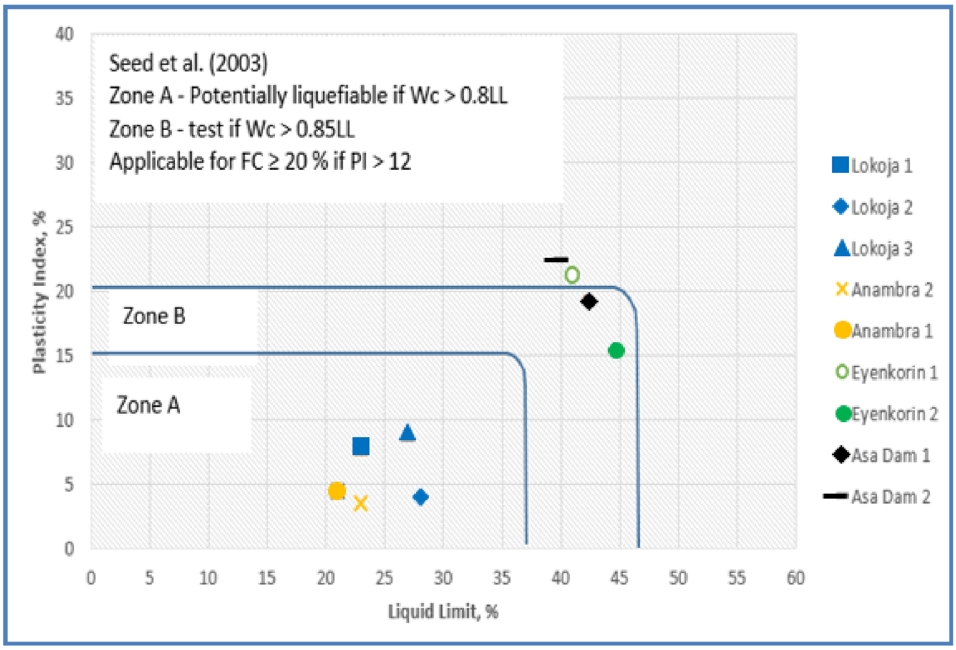


Fig. 5: Plasticity chart showing the recommendations by [18] regarding the assessment of "liquefiable" soil types and the Atterberg Limits of fine-grained soils.

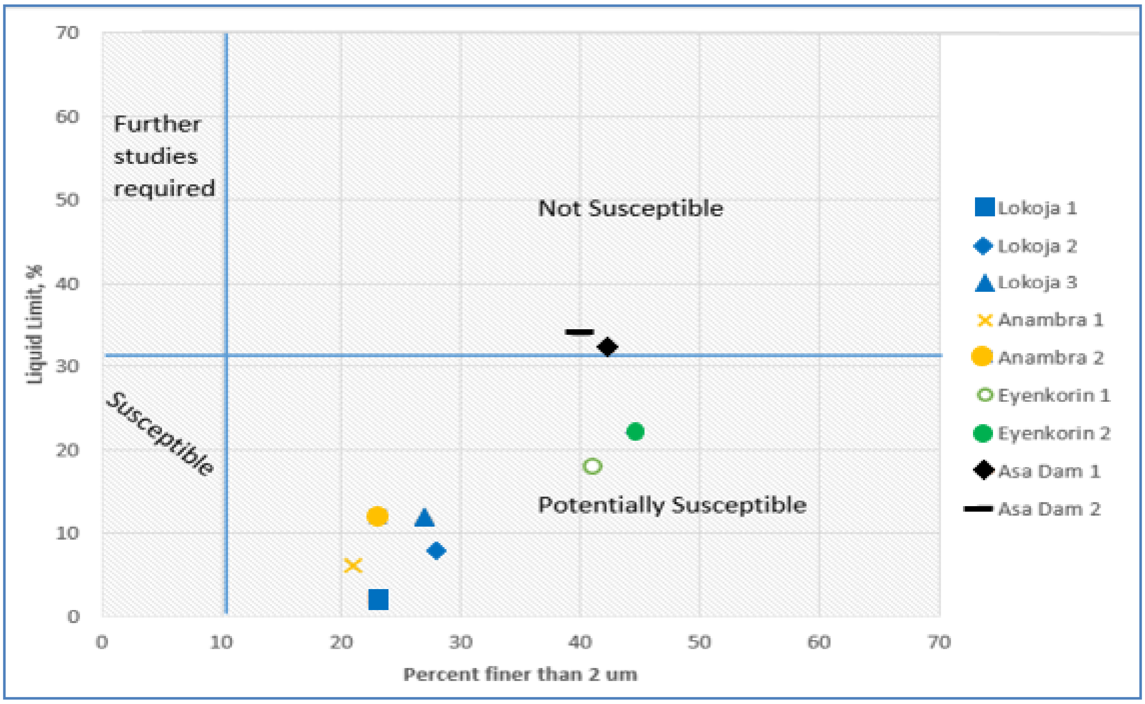


Fig. 6: Liquefaction screening criteria after [8]

Parametric analysis of slope stability

Slope angles, slope length play important roles in the stability of slopes. The slope angle is regarded as the major topographic factor in determining stability. The physical characteristics of the terrain influencing slope instability were measured. The characteristics recorded include slope length, angles, and altitude. The slope angles can be classified as steep angle as they are close to 60-70^{o} in the study areas. Though the embankment slopes in Asa Dam area and Eyenkorin area have values in the range of 30-35^{o} and are classified as moderate angles.

The factor of safety (FOS) obtained from SLOPE/W software were used to classify the slopes into safe, state of impending failure and failed slopes based on general and acceptable value for stable slope of 1.5 for safe and less than 1.0 for unsafe. The analysed samples have values ranging from 1.366 - 2.488 (Fig. 8; Table 6). The value of 1.366 is from the Oko area in Anambra state where landslide occurred. The maximum value of 2.488 was obtained at Asa Dam, which is an embankment slope and it depicts stable slope. The FOS for dry slope was higher when compared to the FOS values from wet slope (Fig. 8). This was due to the effect of pore water pressure on the soil as it reduced the shear strength of the soil. Fig. 8a shows the critical slip surface (CSS) and factor of safety (FOS) for non-optimised wet slope. The slip surface was at the top of the slope and it shows the CSS passing through ground water table (GWT), thus making the slip surface size bigger and occupies all of the entry point. Suction effect has not been considered in the analysis; the located GWT has serious effect on the FOS. Fig. 8c shows an increase in the geometry, and the CSS and FOS were affected drastically. The reduction in FOS from 2.51 to 1.45 (Table 6) is an indication of the effect of pore water pressure and gravity on the failed site. Limit equilibrium methods computed the values of FOS slightly lower than 1.5 which depict instability. The pore pressure at the toe causes reduction in the effective normal stresses, and hence the shear strength.

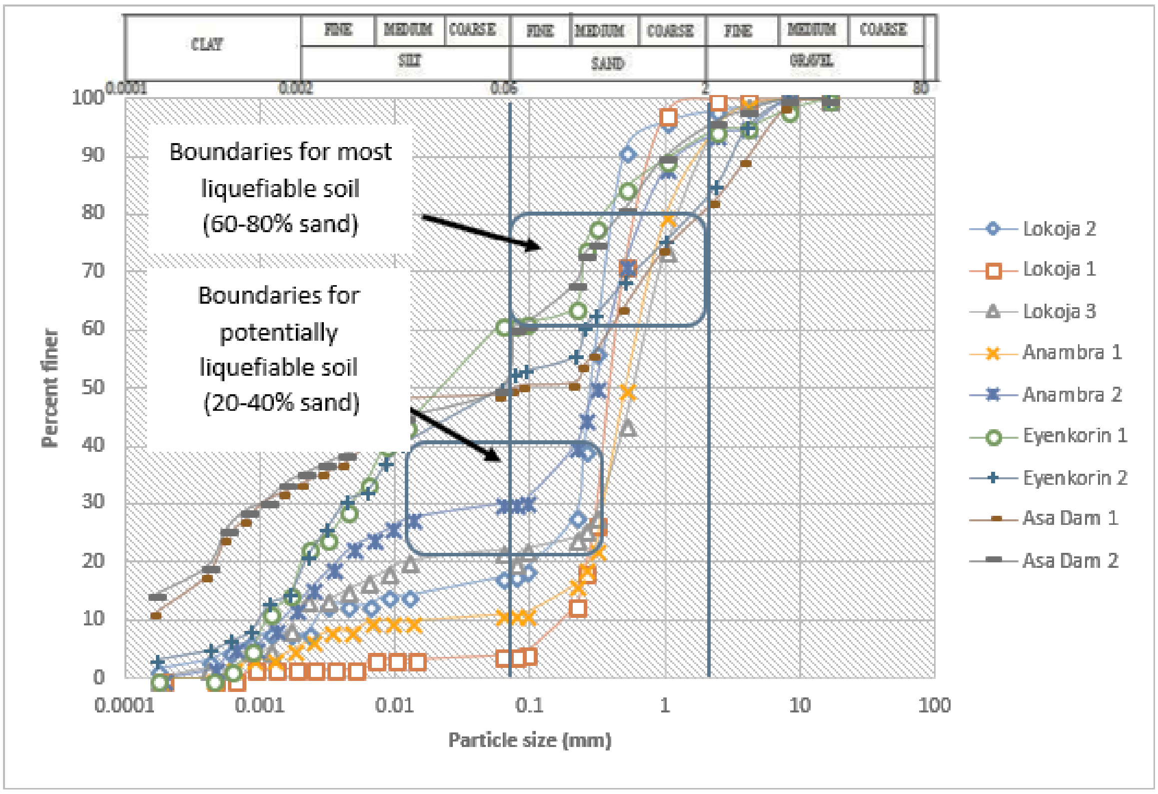


Fig. 7: Boundaries in the gradation curves for soils susceptible to liquefaction after [19]

Table 5: Summary of the grain size analysis and soil classification

Sample ID	S.G	% clay	% silt	% fine	% sand	% gravel	Cu	Cc	Group symbol	Classification after [18]
Lokoja 1	2.53	2	2	4	96	0	5	1.19	SW	Liquefiable
Lokoja 2	2.78	8	10	18	80	2	12	0.0005	SM	Liquefiable
Lokoja 3	2.56	12	8	20	72	2	389	81	SM	Liquefiable
Anambra 1	2.58	6	5	11	83	6	86	38	SM	Liquefiable
Anambra 2	2.47	12	18	30	63	7	267	6	SM	Potentially liquefiable
Eyenkorin 1	2.67	18	35	55	31	16	220	7	CL	Potentially liquefiable
Eyenkorin 2	2.68	22	39	61	31	8	33	0.42	CL	Potentially liquefiable
Asa Dam 1	2.65	32	18	50	30	20	2000	0.035	CL	Potentially liquefiable
Asa Dam 2	2.65	34	26	60	36	4	275	0.074	CL	Potentially liquefiable

Key: SW and SM = Poorly Graded Sand, CL= Well Graded Sandy silt.

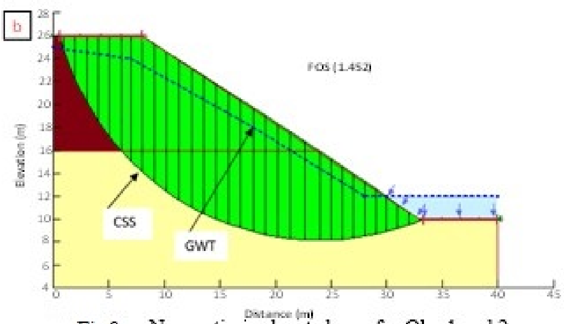


Fig.8 a: Non-optimised wet slopes for Oko 1 and 2 Anambra State

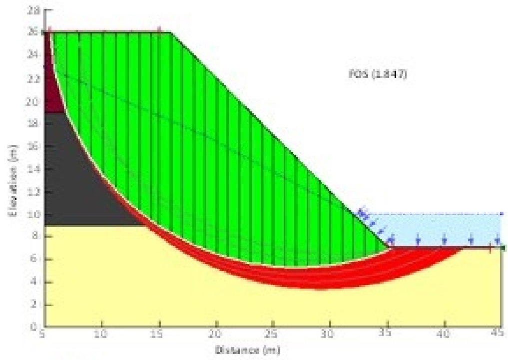


Fig. 8 b: Critical slip surfaces and FOS from parametric analysis for 3 soil layers at Agbaja Hill (Kogi State)

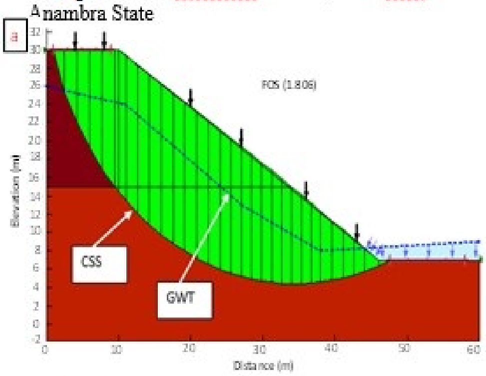


Fig. 8 c: Showing Optimised slope with point load of 40kPa

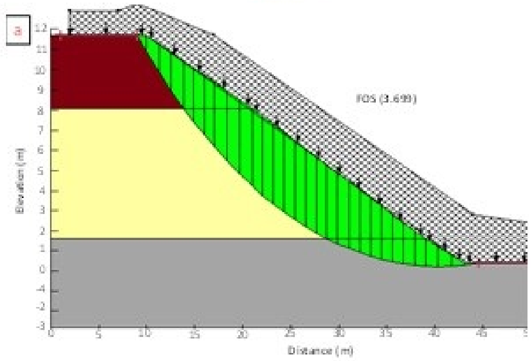


Fig..8 d: Showing Optimised slope with reinforcement load of 50 kPa

Fig. 8: Slopes models from the study areas

Table 6: Summary of the factor of safety (FOS) for the soil samples

	O.D		B.M		J.M		M.P		FOS
	M	F	M	F	M	F	M	F	M
Anambra 1 and 2	1.366		1.396	-	-	1.434	1.452	1.462	1.452
Lokoja 1 and 2	1.885		1.951	-	-	1.883	1.946	1.950	1.946
Eyenkorin 1 and 2	2.430		2.489	-	-	2.462	2.488	2.485	2.196
Asa Dam 1 and 2	2.118		2.200	-	-	2.112	2.196	2.201	2.488

M = Moment, F= Force, O.D = Ordinary method, B.M = Bishop method, J.M = Janbu method, M.P = Morgestein price.

Conclusion

The causes of landslide in susceptible areas of Oko and Lokoja have been studied and compared with a relatively stable terrain in Ilorin area, all in Nigeria. Interpretation of the satellite imagery revealed the rugged and steep nature of the terrains, while geotechnical data indicate over 80% non-plastic fines from Oko and Agbaja areas highly susceptible to liquefaction because of the absence of restraining force between grains. The FOS values for Anambra 1-2, Lokoja 1-3, Eyenkorin 1-2 and Asa Dam 1-2 are 1.452, 1.946, 2.196 and 2.488, respectively. These values indicate stability but care must be taken as the conditions at the study areas show that the slopes are in the state of impending failure. Optimisation effects were also tried and the results show that loads on these slopes might contribute to the failure of the slopes.

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