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Evaluation of Lateritic Soil at Oyigbo as Road Pavement Construction Resource

Morrison, T. and Esonanjor, E.E.
Department Of Geology, Faculty of Science, Rivers State University, Port Harcourt.

Abstract:
Background: *This study evaluates the engineering suitability of lateritic soils from Oyigbo, Niger Delta, for use in road pavement subgrade and sub-base layers, given the need for locally available construction materials that satisfy Nigerian pavement performance specifications.*
Materials and Methods: *Five soil samples were obtained from georeferenced locations and subjected to standard laboratory testing, including natural moisture content, Atterberg limits, particle size distribution, compaction characteristics (OMC and MDD), and California Bearing Ratio (CBR) under soaked and unsoaked conditions, consistent with established soil-testing standards.*
Results: *Natural moisture content ranged from 9.2% to 13.0%. Liquid limit (LL) values ranged from 35% to 42% and plastic limit (PL) values ranged from 9% to 23%, yielding plasticity index (PI) values of 5% to 9%, all within the Federal Ministry of Works and Housing (FMWH) specification of PI ≤ 20%. However, Location 3 recorded an LL of 42%, slightly exceeding the FMWH maximum LL of 40%. Maximum dry density (MDD) ranged from 1845 to 1928 kg/m³ with optimum moisture content (OMC) of 15.3%–16.5%. Soaked CBR values ranged from 9.2% to 13.8%, while unsoaked CBR values ranged from 31% to 39%.*
Conclusion: *Based on these findings, the soils are classified as suitable for use as subgrade material but unsuitable for sub-base applications in road pavement construction. These results are consistent with FMWH and international standards for subgrade layers, providing valuable insight for pavement design in the Niger Delta region.*
Keywords: *Lateritic soils; Road pavement construction; Atterberg limits; Maximum dry density; California Bearing Ratio (CBR)*

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I. Introduction

The economic development of any nation relies heavily on effective interconnectivity, which, in turn, depends on the presence of a robust and high-quality road network. Government authorities at various levels therefore prioritize the provision and enhancement of road infrastructure to stimulate socioeconomic growth. Road construction fundamentally relies on the quality of the underlying foundation soils or rocks on which roads are anchored. As such, the performance and longevity of road pavements are critically dependent on the engineering behaviors of these foundation materials. An adequate understanding of soil behavior is indispensable in addressing engineering and environmental challenges associated with road construction.

A pavement is the structural system of a road, comprising both the surface layer and the underlying support courses [2]. Its primary function is to provide a smooth and safe surface for traffic, while effectively distributing vehicular loads to prevent excessive stress on the subgrade. Well-designed pavements extend the service life of roads by ensuring that stresses transmitted to the foundation soil remain within safe bearing limits.

There are two principal types of pavements: rigid and flexible. Each type utilizes different construction materials and methods, resulting in varying physical properties and performance characteristics. Rigid pavements are generally constructed using concrete slabs placed over a prepared sub-base or directly over the natural subgrade [1]. The high flexural strength of concrete allows the pavement to act as a stiff plate, dispersing loads over a broad area of subgrade [13].

In contrast, flexible pavements, which are more commonly used, are typically built in multiple layers. They consist of compacted layers of granular materials and lateritic soils over the subgrade, topped with an asphalt binder course and an asphalt surface course. Load transfer in flexible pavements primarily occurs through particle-to-particle contact within the aggregate/binder matrix. These pavements are usually designed for a service lifespan of about 20 years, but may fail prematurely due to factors such as rutting, cracking, or asphalt aging [1].

Given the prevalence of lateritic soils in Oyigbo and their potential as construction materials, it is important to evaluate their suitability for use in road pavement foundations. This study aims to assess the engineering properties of lateritic soils in Oyigbo and determine their appropriateness as a resource for road pavement construction.

The integrity and long-term sustainability of pavement structures are fundamentally determined by the quality of pavement design and, critically, by the standard of materials used in their construction. Enhancing the service life of pavements and ensuring their resilience requires judicious selection and use of appropriate construction materials.

II. The Niger Delta Experience

The Niger Delta has witnessed a significant surge in road development projects in recent years, with numerous large-scale road construction activities currently underway. Despite these efforts, a prominent challenge confronting the region is the scarcity of suitable materials for road pavement construction, particularly for sub-base and base-course layers [3]; [1]. Many contractors are often compelled to resort to the use of substandard or marginal materials, a practice that has contributed to the pervasive failure of road infrastructure throughout the Niger Delta. Indeed, the region is reported to have one of the highest incidences of road failure in Nigeria [1].

This chronic problem is exacerbated by the distinctive meteo-hydro-dynamic characteristics of the Niger Delta. The area experiences extremely high annual rainfall, typically exceeding 3,000 mm and lasting approximately nine months each year. The prevalent topsoil is predominantly clay, characterized by low permeability and high-water retention. Such soils are highly plastic, exhibiting significant swelling and shrinkage in response to seasonal variations in moisture content.

These adverse environmental and soil conditions pose significant engineering challenges for road construction. The lack of readily available and suitable construction materials combined with the problematic nature of local soils necessitates thorough geotechnical investigation of alternative resources.

In this context, the present study undertakes a detailed geotechnical evaluation of lateritic soil sourced from Oyigbo. The primary objective is to assess its suitability for use as sub-grade and sub-base materials in road pavement construction across the Niger Delta. By establishing the engineering properties and performance characteristics of Oyigbo lateritic soils, this research aims to provide a scientific basis for more durable, cost-effective, and sustainable road infrastructure in the region. Figure 1 illustrates the structural differences between flexible and rigid pavement.

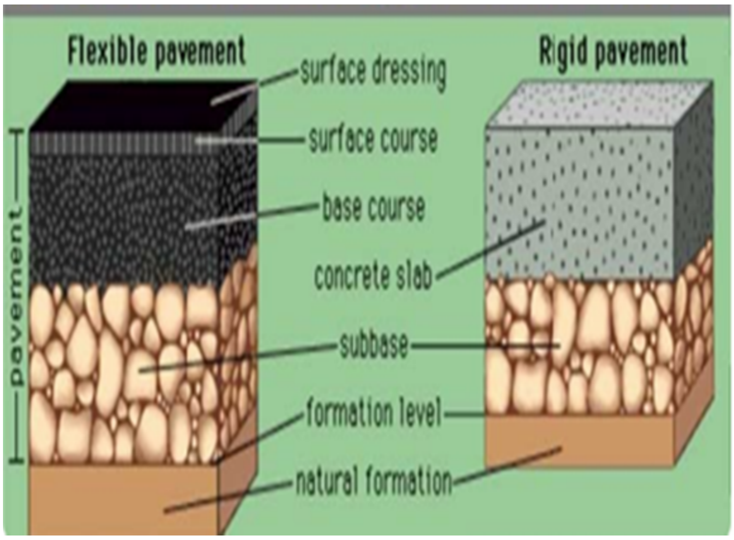


Figure 1: (a) Flexible pavement and (b) rigid pavement. Source: Encyclopedia Britannica Inc, (1999)

III. Local Geology of The Area

The study area is geologically underlain by extensive deposits of the Coastal Plain Sands, which themselves are overlain by soft to firm silty and sandy clays that exhibit lateritic characteristics and belong to the Pleistocene epoch. This region falls within the geologically complex Niger Delta, whose subsurface features have been extensively studied and described [16]; [12].

Stratigraphically, the Niger Delta is composed of three principal lithostratigraphic units: the Akata, Agbada, and Benin Formations. As shown in Figure 2, the Google map locates the study area within Oyigbo, Niger Delta. Figure 3 provides a detailed map of the study location.

- **Benin Formation**: The Benin Formation is the uppermost and most extensive unit, with thicknesses reaching up to 1,400m in parts of Southern Nigeria [14]. It is predominantly comprised of unconsolidated to poorly cemented sands, which are coarse-grained and vary from sub-angular to well-rounded, with occasional clay and shale intercalations. These sands are believed to have been deposited primarily in continental fluvial to deltaic environments [14]. Overlying this formation are distinct geomorphological features such as deltaic plain sands, abandoned beach ridges, mangrove and freshwater swamps, and meander belts, all dating from the Oligocene to Holocene periods [8].
- **Agbada Formation**: The Agbada Formation lies beneath the Benin Formation and consists of alternating layers of sands, silts, and shales. These sediments were deposited in a transitional, paralic (brackish water) environment and collectively form the delta front megafacies. The Agbada Formation has an average thickness of about 3,500m and is dated to the Eocene–Oligocene epochs. It is especially significant as the principal hydrocarbon reservoir rock in the Niger Delta [15].
- **Akata Formation**: The deepest of the three, the Akata Formation primarily comprises uniform, dark, silty shale with occasional lenses of sandstone, particularly at its contact with the overlying Agbada Formation. This formation serves as the main hydrocarbon source rock for the Niger Delta. The Akata Formation ranges in age from the Eocene to the Recent period and reaches thicknesses of approximately 1,100m [15].

Figure 2: Google Location Map of Study

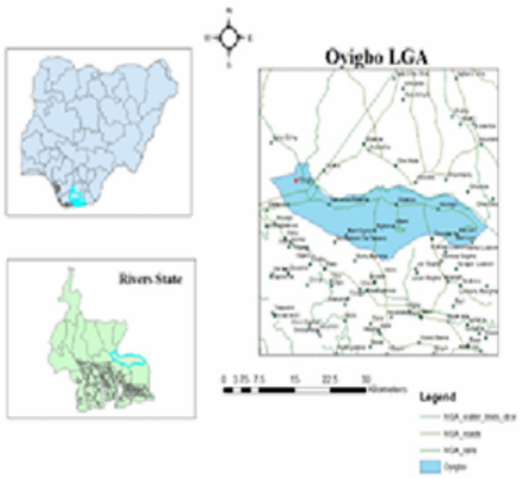


Figure 3: Study Location Map

IV. Material And Methods

The study involved collection of soil samples from five different georeferenced points within the study area using borrow pits and hand-auger. At every point the coordinates and ground elevations were taken using Global Positioning System (GPS). Collected samples were sealed in polythene bags and taken to the laboratory to avoid loss of moisture. The moisture content (Wn) of the soil was determined immediately in the laboratory.

In the laboratory, the samples were air dried for about 9 days, grinded to remove lumps before analysis. Soil parameters determined includes particle size analysis, moisture content, Atterberg limits Compaction tests and California Bearing Ratio (CBR). All tests were done according to British Standard of Test [6] and [5]. The georeferenced coordinates and elevations of each soil sampling location are presented in Table 1

Table 1: Geographical position of sampling points

Location	Northing	Easting	Elevation
1	539938.87	295773.65	10.6
2	539926.91	295776.70	8.2
3	539738.78	295832.71	8.6
4	539736.01	295847.91	9.6
5	539734.21	295851.21	7.1

For the grain size analysis, the samples were first soaked in calgon solution to disaggregate the samples before wet sieving. The liquid limit (LL) was determined using the Casagrande cup. It is the percentage moisture content that closes a distance of 0.5inches grove after 25 blows. The plastic limit (PL) was determined as the moisture content, expressed as a percentage of the weight of the oven-dry soil. It is the moisture content at which the soil crumbles when rolled into a thin thread of 3mm diameter.

Compaction test was carried out to determine the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) of the soil. To carry out the compaction tests, soil samples were compacted in a CBR mould. The compaction was done in three layers of 25mm each. A rammer of 4.5 kg falling freely from a height of 450 mm was used to apply 25 blows. was used to apply 25 blows to the sample. The OMC and MDD were also used to prepare samples for unsoaked California Bearing Ratio (CBR) and soaked CBR tests after 96hours of soaking. The load was recorded as penetration achieved 2.5 and 5.0mm. The average CBR values are computed at the ends of the specimen.

V. Results And Discussion

The foundation materials determine to a large extent the quality performance of pavement. Not every soil is suitable for sub grade or foundation material of a pavement. For a suitable subgrade material, certain engineering standards have to be met be a soil so as to sustain the structure. Such minimum standards for materials for subgrade, sub-base and base course have been set by the government through the authority of the Federal Ministry of Works and Housing [9]. It is a standard to which all pavement construction materials must conform with in the Nigeria.

The results of the various analysis which are presented in Tables 2 to 8 are therefore compared with the [9] standard in other to determine their conformity with the Federal Ministry of Works & Housing Standard [9].

Moisture Content

Water is an enemy to the sustainability of pavement structure. High moisture content (Wn) create problem to the stability of road pavements as the water creates bubbles which evaporates creating pot-holes ion the surface [12]; [3]. Also, the ingress of water into the subgrade foundation of pavement lowers the bearing potential of the subgrade, increase in moisture content leads to a decrease in the shear strength of the material because of the development of pore pressure [11]; [4]

The moisture content of the soils range between 9.2 and 13.0% (Table 2). This is within the specification of FMWH [9]. The FMWH [9] specified an average range of 5 – 15% for moisture content of soils for pavement construction. The soil is therefore low in its moisture adsorption or retention capability.

Presented in Table 3 is the specific gravity (SG) of the soils. The Table indicate that the SG of the soils range from 2.63 to 2.68. All the soil samples therefore met the specific gravity standard of the FMWH [9] which put SG ≥ 2.6.

Table 2: Consistency tests results of the soil samples

Sample Location	Wn (%)	LL%(%)	PL(%)	PI	Plasticity
1	13.0	38	19	19	Medium low
2	11.1	36	19	17	Medium low
3	12.2	42	23	19	Medium low
4	9.2	35	20	15	Medium low
5	11.8	40	21	19	Medium low
FMWH (2000)	(5 – 15%)	Maximum LL = 40%		≤ 20%	Medium low

Wn = Moisture content, LL = liquid limit, PL = plastic limit, PI = plasticity index

Table 3: Specific gravity values

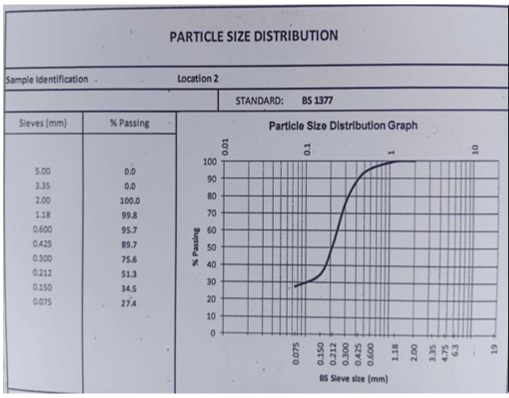
Parameter	Loc 1	Loc 2	Loc 3	Loc 4	Loc 5
Specific Gravity (SG)	2.65	2.68	2.64	2.63	2.65

Grainsize Analysis

Table 4 presents the grainsize analysis of the soil from the five locations. The percentage passing sieve no 200 is between 24.3 and 28.9%, meaning the soil has less than 30% in average of five fraction. Also, while the sand fraction has highest percentage by composition (69.3 to 72.4%), the gravel content range 13 to 42% using the ASSHTO classification system, all the soil samples belong to the A-2-6 group with liquid limit (LL) below 40% except locations 3 which belongs to A-2-7 with LL above 40%.

The gradation curve of the soil is indicative that they are sorted with limited amount of fines for binding of the coarse materials (Figure 4)

Atterberg Limits



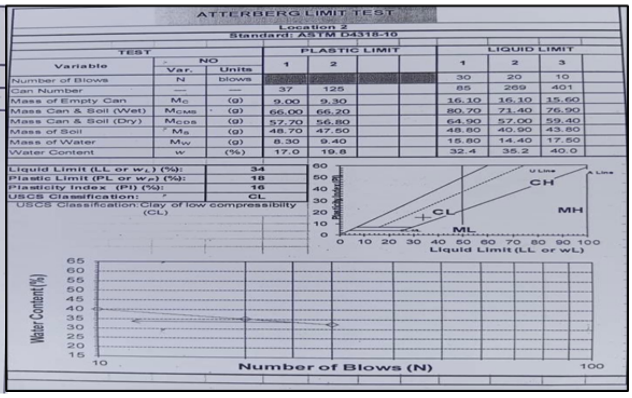


Figure 4.0: Particle Size Distribution results **Figure 5.0: Atterberg Limits tests**

Table 4: Grainsize analysis of soil

Sample Location	% Clay	% Silt	% Sand	% Gravel	% Passing Sieve No 200	AASHTO
1	14.3	13.2	69.3	4.2	27.5	A - 2 - 6
2	13.3	11.0	72.4	3.3	24.3	A - 2 – 6
3	14.3	14.5	69.9	1.3	28.8	A - 2 – 7
4	13.4	12.5	71.3	2.8	25.9	A - 2 – 6
5	13.3	12.1	71.8	2.8	25.4	A - 2 – 6

Results of the Atterberg Limits tests are presented in Table 5.0 These are the liquid limits (LL), plastic limits (PL) and the plasticity index (PI). The values of the LL range from 35 to 42%, PL between 19 and 23% while PI is between 15 and 19.

FMWH [9] specified maximum LL of 40% and PI ≤ 20%. Therefore, sample from all the locations are within the liquid limit specification of ≤ 40% except location 3 which value is > 40%. In terms of the plasticity index, all within FMWH [9] specification.

Casagrande chart classification of the soil samples is presented in figure 5. This shows the soil to be clay of low compressibility (CL) with intermediate plasticity following Whitlow [17] classification of soil based on liquid limit, the soils are all of intermediate plasticity

Table 5: Whitlow (1995) soil classification based on LL

Liquid Limit (%)	Plasticity
< 35	Low
35 – 50	Intermediate
50 – 70	High
70 – 90	Very High

Permeability Characteristics of Soils

The permeability characteristics of soils are very important as it contributed to a lot of engineering problems due to the effect of water on soil behavior. The coefficient of permeability (k) of the soil varies from 2.31 x 10^{-6} to 2.65 x 10^{-8} which is indicative of impermeable to moderate (fan) permeability [16]. However, due to the intensity and long duration of rainfall in the region, adequate drainage is emphasized to drain excess water thereby avoiding water seepage into the foundation structure. Seepage of water into pavement weaken the foundation soil as a result of pore pressure build up thereby lowering the bearing pressure. Also, the swelling and shrinkage of the soil due to expansion and contraction of pore water within the soil often result into cracks and potholes on the road surface. This is one of the major road pavement problems in the region [3], [16], & [12]; [1].

Compaction Analysis

The dry density of subgrade materials relative to their moisture content are determined to ascertain the behavior of the subgrade soil under different moisture content. Water disaggregate the cohesive bond between particles thereby weakening the strength of the formation structure. The best soil for pavement subgrade construction is one that achieves high maximum dry density (MDD) at *a* minimum option moisture content (OMC) [10]; [2]. This means soils with low water retention and adsorption capacities.

The result of the compaction characteristics of the soil is given in Table 6. The relationship between moisture content and corresponding dry density for the various samples is illustrated in Table 7. The OMC-MDD relationship of the soils is indicative of moderate soils in their applicability for subgrade, sub-base construction. It indicates that the MDD values range from 1845 to 1928klm^3 at OMC of 15.3 to 16.5%, meaning the compacted densities are higher at low optimum water content.

Table 6: Compaction characteristics of the soils

Sample Location	Maximum Dry Density (MDD)(kg/m^3)	Optimum Moisture Content (OMC) (%)	Group Symbol	Description
1	1816	16.0	SM	Silty soil, sand and poorly graded
2	1867	16.2	SM	Silty soil, sand and poorly graded
3	1928	16.5	SM	Silty soil, sand and poorly graded
4	1845	15.3	SM	Silty soil, sand and poorly graded
5	1864	16.4	SM	Silty soil, sand and poorly graded

Table 7: Relationship between Moisture Content and Dry Density

Location 1		Location 2		Location 3	
Average Wn (%)	**Dry Density (kg/m^3)**	**Average Wn (%)**	**Dry Density (kg/m^3)**	**Average Wn (%)**	**Dry Density (kg/m^3)**
11	1628	11.3	1568	9.7	1678
14.9	1756	14.3	1762	12.1	1763
16.0	1876	16.2	1867	15.3	1845
18.2	1753	17.3	1732	17.0	1752
19.7	1650	18.5	1678	19.5	1650
OMC = 16.0%, MDD = 1876kg/m^3		**OMC = 16.2%, MDD = 1867kg/m^3**		**OMC = 15.3%, MDD = 1845kg/m^3**	

OMC = Optimum Moisture Content; MDD = Maximum Dry Density; Wn = Moisture Content

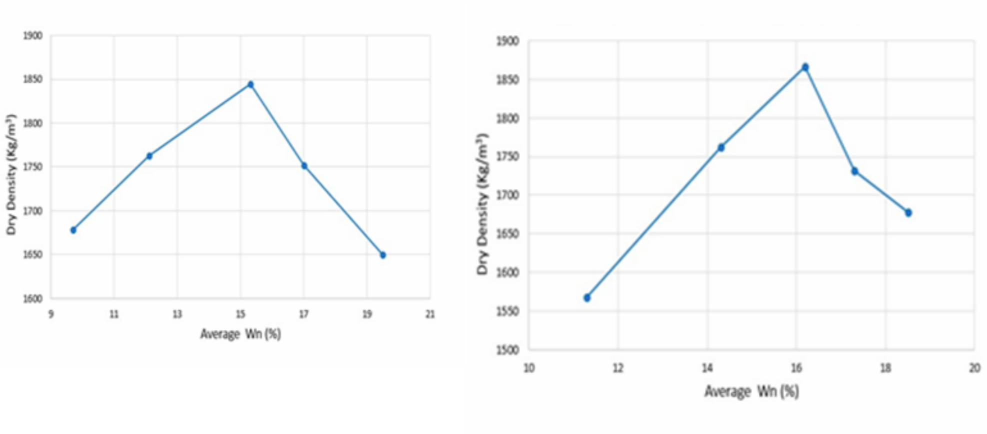


Figure 6: Graph of Dry Density against Average water content

California Bearing Ratio (CBR)

The Subgrade performance of the soils was also analyzed based on their California bearing ratio (CBR) CBR is test to determine the quality of subgrade and sub-base materials. It consists of two types: soaked and unsoaked. The soaked test is to create a water-logged condition that some pavements sometimes experience. Unsoaked CBR ranged from 31 to 39% while soaked CBR was between 9.2 and 13.8%. The FMWH [9] recommended for subgrade, sub-base and base-coarse for CBR are 10% (soaked) minimum, 30% (soaked) minimum and 80% (unsoaked) respectively. This indicates that soil cannot be used as sub-base material as none of the samples meet the FMWH [9] specification. However, it could be used for subgrade as Table 8 indicates.

According to Road Note 31 (Table 9), classification of subgrade (which grouped soils into six groups S_1 to S_6) based on their CBR values, with S_1 having CBR of 2% and S_6 with CBR of 30% and above, the soil is suitable for subgrade construction. Figure 6.0(a) and (b) are the representative California Bearing Ratio (CBR) Curves for the Study Area.

Table 8: California Bearing Ratio (CBR) values of the soil

Sample Location	CBR (%) Soaked	CBR (%) Unsoaked	For Subgrade	For Sub-base
1	13.1	37	Good	Poor

2	11.0	36	Good	Poor
3	9.2	31	Poor	Poor
4	13.8	37	Good	Poor
5	12.7	39	Good	Poor

FMWH (2000)
Subgrade = 10% (soaked) minimum
Sub-base = 30% (soaked) minimum
Base course = 80% (unsoaked)

Table 9: Road Note 31 Classification of Subgrades

S	AASHTO	Sub-grade	CBR Values
1	---	Very poor	2
2	A–7–5 / A–7–6 / A–6	Poor	3–4
3	A–4	Fair	5–7
4	A–2–6 / A–2–4	Good	8–14
5	A–2–6 / A–2–4	Good	15–29
6	A–1–b / A–1–a	Excellent	≥ 30

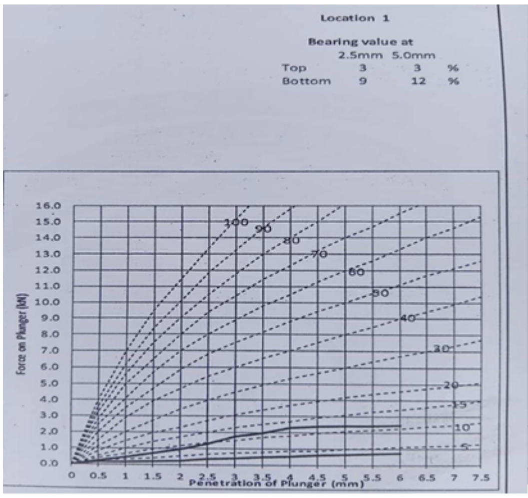


Figure 6.0: Bearing Values at Location 1

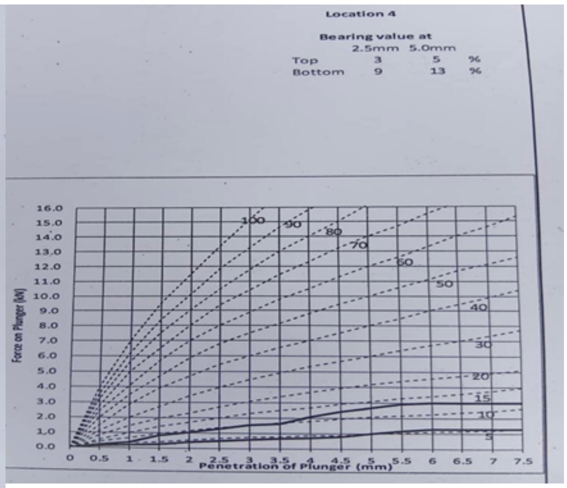


Figure 7.0: Bearing Values at Location 4

VI. Conclusion

The sustainability of a road pavement is very much dependent on the foundation sub-grade structure. Materials that have low water retention and absorbability are better suited for road pavement construction. The above study was carried out to determine the sustainability of the material for road pavement construction. The results indicate that the soil has Wn = 9.2 -13.0%, LL = 35 – 42% WITH pl = 19 – 23%. Also, it has OMC in the range 15.3 to 16.5% with corresponding MDD of 1845 – 1928kg/m^3. The CBR for soaked is between 9.2 and 13.8% while unsoaked is in the range of 31 to 39%. Following the Federal Ministry of Works and Housing (FMWH) [9] standard for road pavement construction materials, the soil is suitable for subgrade construction but a poor sub-base material.

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