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(Research Article)

Geotechnical Investigation for the Construction of a Railway Double Cell Culvert in Port-Harcourt, Rivers State

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Abstract

In Nigeria, where the relationship between soil conditions, water bodies, and infrastructure stability is crucial, geotechnical investigations are essential to the development of railway hydraulic structures. Thorough geotechnical study is necessary to guarantee the dependability and safety of hydraulic infrastructure like bridges, culverts, and embankments as the nation works to upgrade its railway network. This study examines the methods and conclusions of geotechnical studies conducted for a railway hydraulic structure projects in Port-Harcourt, Rivers state, Nigeria with an emphasis on site-specific difficulties, groundwater conditions, and soil characteristics. In order to ascertain soil stability, bearing capacity and possible hazards including erosion, settlement, and seepage, the research emphasizes the significance of soil testing, which includes borehole drilling, laboratory analysis, and in-situ testing. The study also explores how these studies help with the design and building of robust and sustainable hydraulic structures, tackling the difficulties brought on by Nigeria's diverse topography and climate. This study offers important insights into the function of geotechnical investigations in guaranteeing the long-term durability and safety of Nigerian railway infrastructure by analyzing important geotechnical concerns.

Keywords: Geotechnical Investigation, Railway, Culvert, Modulus of Subgrade Reaction, Construction.

1. Introduction

The railway industry in Nigeria is one plagued with series of dilapidation of its alignment, structural members and railway components. The eastern narrow gauge railway constructed during the British colonial era is the nation's oldest railway alignment, trans-versing the southern area to the Northern area, spanning over 2000km. However, in recent years, the government has sort to revitalize and revamp the rail transport sector to foster inter-state conveyance of goods and service, thereby enhancing socio-economic growth. For every railway infrastructural development, understanding the peculiarities of the environs is of keen interest in the design and implementation phase of the project. Feasibility studies involving soil investigations and exploration are largely paramount. Soil Investigation is a crucial aspect of civil Engineering Construction process. Structures to be founded on the soil, induces stresses in various forms to the soil. These stresses, if not fully contained by the soil, leads to the development of shear failures or deformations of the soil, hence affecting the stability of the structure as well as leading to failure of the structure. Soil investigation is a process undertaken by engineering professionals to ascertain the properties of the soil at surface or sub-surface levels.

This process involve exploratory approach related to excavations of trial pits, borings, soil testing and interpretation of results. The soil investigation carried out in this study is primarily for the construction of a railway hydraulic structure (frame culvert) for the; Rehabilitation and Reconstruction of the Port Harcourt – Maiduguri Eastern Narrow Gauge Railway project in Nigeria.

Culverts are a type of hydraulic structure mostly constructed over a water body to enable the free flow of water through it. Culverts can also function as a bridge such that it provides connective routes for roads, as well as railways. The stability of the culvert is hinged on the properties of the soil underlying the structure, which primarily receives all induced stresses.

The culvert structure discussed in this study functions as a bridge for a railway, constructed over an urban storm-water discharge path. Therefore, the stresses induced from the train is largely significant, transitioning from the railway components (ballast, sleepers and rail) to structural members of the culvert and then the soil beneath the foundation. The

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proposed construction area for the culvert is characterized by commercial activities, contributing to the production of significant amount of biodegradable and non-biodegradable waste materials. The methodology as regards the geotechnical investigation employed, prelude to the construction of the proposed culvert is discussed in the later sections of this paper. The culvert is designed as a double cell culvert spanning a length of 12 meters with a width of 5.5 meters. Hence, one borehole was sunk to a depth of 25 meters at the center point of the proposed culvert location.

2. Construction Area

The proposed construction area is situated in a densely populated market in D-line, Okija road, Port Harcourt, Rivers state and is characterized by deposition of various kinds of waste materials including scrap metals waste, domestic waste, sewages etc. The surface storm-water was observed to be largely composed of these waste materials from the area and wastes transported from other areas by the flow of water.

In consideration of the nomenclature employed in the project for locations or chainages, the area is referred to as DK 4 + 252. The representation of the culvert location on Google Earth is shown in Figure 1 and 2. The red lines represent the railway alignment, while the culvert location is represented by the red box. The flow path of the urban storm-water is also captured.

Figure 1. Satellite imagery showing the culvert location

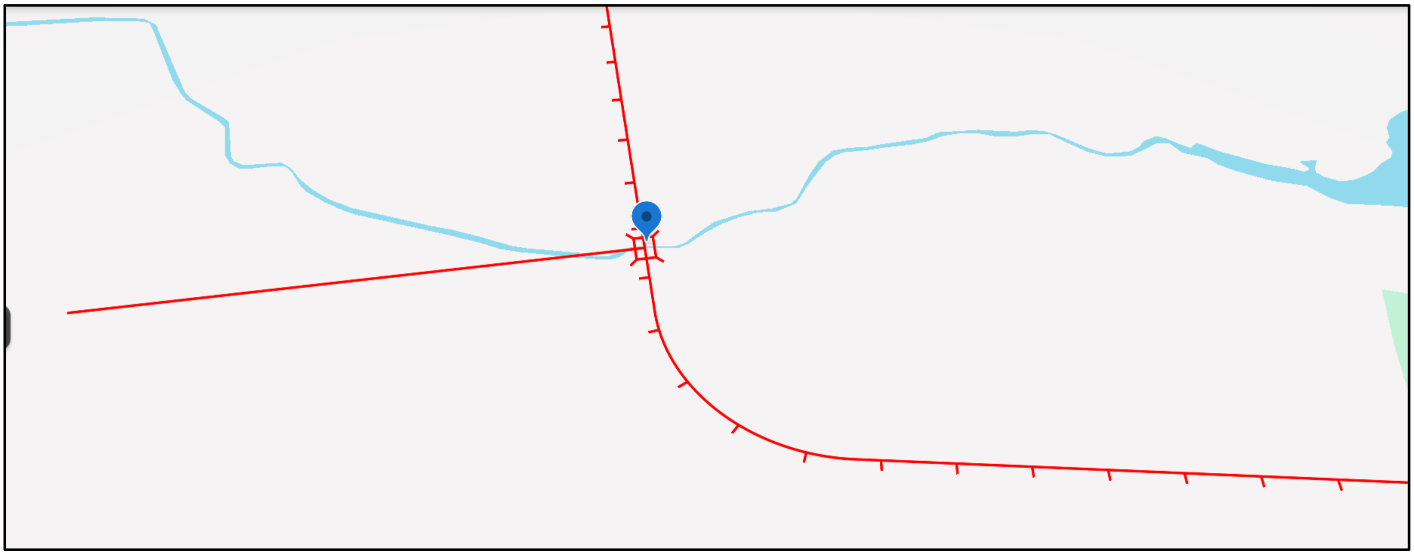

Figure 2. Flow path of the water

3. Methodology

3.1 Drilling and coring: Soil coring is a method used in soil investigation to obtain subsurface soil samples to assess the physical and mechanical properties of the soil as it concerns engineering use. The soil samples obtained by this technique are usually in cylindrical shapes. The coring involved the use of a rotary drilling rig, with drill steel rods attached to the core barrel. A driller operates the drilling rig while a logger (geologist) logs the soil obtained. The core barrel is advanced into the soil by rotary movement, which cuts through the soil as it drives down. The penetration of the core barrel into the soil was enabled by a bentonite slurry, which was used as a lubricating drilling fluid. The samples obtained in cores are retained in the core barrel in an undisturbed state; hence, the soil retains its natural form and structure. The core barrel is hoisted to the surface periodically and the cores are extruded into wooden core boxes. The core samples are arranged in the core box in accordance with the soil stratification, with each length of box measuring 1m. All cores were obtained to a subsurface depth of 25 meters and the borehole log showing the soil stratification is shown in Figure 3.

3.2 Standard penetration test: The Standard Penetration Test (SPT) was conducted to determine the penetration resistance of the soil. The test involves penetrating the soil with a split spoon sampler by dropping a 65kg hammer, falling from a height of 750mm. The number of blows required to cause a penetration of 450mm is recorded. The first 150mm penetration is considered as the seating drive while the SPT N-value is taken as the number of blows corresponding to a 300mm penetration of the split spoon sampler. The SPT provides in-situ information on the consistency of the cohesive soil or cohesion-less soil. The test was carried out at intervals of 2m. Typical delineation of the consistency of soil based on its SPT N-value is shown in Table 1. The SPT was carried out in accordance with BS 5930. [3]

3.3 Soil classification: Soil samples taken to the soil laboratory for testing were labelled accordingly, wrapped with an aluminum casing and further inserted into nylon bags to impede loss of moisture. Two sample types were obtained; disturbed and undisturbed samples. The Disturbed samples were used for the soil classification process that involves ascertaining the index properties of the soil. The index properties of the soil that enabled for its classification were determined by conducting variations of tests which includes; Natural Moisture Content, Sieve analysis, Atterberg Limits and Specific Gravity Tests. These laboratory tests were carried out as per BS 1377 and their corresponding results are outlined in Table 1 through to Table 3. [1] [2] and [3].

3.4 Shear strength: The shear strength of a soil is the maximum shear stress the soil can sustain before a shear failure is developed. The measure of the shear strength is enabled by conducting a Direct Shear Box Test or a Tri-axial Test to obtain the shear strength parameters such as; Cohesion (C) and Angle of Internal Friction (ϕ). In this work, the shear strength parameters of the soil was obtained using the Direct Shear Box Test method.

3.4.1 Direct shear box test: The direct shear box test according to BS 1377 is designed to simulate conditions under which the soil may fail due to shear forces. The undisturbed sample is trimmed into dimensions of 60 mm by 60 mm and loaded into the shear box, after which it is clamped to prevent lateral movement while a normal load is applied on the soil through the loading device at a constant strain rate. The normal load applied on the soil sample simulates the vertical overburden pressure or stress the soil would experience on the field. The normal load application is progressively increased to the desired maximum normal load condition to obtain various shear strength values corresponding to the normal loads. The horizontal displacement and shear force is then recorded. [2]

The shear stress is obtained by the mathematical expression given as;

$$\tau = \frac{Fs}{A} \tag{1}$$

Where,
Ʈ is the Shear stress
Fs is the Shear force at failure
A is the Area of the shear plane

The normal stress is obtained by the mathematical expression given as;

$$\delta = \frac{Fn}{A} \tag{2}$$

Where;
δ is the Normal stress
Fn is the Normal load applied
A is the Area of the shear plane

In addition, the obtained values are plotted on a graph for shear stress at failure against the corresponding normal stress and a linear failure envelope is drawn through the points. According to Mohr-Coulomb criterion, the shear strength of the soil is computed using that;

$$\tau = C + \delta \tan \phi \tag{3}$$

Where;
Ʈ is the Shear stress at failure
C is the Cohesion of the soil
δ is the Normal stress
ϕ is the Angle of Internal Friction of the soil

The slope of the line gives the angle of internal friction and the intercept with the shear stress axis gives the cohesion of the soil. The results of the direct shear box test is outlined in Table 3.

3.5 Plate load test: The test is conducted to determine the modulus of subgrade reaction of the soil. It measures the deformation of the soil in relation to an applied load. The test involves using a circular steel plate of 300m diameter, connected to a hydraulic pump having a pressure meter. In this study, a drum roller compacter was used to impose the load via a hydraulic jack. The pressures are exerted on the subgrade incrementally until the required design load is attained. The dial gauge measures the deformation or settlement of the soil in response to the pressure increments. The result is plotted on a graph of settlement against the corresponding pressure. The modulus of subgrade reaction, denoted as K, is obtained as the pressure corresponding to a settlement of 1.25mm divided by 1.25mm. It is given mathematically as;

$$K = \frac{\text{P at 1.25mm settlement}}{1.25} \tag{4}$$

4. Results and Analysis

4.1 Bore-hole and coring: The borehole logging and the cores obtained as shown in Figure 3 and figure 4 respectively, reveals that the site location is predominantly composed of sand materials, extending to a depth of 25 meters where the drilled borehole for the investigation was terminated. In addition, it was observed that the top layer was primarily composed of domestic waste with a layer thickness of 0.8 meters.

4.2 Standard penetration test: The soil layers composed of sand, which are cohesion-less were observed to have SPT N-values of 1, up to a depth of 7.45 meters, indicative of a soil in a very loose state. The soil underlying this “very loose” layer was observed to have N-value ranging from 5 to 7 indicative of a loose soil layer. Furthermore, the soil layer became medium dense as the depth increased. The SPT N-value were observed to be 11 and 13 at depths of 22 meters and 25 meters respectively. The increased values infers that the soil is in a relatively compact state and possess the capabilities to support the culvert load.

However, considering the very loose and loose soil at depths closer to the ground surface, the stability of the culvert is not guaranteed. Hence, to transmit the culvert load to a more stable stratum as observed at depths of 22 - 25 meters, the culvert will be founded on piles. Another suggestive approach is to adopt a ground improvement methodology involving stabilization of the upper soil strata to a suitable thickness with capacity to support the imposed load from the structure.

5. Ground Improvement Technique

Sequel to the results obtained from the ground investigation, with the SPT revealing soft organic soil and loose cohesion-less soil. A ground improvement technique was undertaken to increase the bearing capacity of soil. The ground improvement technique was reviewed for its cost effectiveness and it was considered a viable option over the implementation of a deep foundation (piles). The weak soil layer primarily composed of organic soil was excavated and replaced with boulders and crushed stones. The boulders were densely packed and the crushed stones were used as fillers to reduce the voids between the boulders. The total thickness of soil replacement reached 6m, with each layer of crush stones compacted with a drum roller compactor at thickness of 300mm. The compacted layers were tested for its stability using the plate load test until the final layer was completed having the appropriate layer stiffness. The results of the plate load test is tabulated in table 4 and the corresponding settlement graph is shown in figure 5.

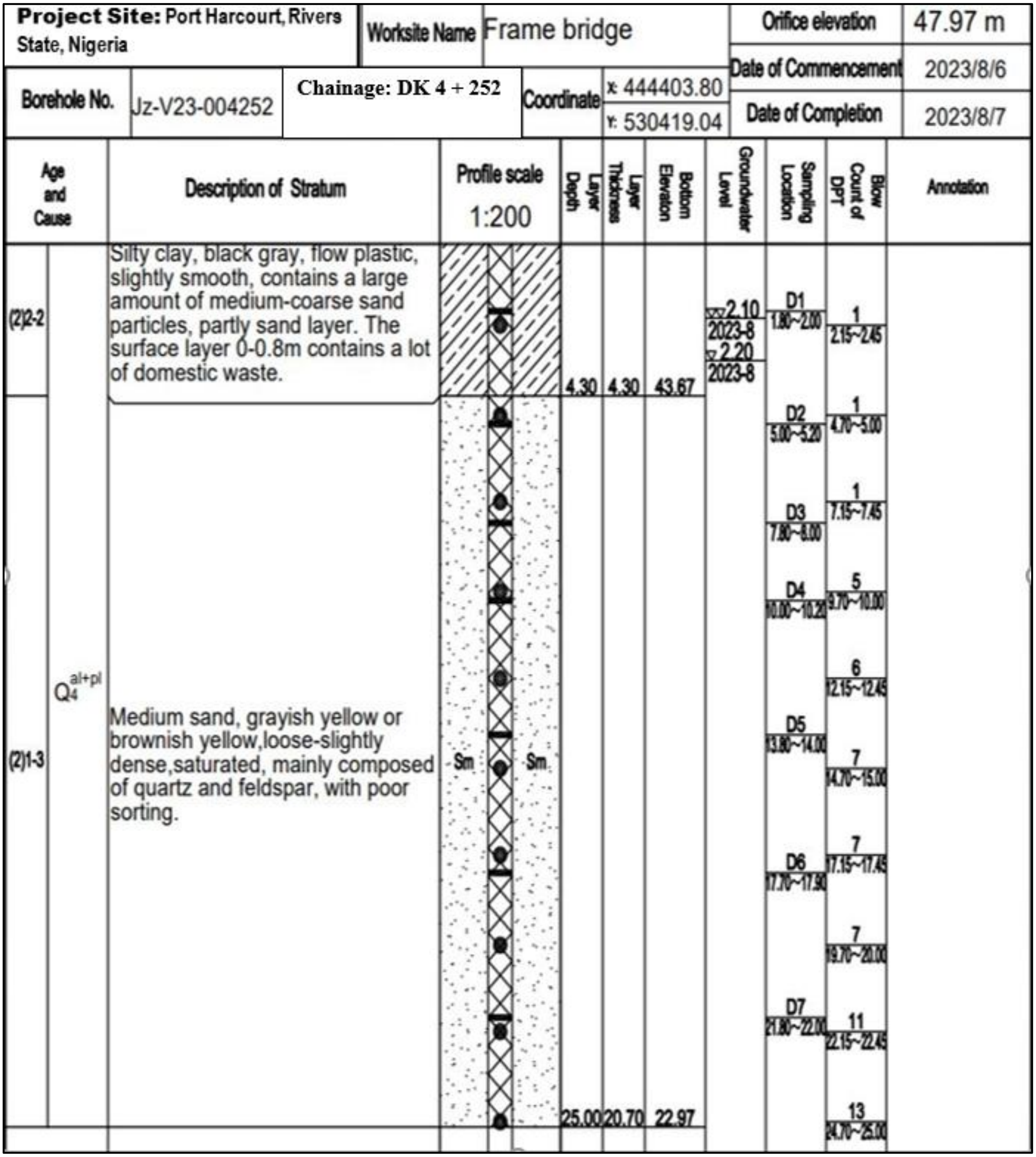

Figure 3. Borehole log

0 – 5 meters depth

5 – 10 meters depth

10 – 15 meters depth

15 – 20 meters depth

20 – 25 meters depth

all cores

Figure 4. Soil cores (soil stratification)

Table 1. SPT test results

Stratum N0	Borehole N0	Location	Depth (m)	SPT N-value	Field Description	Consistency
(2)1-3	Jz-V23-004252	DK 4 + 252	2.15 – 2.45	1.00	Mucky soil	Very loose
(2)1-3	Jz-V23-004252	DK 4 + 252	4.70 – 5.00	1.00	Medium sand	Very loose
(2)1-3	Jz-V23-004252	DK 4 + 252	7.15 -7.45	1.00	Medium sand	Very loose
(2)1-3	Jz-V23-004252	DK 4 + 252	9.70 – 10.00	5.00	Medium sand	Loose
(2)1-3	Jz-V23-004252	DK 4 + 252	12.15 – 12.45	6.00	Medium sand	Loose
(2)1-3	Jz-V23-004252	DK 4 + 252	14.70 – 15.00	7.00	Medium sand	Loose
(2)1-3	Jz-V23-004252	DK 4 + 252	17.15 – 17.45	7.00	Medium sand	Loose
(2)1-3	Jz-V23-004252	DK 4 + 252	19.70 – 20.00	7.00	Medium sand	Loose
(2)1-3	Jz-V23-004252	DK 4 + 252	22.15 – 22.45	11.00	Medium sand	Medium dense
(2)1-3	Jz-V23-004252	DK 4 + 252	24.70 – 25.00	13.00	Medium sand	Medium dense

Table 2. Particle size distribution results

Depth (m)	Field description	Particle sizes						d60	d30
		20 ~ 2 (mm)	2 ~ 0.5 (mm)	0.5 ~ 0.25 (mm)	0.25 ~ 0.075 (mm)	＜0.075 (mm)	0.075 ~ 0.005 (mm)		
		(%)	(%)	(%)	(%)	(%)	(%)		
1.80-2.00	Mucky soil	1.20	13.60	38.10	20.80	26.30	26.30	0.13	0.32
5.00-5.20	Mucky soil	6.70	15.90	35.30	21.20	20.90	20.90	0.16	0.35
7.80-8.00	Medium sand	2.70	13.70	44.50	24.20	14.90	14.90	0.19	0.34
10.00-10.20	Medium sand	6.60	38.30	34.20	18.30	2.60	2.60	0.31	0.57
13.80-14.00	Medium sand	9.30	38.50	31.10	16.70	4.40	4.40	0.31	0.63
17.70-17.90	Medium sand	6.70	41.00	30.90	15.60	5.80	5.80	0.31	0.62
21.80-22.00	Medium sand	5.50	20.10	29.90	28.40	16.10	16.10	0.15	0.35

Table 3. Direct shear box test results

Depth (m)	Field description	Angle of internal friction (Φ)	Cohesion(C) Kpa
1.80-2.00	Mucky soil	32.30^0	6.80
7.80-8.00	Medium sand	31.90^0	3.70
13.80-14.00	Medium sand	31.50^0	4.40
21.80-22.00	Medium sand	32.70^0	3.20

Table 4. Plate load test results

s/n	Pressure meter value (Mpa)	Bearing load (Mpa)	Dial gauge reading (0.01mm)			Total settlement (0.01m)
			1	2	Average	
-	0.00	0.00	0.00	0.00	0.00	0.00
1	2.12	0.04	0.01	0.02	0.02	0.02
2	3.93	0.08	0.08	0.09	0.09	0.11
3	5.74	0.12	0.14	0.11	0.13	0.24
4	7.56	0.16	0.21	0.19	0.20	0.44
5	9.37	0.20	0.37	0.29	0.33	0. 77
6	11.18	0.24	0.51	0.39	0.45	1.22

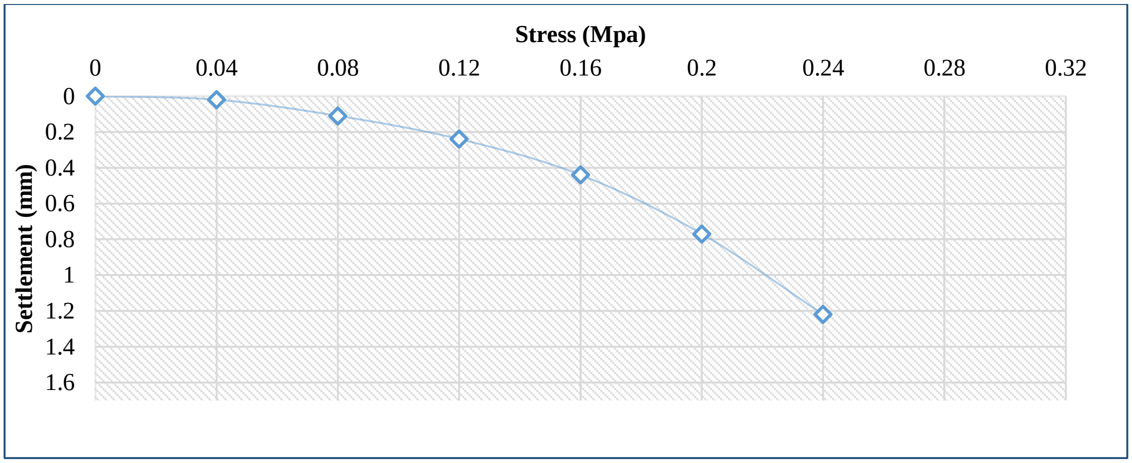

Figure 5. Plate load settlement graph

6. Conclusions

- The soil at shallow depths were observed to lack considerable engineering properties to support the load of the structure. However, deeper soil strata were compact and in a medium dense state as observed in its SPT N-values.
- To provide a suitable layer for the foundation of the structure, it was concluded to excavate the loose soil to a maximum depth of 3 meters and stabilize the strata with boulders and crushed stones to increase the bearing capacity of the layer.
- The stabilised strata was tested for its modulus of subgrade reaction using the Plate Load Test method and was found to have a value of 192Mpa/m.

Nomenclature

BS – British Standard
SPT – Standard Penetration Test
N value – Number of Blows required for 300mm Penetration
K – Modulus of Subgrade Reaction
P – Pressure
Ʈ – Shear stress at failure (shear Strength)
C – Cohesion of the soil
δ – Normal stress
ϕ – Angle of Internal Friction of the soil

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