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INVESTIGATION OF PLATE LOAD TEST IN SOIL STABILIZATION USING STONE COLUMNS: CASE STUDY OF OWODE ELEDE, LAGOS STATE, NIGERIA

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Abstract

Soil stabilization refers to techniques employed to enhance the stability and strength of a particular soil mass, thereby improving its engineering and physical characteristics. A commonly used method for ground improvement involves the installation of stone columns, which are also referred to as granular piles or aggregate piers. The main aim of implementing stone columns is to reduce settlement, shorten consolidation duration, and improve the soil's bearing capacity. This research evaluates the use of the Plate Load Test carried out within the study area at Owode Elede, Lagos State in Nigeria, to ascertain the ultimate load and the associated settlement. The results of this study are corroborated by the geotechnical properties of the soil, with approximately 35% of the material passing through sieve number 200. Furthermore, the average Liquid Limit and Plastic Limit values of 43% and 20%, respectively, suggest that the soil exhibits low compressibility.

KEYWORDS: Plate Load, Soil stabilization, Owode Elede, Stone column

Introduction

Background of the study

Soil stabilization is defined as a process that integrates different methods to improve the stability and strength of a specific soil mass, along with its engineering and physical characteristics. This technique is commonly employed in cases where the existing soil is inadequate for construction purposes. By stabilizing the soil,

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enhancements are made to its shear strength, bearing capacity, and shrink-swell properties, thereby reducing the risk of unfavorable engineering issues, such as washout or collapse (Archibong et al, 2020).

The stabilization process involves various techniques, including compaction, pre-consolidation, and drainage, among others. Nonetheless, the composition of the soil mass is the most critical element in achieving stabilization, as the behavior of pure sands and pure clays differs significantly in practical applications. Sand grains larger than 75 microns contribute to the strength and hardness of the soil. However, these larger particles tend to lack cohesiveness and binding capabilities, making them susceptible to erosion from unstable slopes. In contrast, clay soils, which consist of particles smaller than 75 microns, possess sufficient intergranular binding forces but often exhibit inadequate shear strength, particularly when saturated. Consequently, while water poses challenges for clay soils, it enhances the cohesiveness of sandy soils. When these two soil types are appropriately blended, the resulting mixture typically exhibits superior engineering properties (santosh, 1987).

'Soil stabilization can be achieved with or without the use of any additives, or alternatively, various materials such as cement, lime-pozzolana, and lime can be incorporated. Preparing the soil for construction, may also involve the application of geotextiles or reinforcement with strips' (Arora, 2011)

'The primary purpose of soil stabilization is to manage the grading of soils and aggregates during the construction of bases and sub-bases for highways, airfields, parking lots, and other development projects where the underlying soils are inadequate for building. While its main objective is to enhance the natural soil for highway and airfield construction' (Achibong, et. al., 2020), a broad range of sub-grade materials, including expansive clays and granular substances, can be effectively treated through stabilization.

One effective technique for improving soil conditions is the use of stone columns. By implementing stone columns in soft soil, it is possible to manage maximum settlement and achieve the desired load-bearing capacity. As noted by (Soumyakrishna et. al, 2021), 'the gravel column method can also mitigate soil liquefaction, accelerate consolidation settlement, and facilitate the drainage of pore water pressure'.

Bearing capacity and settlement are the basic data needed for the design of shallow foundations and other related construction. The traditional method of gathering undisturbed samples and conducting laboratory tests on them gives erroneous bearing capacity and settlement values in most cases because of sample disturbance and other processes which occur during sample collection and laboratory tests (Ibrahim, 2023).

Therefore, plate load testing is used for this research work, being an in-situ test that provides a more accurate bearing capacity estimate for soil deposits.

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Problem Statement

The civil engineer seeks a soil stratum which provides strength and stability to carry out the construction of buildings, roads, bridges, embankments, etc but homogeneous soils do not exist independently in nature, due to difference in soil structure, moisture content, environmental factors, etc. but vary somewhat from one point to another, horizontally and even more vertically. The issue of soil heterogeneity in reality makes the civil engineer seek various ways to achieve better engineering performance including soil stabilization.

Aim

The aim of this research is to investigate the plate load test to determine the ultimate load and the associated settlement for stone column implementation as a method of soil stabilization.

Objectives

The objectives of the research are:

- To determine the properties of the soil by carrying out preliminary tests on the soil sample from the study area; Owode-Elede, Lagos State.
- To determine the site geology and geological properties of the study area.
- To explore plate load test as a method of determining the initial and final bearing capacity of the soil to establish stabilization of the soil using stone columns.

Study Area

The study area is Owode Elede area of Lagos State. The Site is at Owode Elede after Mile 12 along Ikorodu road, Lagos State, Nigeria. The site was a cleared land, recently filled with sand, gravels and hard core and well compacted, hence a flat topography. Subsoil information in the near surface, revealed GRANITE. The base plate for the test was placed 0.00mm depth i.e. on the topsoil. The main access to the site is Ikorodu Road. Figure 3.1 shows the vicinity map of the area.

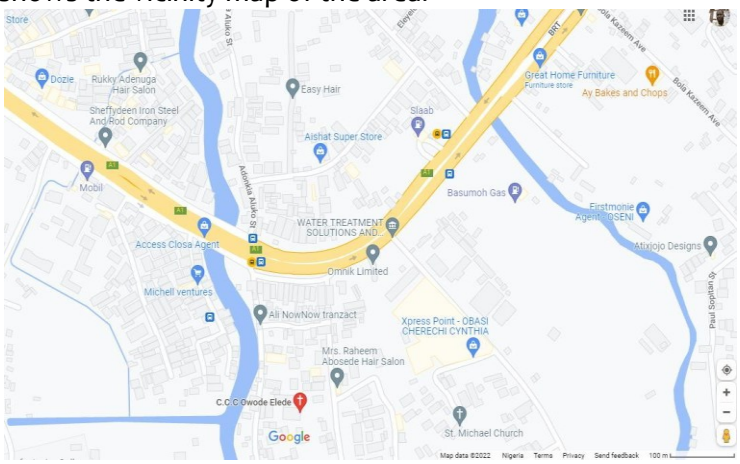

Figure 1: Site vicinity map
Field Work

Location of Test Points

The test point was marked on site as the crucial area required to know the settlement and bearing capacity of the site. Geotechnical Investigation field Work 1No. Plate Load

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Test was carried out to a maximum applied load of 70KN over a square base plate dimensioned 450mm producing an ultimate pressure of 345.7KN/m^2.

Equipment on Site

The following equipment were mobilised to site to execute the above works:

7. A standard steel form Kent ledge with Steel Water Tanks as dead weight to about 100kN load (approximately)
8. Square Base Plate (450mmwidth and 25mm thickness)
9. Hydraulic Pump and pressure gauge.
10. 2Nos. Strain gauges for recording experience settlement
11. A horizontal bar as Reference Beam (to serve as reaction for the strain gauges)
12. A digital timer for recording time

PROCEDURES

The above mentioned equipment were assembled as presented in plate 1 & 2 in accordance with the standard, specified in the BS 8004, 1986 for the Plate Bearing Test. The test procedure was generally in accordance with the guidelines contained in the BS 8004, 1986 section 7.5. The load was applied at an incremental rate of one-fourth (25%) the Test Load with each loading stage being held for sixty minutes (1 hour) while the ultimate load attained was maintained for twelve (12) hours. Load decrement was at the rate of (25%) holding each loading stage for sixty minutes. Nothing unusual was recorded during the test operation and no groundwater influence was noticed within the test point. The detailed records for the test are presented in a table 1 and 2.



Plate 1: Recording during the Plate Load Test (PLT)

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Plate 2: Two Dial Gauges for Measuring Settlement

RESULTS

Plate Load Test Records

LOCATION	OWODE-ELEDE
JACK CAPACITY	100 TONS TYPE ENERPAC
PUMP	700 BAR HYDRAULIC PUMP
PLATE SIZE	500mm X 500mm
WORKING LOAD	70KN

Table 1: Equipment set up specification

DATE	TIME	LOAD(KN)	DIAL GUAGE READINGS		SETTLEMENT(mm)
			GUAGE 1	GUAGE 2	
18/01/2023	11:00	0	0	0	0
18/01/2023	11:01	17.5	0.94	1.25	1.1
18/01/2023	11:05		1.00	1.29	1.15

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DATE	TIME	LOAD(KN)	DIAL GUAGE READINGS		SETTLEMENT(mm)
18/01/2023	11:10		1.02	1.38	1.2
18/01/2023	11:15		1.04	1.41	1.23
18/01/2023	11:20		1.04	1.42	1.23
18/01/2023	11:25		1.06	1.43	1.25
18/01/2023	11:30		1.08	1.45	1.27
18/01/2023	0:00		**1.15**	**1.53**	**1.34**
18/01/2023	0:01	35.0	2.13	2.25	2.19
18/01/2023	0:05		2.19	2.30	2.25
18/01/2023	0:10		2.28	2.36	2.32
18/01/2023	0:15		2.37	2.45	2.41
18/01/2023	0:20		2.41	2.46	2.44
18/01/2023	0:25		2.52	2.55	2.54
18/01/2023	0:30		2.54	2.57	2.56
18/01/2023	1:00		**2.86**	**2.89**	**2.88**
18/01/2023	1:01	52.5	3.10	3.44	3.27
18/01/2023	1:05		3.16	3.48	3.32
18/01/2023	1:10		3.22	3.50	3.36
18/01/2023	1:15		3.25	3.53	3.39
18/01/2023	1:20		3.28	3.55	3.42
18/01/2023	1:25		3.29	3.55	3.42
18/01/2023	1:30		3.32	3.57	3.45
18/01/2023	2:00		**3.66**	**3.76**	**3.71**
18/01/2023	2:01	70	4.37	4.01	4.19
18/01/2023	2:05		4.52	4.03	4.28
18/01/2023	2:10		4.61	4.04	4.33
18/01/2023	2:15		4.63	4.06	4.35
18/01/2023	2:20		4.64	4.06	4.35
18/01/2023	2:25		4.71	4.07	4.39
18/01/2023	2:30		4.75	4.11	4.43
18/01/2023	3:00		4.76	4.23	4.50
18/01/2023	4:00		4.79	4.39	4.59
18/01/2023	5:00		4.80	4.59	4.70
18/01/2023	6.00		4.81	4.60	4.71
18/01/2023	7:00		4.82	4.60	4.71
18/01/2023	8:00		4.82	4.60	4.71
18/01/2023	9:00		4.82	4.60	4.71
18/01/2023	10:00		4.82	4.60	4.71
18/01/2023	11:00		4.82	4.60	4.71
19/01/2023	12:00		4.82	4.60	4.71

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DATE	TIME	LOAD(KN)	DIAL GUAGE READINGS		SETTLEMENT(mm)
19/01/2023	13:00		4.82	4.60	4.71
19/01/2023	14:00		4.82	4.60	4.71
19/01/2023	14:01	52.5	4.82	4.60	4.71
19/01/2023	14:05		4.82	4.60	4.71
19/01/2023	14:10		4.82	4.60	4.71
19/01/2023	14:15		4.82	4.60	4.71
19/01/2023	14:20		4.82	4.60	4.71
19/01/2023	14:25		4.82	4.60	4.71
19/01/2023	14:31	35	4.82	4.60	4.71
19/01/2023	14:35		4.82	4.60	4.71
19/01/2023	14:40		4.82	4.60	4.71
19/01/2023	14:45		4.82	4.60	4.71
19/01/2023	14:50		4.82	4.60	4.71
19/01/2023	14:55		4.82	4.60	4.71
19/01/2023	15:00		4.82	4.60	4.71
19/01/2023	15:01	17.5	4.54	4.32	4.43
19/01/2023	15:05		4.53	4.31	4.42
19/01/2023	15:10		4.50	4.30	4.40
19/01/2023	15:15		4.49	4.28	4.39
19/01/2023	15:20		4.80	4.27	4.54
19/01/2023	15:25		3.76	3.69	3.73
19/01/2023	15:30		3.72	3.64	3.68
19/01/2023	15:31	0	3.68	3.59	3.64
19/01/2023	15:35		3.66	3.58	3.62
19/01/2023	15:40		3.59	3.57	3.58
19/01/2023	15:45		3.59	3.57	3.58
19/01/2023	15:50		3.59	3.57	3.58
19/01/2023	15:55		3.59	3.57	3.58
19/01/2023	16:00		3.59	3.57	3.58

Table 2: Time Loading Records

APPLIED LOAD (KN)	APPLIED PRESSURE (KN/m^2)	SETTLEMENT (mm)
0	0	0.00
17.5	86.42	1.34
35	172.84	2.88
52.5	259.26	3.71
70	345.68	4.71
52.5	259.26	4.71

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APPLIED LOAD (KN)	APPLIED PRESSURE (KN/m²)	SETTLEMENT (mm)
35	172.84	4.71
17.5	86.42	3.68
0	0	3.68

Table 3: Load/Corresponding Settlement for Test Point

Summary of results from soil investigations

Sieve Analysis

Depth (m)	% Passing			
	2.00mm	425µm	63µm	2µm
0.75	80	33	2	
3.00	85	31	4	
3.75	85	30	8	
12.75	79	32	9	
13.50	89	28	6	
14.25	93	42	25	

Atterberg Limits

Depth	Natural Moisture content (%)	Liquid Limit (%)	Plastic Limit (%)	Plastic Index
3.00	21	44	21	23
14.25	21	42	19	23

Triaxial Tests

Depth (m)	Dia. Type (mm)	σ_3 (KN/m²)	Cu (KN/m²)
3.00	38	100	60
		200	
		400	
14.25	38	100	67
		200	
		400	

Subgrade Reaction "K"

From the relationship:

K = P/S

Where K = Subgrade Reaction, and

P= Applied Pressure (KN/m²) at a specific settlement

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S is a particular settlement (usually taken as 1.25mm)
Subgrade reaction for the site is thus computed as:
Test Point 1,
At settlement of 1.25mm, representative corresponding (Average) pressure is 80KN/m^2 at the depth of 0.0m is:
K = 80.0/0.00125, = 65,600.00MN/m^2

Discussion of Results

Comprehensive study was carried out to investigate plate load test as a method of determining the load bearing properties of the study area; Owode Elede, Lagos state, Nigeria, being part of the parameters needed in the design of stone columns as a method of soil stabilization. Preliminary tests; sieve analysis, liquid and plastic limit and triaxial tests were carried out, as well as the plate load test. Stone columns act as vertical drains and thus speeding up the process of consolidation, replaces the soft soil by a stronger material and initial compaction of soil during the process of installation thereby increasing the unit weight. The load settlement data obtained from the Plate Load Test carried out at Owode Elede area, shows that the soil is loose to medium Cohesionless soil or stiff clay. This data if plotted will give a definite failure Point (departure from the Initial Straight Line) showing that the material under consideration is either a dense sand or firm to stiff sandy clay. This is also verified by the geotechnical Properties of the soil, which depicts a value above the A line plot on the Plasticity Chart and percentage finer on sieve no 200 was about 35%. Also, the average Liquid Limit and the Plastic Limit values of 43% and 20% respectively show that the soil under consideration is low in compressibility.

CONCLUSION

Stone columns serve as vertical drainage systems, expediting the consolidation process by substituting soft soil with a sturdier material and achieving initial soil compaction during their installation, which increases the unit weight. Furthermore, these columns mitigate the risk of liquefaction and related damage by facilitating drainage pathways that prevent the buildup of high pore pressure.

They are particularly effective in soft soil types such as non-cohesive clay, silt, and peat, and are generally installed through a volume displacement method, which involves excavating a hole of predetermined diameter and depth.

The Load Settlement data derived from the Plate Load Test performed at Owode Elede categorizes the soil as loose to medium cohesionless soil or stiff clay. The data shows a clear failure point, indicating a deviation from the initial linear trend, which suggests that the material is likely dense sand or firm to stiff sandy clay.

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Recommendations

In order to achieve and establish soil stabilization using stone column, this research work needs to be enhanced as follows:

1. There is need to carry out all investigative tests on at least two test points in the study area.
2. The subgrade reaction, K, already determined in this research, should be used to determine replacement ratio.
3. The stone column should be designed to determine stone column length, diameter and geometry.

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