

Geotechnical Subgrade Assessment for Pavement Design in Parts of Niger Delta

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ABSTRACT: The Study is aimed at locating the relevance of sub-grade assessment in pavement design in the the Sombreiro-Warri Deltaic plains of the Niger Delta. The study reveals A-2-4 to A-2-7 soils using the AASHTO classification systems with Group Index of 0 - 2. CBR values of about 10% and average Penetration Index of about 20% were recorded. Compactions curves reveals the nature of the soils as clayey Sand and silty Sand. Penetration Index assessment shows three distinct layers, with the upper layer correlating with the laboratory CBR values using empirical relations; thus, prompting the cutting of this layer prior to placement of subsequent pavement layers. These values depicts a low quality sub-grade, thus necessitating the significance of capping with compacted material of fines < 35% and at least a soaked CBR value > 8% in the design of a functional pavement system. Minimum thickness of the pavement layers are improvised for the different Road types. Though the swelling potential and water table values in these areas are not critical, relative compaction values > 95% and adequate drainage systems are prerequisite for distress and failure mitigation on pavements in the study areas.

KEYWORD: Sub-grade, Sub-base, base, Pavement, Capping, Drainage, Niger Delta, CBR, DCP, Penetration Index, Roads,

I. INTRODUCTION

Sub-grade assessment is a critical factor for pavement construction in the Niger Delta region, due to the poor engineering characteristics of the superficial deposit underlying the surface. Sub-grade is referred to as the top surface of a roadbed upon which the pavement structure and shoulders are constructed. The purpose of the sub-grade is to provide a platform for construction of the pavement and to support the pavement without undue deflection that could impact the pavement's performance (NHI-05-037). Arumala and Akpokodje (1987) reported widespread pavement failures in most of the completed highways in the Niger Delta region and many roads sections have been rendered un-trafficable barely two years after completion. Improper Sub-grade assessment results to premature pavement failure, that leads to reduction in serviceability of the pavement performance.

Novikov and Miskovsky (2010) cites the relevance to develop a sub-grade with a California Bearing Ratio (CBR) value of at least 10. Research has shown that if a sub-grade has a CBR value less than 10, the sub-base material will deflect under traffic loadings in the same manner as the sub-grade and cause pavement deterioration (Islam, 2011). The stability and durability of pavement depends on the traffic load or intensity and the strength of pavement layers (Kiehl and Briegleb, 2011). While the integrity of a flexible pavement surface reflects the entire behavior of the sub-grade layer, it thereby, emphasizes more attention on making the soil sub-grade of superior soil properties (Ahmed *et al*, 2012). Ogunidipe and Olumide(2012) cites the inadequacies in pavement structural design as a cause in Pavement failure. Talukder (2009) emphasis poor sub-grade soil properties as a principal causes.

Soils in most parts of the Niger Delta are characterized as weak and low bearing (Tse *et al*, 2004). Soaked CBR of less than 2 % and high percentage of fine ranging from 17% to 94% were revealed

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

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in certain geomorphic regions in the Niger Delta (Arumala & Akpokodje, 1987). The general poor performance of roads in the Niger Delta can be attributed principally to the substandard paving properties of the soil materials. (Arumala & Akpokodje 1987).

Though subgrade quality affects pavement performance, durability of roads in the Niger Delta is a possibility once design considerations are given to the poor geotechnical properties of the soil (Arumala & Akpokodje, 1987). The study involves the Geotechnical assessment of subgrade in parts of the Niger Delta for a proper pavement design.

The Survey is for three different Roads;

1. Construction of 1km Abulele Road, Evboriaria Quarters, Sapele Road, Oredo LGA, Edo (Point 1) 6.356220, 5.618779
2. Okada /Usen , Ovia North East LGA Phase 1(Point 2 & 3)
6.591535, 5.596336
3. Okada /Usen , Ovia North East LGA Phase 2 (Point 4 & 5)

II. SITE DESCRIPTION AND GEOLOGY

The general geology of the Niger Delta consists of various types of Quaternary deposits overlying the three major lithostratigraphic units. These are from bottom to top the Akata, Agbada and Benin Formations. The units have been extensively studied and described in literature, including the classic work of Short and Stauble (1967) Geomorphically, the site is located within the Sombreiro-Warri Deltaic plains where the sub-soils comprises distinct units or intercalations of sand, clay and some silt.

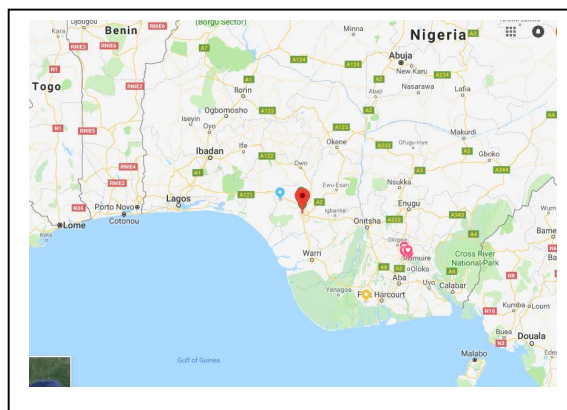


Fig 1. Showing Location of Study Area

III. METHODS OF STUDY

Investigative procedures comprising, Dynamic Cone Penetrometer, borings at a pre-determined locations at the proposed construction of 3km flexible pavement and relevant laboratory analysis on retrieved samples.

Soil Borings:

A 1.5m deep boring was made using a post-hole auger was spatially carried out . This is as stipulated in AASHTO (1993) Guidelines. Disturbed and undisturbed soil samples were collected at intervals of 0.5m and wherever a new soil formation was encountered. Newcomb and Birgisson (1999), states spacing of boring location on the order of 12 per km (20 per mi) to as few as 2 per km (3 per mi), with spacing generally decreased with high-volume roads and fine-grained soils.

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Testing Method:

The Testing comprised of California Bearing Test which gives a measure of the material quality in terms of its stiffness and resistance to permanent deformation; samples were taken within the top 0.5m, Atterbergs Limits (liquid and Plastic Limit) ASTM D423-66 and D424-57 standards respectively, Standard Proctor Test (ASTM D-698) which gives us an indication of the optimum moisture content / maximum dry density, Moisture Content and Sieve Analysis for Particle Size gradation (ASTM D422-63).

Dynamic Cone Penetrometer:

This is an in situ testing method. The principle behind the DCP is that a direct correlation exists between the strength of a soil and its resistance to penetration by solid objects, such as cones (Newcombe and Birgisson, 1999). The DCP consists of a cone attached to a rod that is driven into soil by means of a drop hammer that slides along the penetrometer shaft. The mass of the hammer can be adjusted to 4.6 and 8 kg. A number of empirical correlations exist to relate the DCP penetration index (DPI) to subgrade strength parameters required for pavement design. The most widely used is stated below by Webster *et al* (1994).

Table : showing CBR relations (Webster *et al* 1994)

CBR	=	$292/(DPI)^{1.12}$	for gravel, sand, and silt
CBR	=	$1/0.002871 \text{ DCP}$	for highly plastic clays
CBR	=	$1/(0.017 \text{ DCP})^2$	for low plasticity clays

IV. RESULTS OF GEOTECHNICAL STUDIES

Soil Stratigraphy:

The data from the soil sampling, DCP Test and laboratory tests were carefully evaluated for the determination of the stratification of the underlying soils. The evaluation discovered a primary zone.

Bore-hole Parameters for Point 1

Subgrade is made up of clayey Sand Layer with Water Level not encountered within the depth drilled.

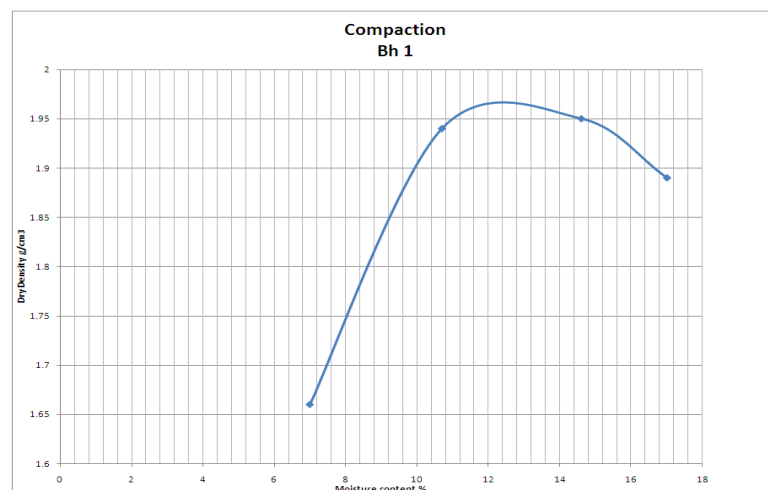


Fig. 2: Compaction curve for Point 1

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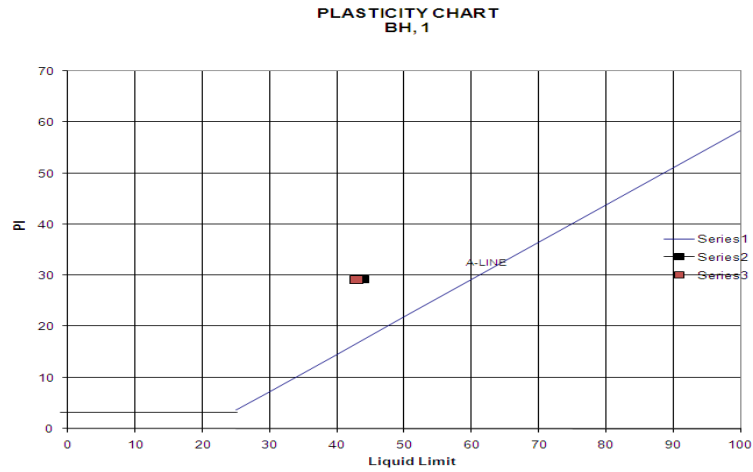


Fig. 3: Plasticity Chart for Point 1

Particle Size Distribution for BH1:0.5m

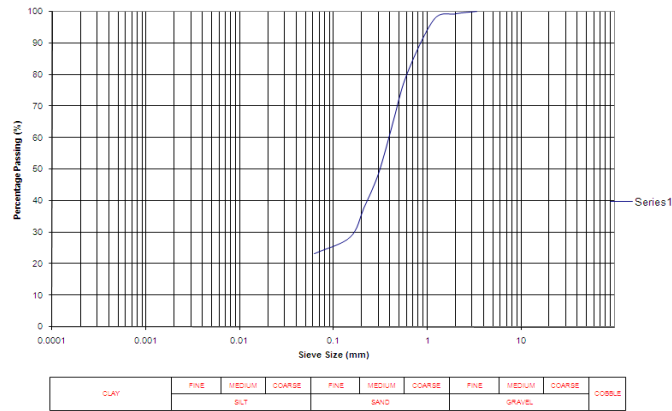


Fig.4: Particle Size Distribution Chart for Point 1

Table 1: Subgrade Parameters for Point 1

Soil Type (AASHTO)	CBR Value %	MDD Mg/m ³	OMC %	finer Fraction (%)	Sand Fraction (%)	M.C (%)	Unit weight (KN/m ³)	Group index
A-2-7	9.2	1.965	13.0	23.2	76.8	10	17.9	2

Table 2: Index Properties for Point 1

Soil, USCS	Soil Activity	Consistency Index(%)	Liquidity Index (%)
SC	1.25	116	-16

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Table 3 Atterberg Limit , BH 1 for Point1

Depth(m)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index(%)
0.5m	44	14.8	29.2
1	43	13.8	29.2

Table 4: Swelling Potential for Point1

Swelling Potential based on Plasticity Index	Low-Medium	
Swelling Potential based on Soil Activity	Low -Medium	Appr. 5%

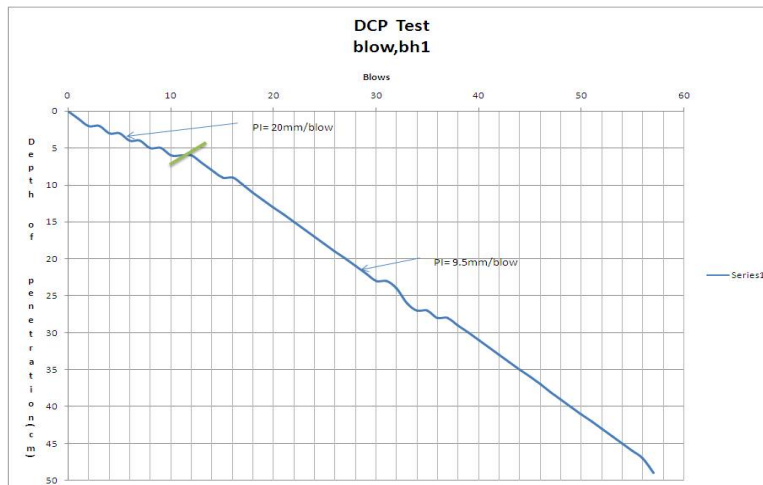


Fig. 5: Dynamic Cone Penetrometer Profile for Point 1

Table 5: Dynamic Cone Penetrometer Test, for Point 1

Test point	Layer	Penetration Index(PI)mm/blow	Thickness(Approx)cm
1	1	20	6
	2	9.5	43

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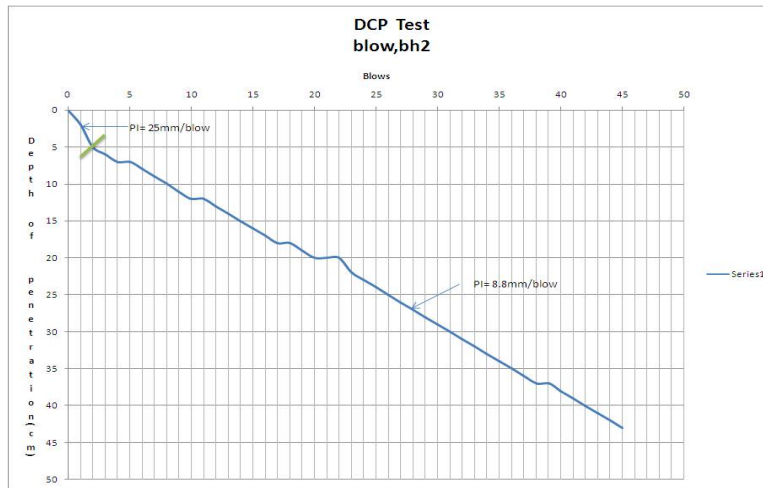


Fig. 6: Dynamic Cone Penetrometer Profile -2, for Point1

Table 6: Dynamic Cone Penetrometer Test -2, for Point1

Test point	Layer	Penetration Index(PI)mm/blow	Thickness(Approx)cm
2	1	25	5
	2	8.8	38

Bore-hole Parameters for Point 2 and 3

Subgrade is made up of clay Sand and silty Sand Layer with Water Level not encountered within depth drilled.

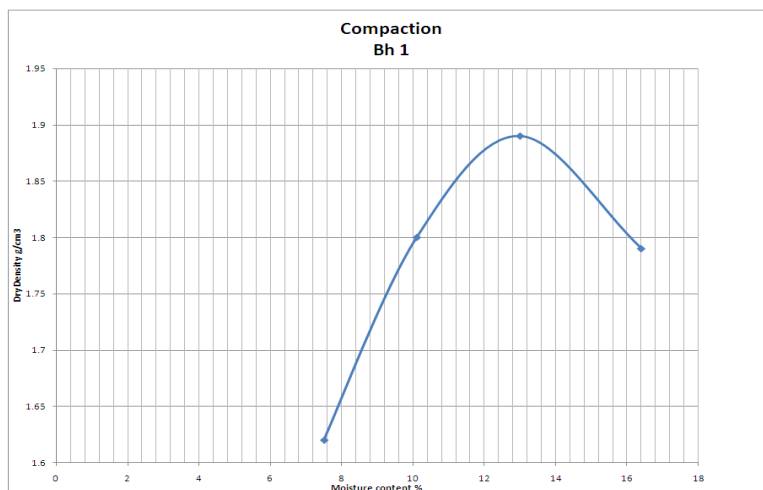


Fig. 7: Compaction curve for Point 2

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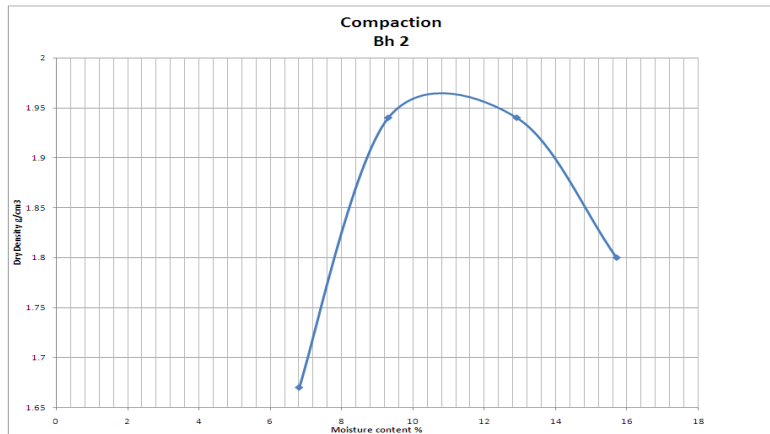


Fig. 8: Compaction curve for Point 3

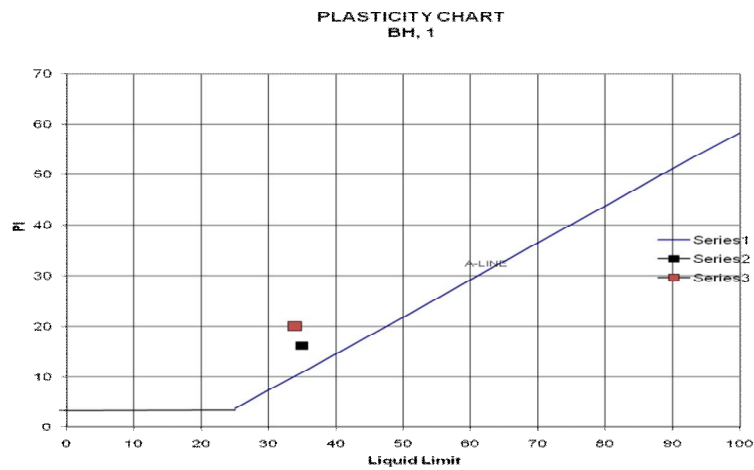


Fig. 9: Plasticity Chart for Point 2

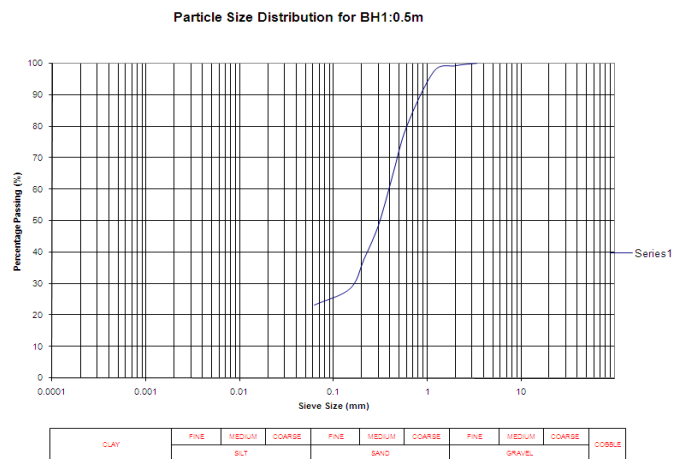


Fig. 10: Particle Size Distribution Chart for Point 2

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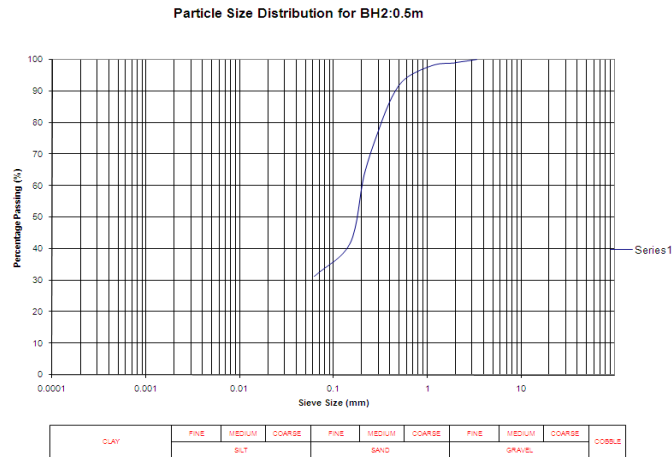


Fig. 11: Particle Size Distribution Chart for Point 3

Table 7: Subgrade Parameters for Point 2

Soil Type (AASHTO)	CBR Value %	MDD Mg/m ³	OMC %	Fines Fraction (%)	Sand Fraction (%)	M.C (%)	Unit weight (KN/m ³)	Group index
A-2-6	9.4	1.89	13.5	31.9	68.1	10.8	17.8	2

Table 8: Subgrade Parameters for Point 3

Soil Type (AASHTO)	CBR Value %	MDD Mg/m ³	OMC %	Fines Fraction (%)	Sand Fraction (%)	M.C (%)	Unit weight (KN/m ³)	Group index
A-2-4	10.6	1.965	11	31.2	68.8	9.1	17.9	0

Table 9: Index Properties for Point 2

USCS	Soil Activity	Consistency Index(%)	Liquidity Index (%)
SC	0.6	116	-16

Table 10: Atterberg Limit for Point 2

Depth(m)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index(%)
0.5m	35	18.75	16.25
1.0m	34	14	20

Table 11: Swelling Potential for Point 2

Swelling Potential based on Plasticity Index	Low-Medium	
Swelling Potential based on Soil Activity	Low -Medium	Appr. 5%

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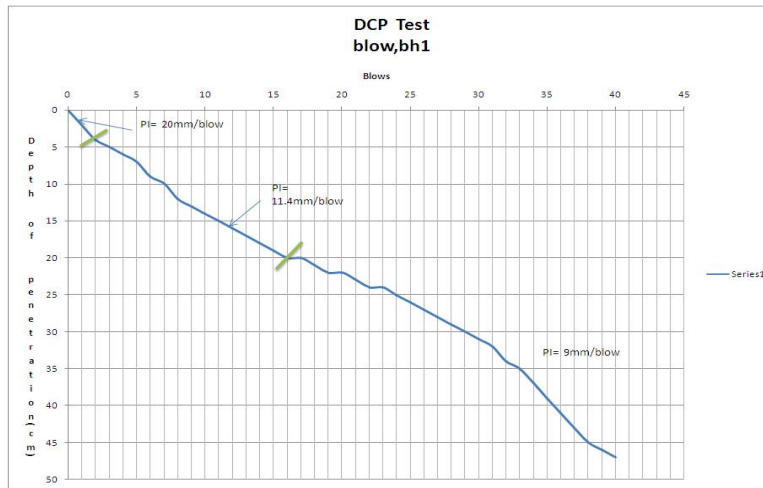


Fig 12: Dynamic Cone Penetrometer Profile for Point 2

Table 12: Dynamic Cone Penetrometer Test for Point 2

Test point	Layer	Penetration Index(PI)mm/blow	Thickness(Approx)cm
1	1	20	4
	2	11.4	16
	3	9	27

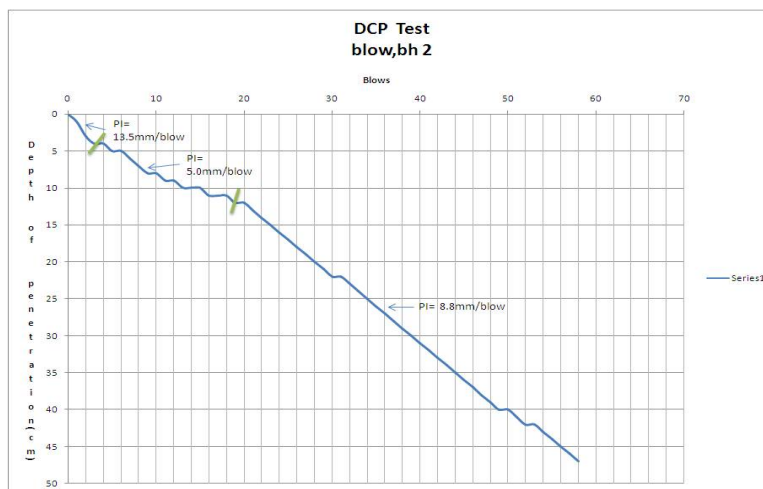


Fig.13: Dynamic Cone Penetrometer Profile for Point 3

Table 13: Dynamic Cone Penetrometer Test for Point 3

Test Point	Layer	Penetration Index(PI)mm/blow	Thickness(Approx)cm
2	1	13.5	4
	2	5.0	8
	3	8.8	35

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Bore Hole Parameters for Point 4 and 5

Subgrade is made up of Silty Sandy Layer with Water Level not Encountered Soil Parameters

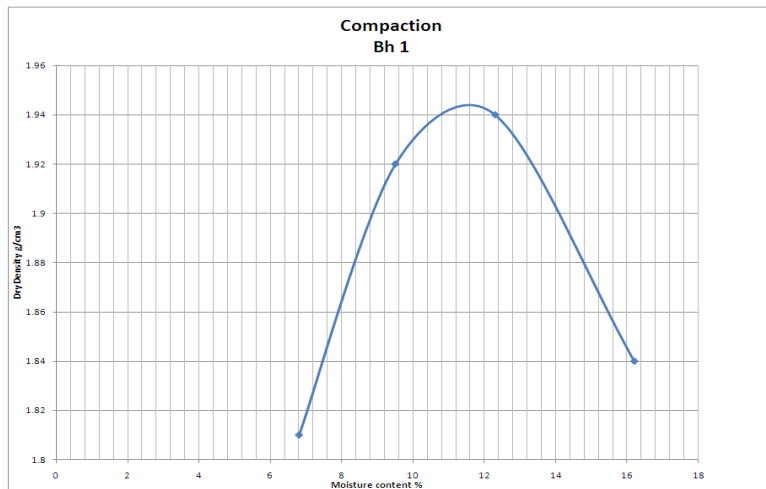


Fig.14: Compaction curve for Point 4

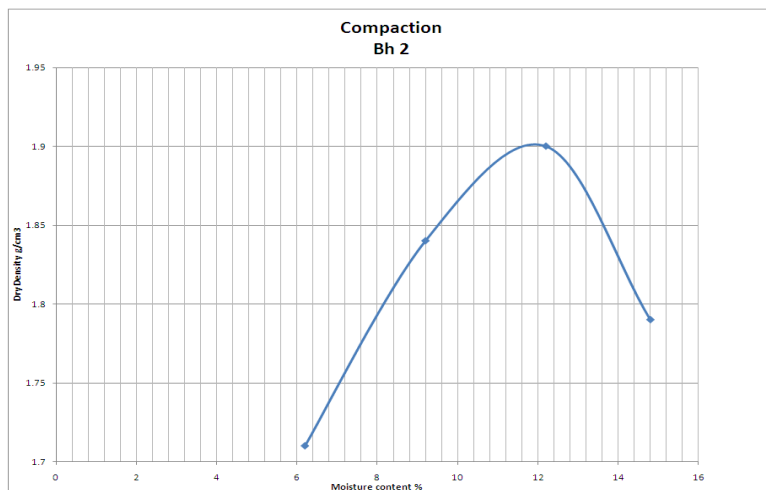


Fig.15: Compaction curve for Point 5

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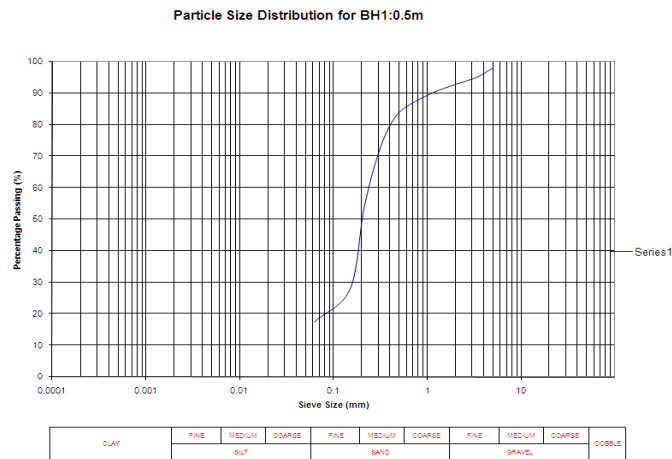


Fig. 16: Particle Size Distribution Chart for Point 4

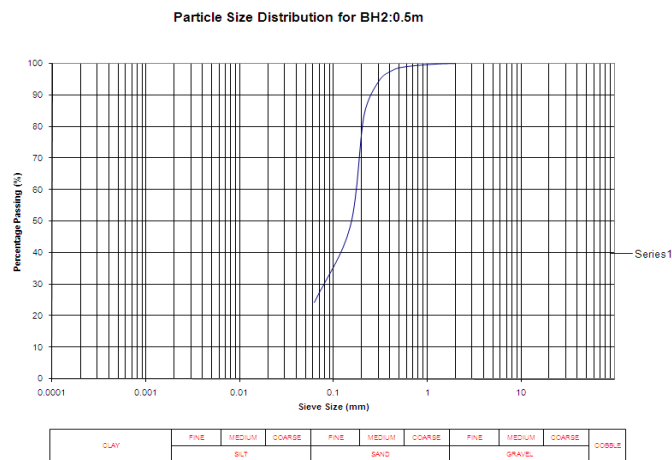


Fig. 17: Particle Size Distribution Chart for Point 5

Table 14: Subgrade Parameters for point 4

Soil Type (AASHTO)	CBR Value %	MDD Mg/m ³	OMC %	finer Fraction (%)	Sand Fraction (%)	M.C (%)	Unit weight (KN/m ³)	Group index
A-2-4	10.7	1.945	11.6	17.5	82.5	9	17.8	0

Table 16: Subgrade Parameters for Point 5

Soil Type (AASHTO)	CBR Value %	MDD Mg/m ³	OMC %	finer Fraction (%)	Sand Fraction (%)	M.C (%)	Unit weight (KN/m ³)	Group index
A-2-4	9.3	1.9	11.8	24.3	75.7	9.1	17.8	0

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Table 17: Swelling Potential

Swelling Potential based on Plasticity Index	Low-Medium	
Swelling Potential based on Soil Activity	Low -Medium	Appr. 5%

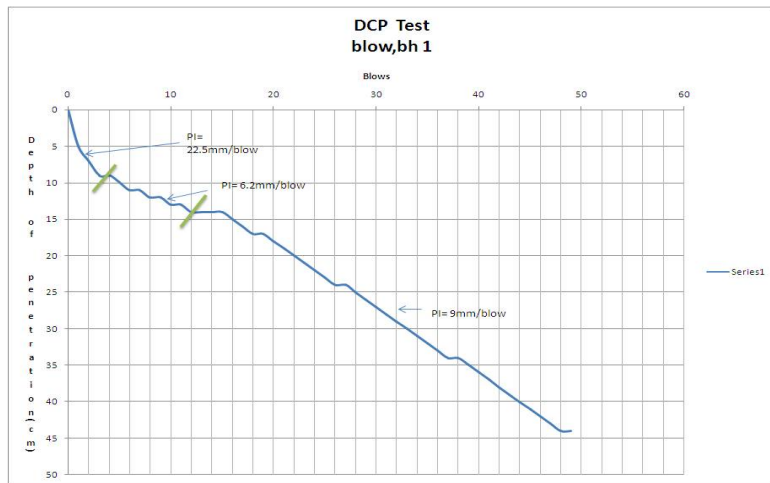


Fig 18: Dynamic Cone Penetrometer Profile for Point 4

Table 18: Dynamic Cone Penetrometer Test for Point 4

Test Point	Layer	Penetration Index(PI)mm/blow	Thickness(Approx)cm
1	1	22.5	9
	2	6.2	5
	3	9	30

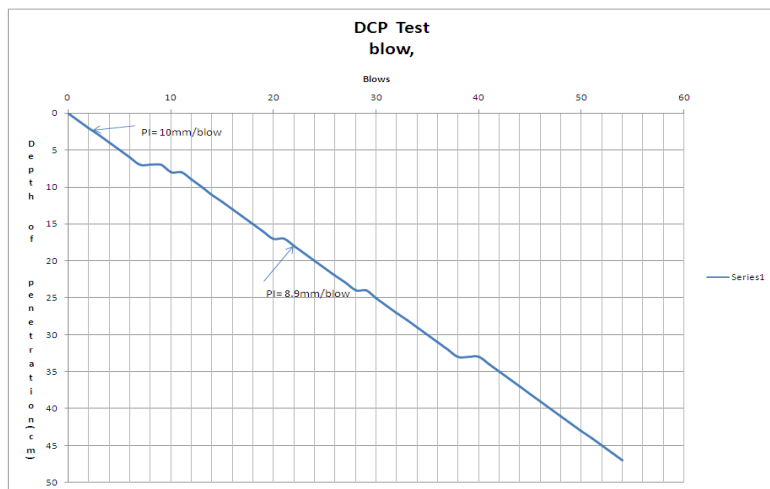


Fig 19: Dynamic Cone Penetrometer Profile for Point 5

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Table 19: Dynamic Cone Penetrometer Test for Point 5

Test Point	Layer	Penetration Index(PI)mm/blow	Thickness(Approx)cm
2	1	10	7
	2	8.9	40

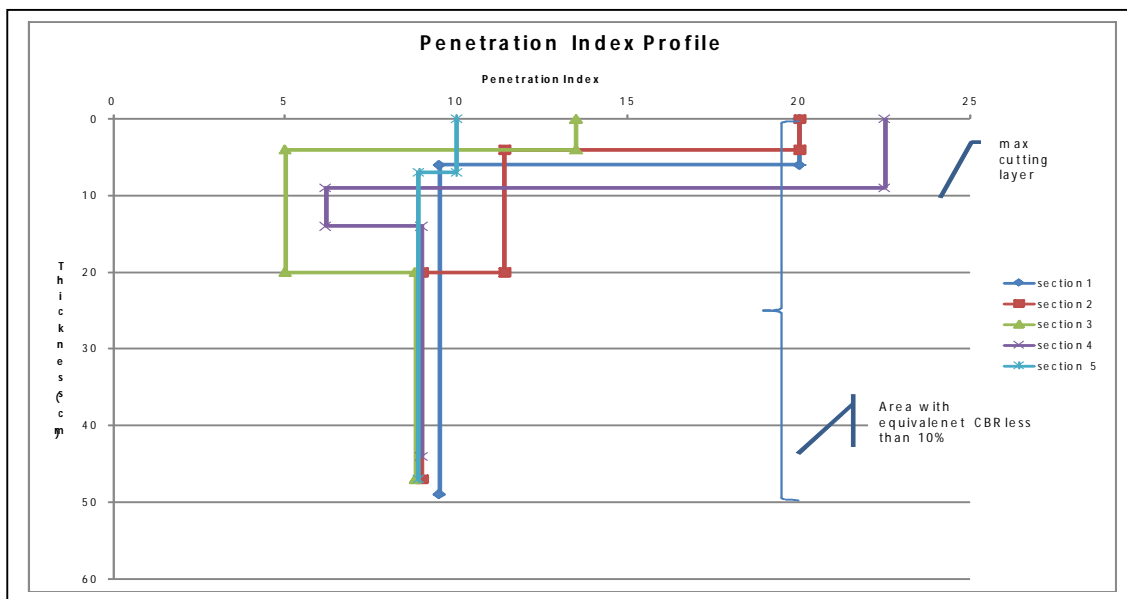


Fig. 20: Showing Penetration index of the different sections

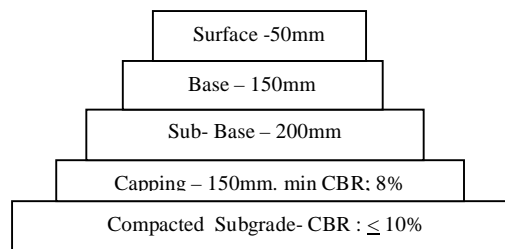


Fig. 21: Showing Layered Pavement System for Trunk Roads for flexible Pavements

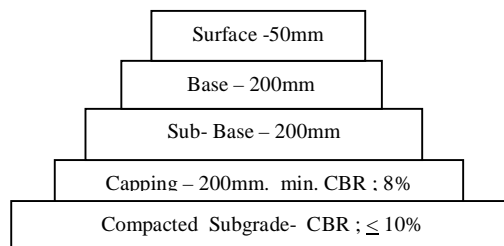


Fig. 22: Showing Layered Pavement System for Express Roads for flexible pavementP

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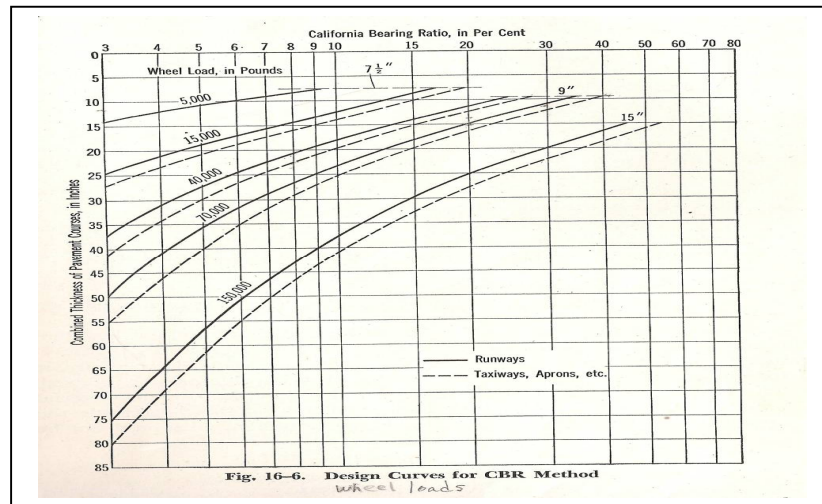


Fig. 23: Design Curves for CBR method

V. DISCUSSIONS

Subsurface exploration programs and laboratory investigations shows that the subgrade is generally characterized by clayey/ silt/ Sandy soil with varying degrees of densification.

For Point 1, fig. 1, the Compaction curves depicts a Steep to Flat curve, indicative of a sandy-clay soil. The sub-grade is classified as A-2-7(2), with a the fines/ Sand Ratio of 23.2/76.8. The Average soaked California Bearing Ratio shows values of about 9.2%. OMC, MDD and PI, 13%, 1.965mg/m³ and 29.2% respectively, this value also reflects the sandy-clayey nature of the soil. Penetration Index is less than 10mm/blow, soil volume increase is not anticipated due to the low Swelling Potential of the subgrade. Moisture content of 10% was recorded; this value which depicts a sandy nature also reflects lower values relative to the optimum value needed for attaining Maximum Dry Density of the Soil. Plasticity Chart reveals soils above the A-Line; this also implies Inorganic clays and silts with medium plasticity.

For Point 2 and 3, the Compaction curves depicts a Steep to Flat Curve, indicative of a sandy-clay soil. The subgrade is classified as A-2-6(2), with a the fines/ Sand Ratio of 31/69. The Average soaked California Bearing Ratio shows values of about 10.6%. OMC, MDD and PI, shows value >13.5%, >1.965mg/m³ and 16.2% respectively; reflecting the sandy-clayey nature of the soil. Penetration Index is less than 13mm/blow. Soil volume increase is not anticipated due to the low Swelling Potential of the subgrade and also a moisture content of 10.8% was also recorded. This value which reflects a sandy nature also reflects lower values relative to the optimum value needed for attaining Maximum Dry Density of the Soil.

For Point 4 and 5, with steep compaction curve reflects a sandy soil. The subgrade is classified as A-2-4(0) with the Fines/ Sand Ratio 18/82. The Average soaked California Bearing Ratio shows values of about 10.7%. OMC and MDD, 11.8% and 1.945mg/m³ respectively with no PI values; thus reflecting a sandy silty soil. Penetration Index is less than 10mm/blow. Swelling Potential of the subgrade is generally Low with a moisture content of 9%, depicting a sandy nature, and also reflecting lower values relative to the optimum value needed for attaining Maximum Dry Density of the Soil.

Generally the fine fraction is substantial, resulting in the low CBR values despite a low Group index of less than 2. Although fine fractions of less than 40% fines are observed, they still lack adequate amounts of the coarse fraction (56 to 93% passed through a 0.425mm sieve). With a low CBR value of about 9% and an average Penetration Index at the upper surface the soil will definitely needs development.

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Figure 20, shows profile of the penetration index of the different sections of the road alignment. The study reveals an average of three layers. The Penetration Index of about 20% within the upper layer (10cm or 100mm) was recorded within section 1, 2, and 4, an indication of low quality Subgrade with equivalent CBR of about 10% based on empirical calculation stated above. This implies that cutting should be done within this area to remove this weak zone prior to the placement of subsequent layers. In situations where cutting is not economical, capping should be strictly adhered to.

Thus, minimum capping/Subbase of 150mm with fines < 35% is essential to increase the structural capacity of the pavement system (*Roads Notes 31, 1971*). Also Soil Activity of the sample encountered is about 5%, depicting a low-medium soil swelling potential. This implies that soil will not experience swelling or shrinking during wet and dry weather.

Though water table was not encountered within the explored depth, an optimum pavement systems or sub-grade condition requires drains outlets and edge drain in the pavement system designs for collecting and removing any accumulated water from the drainage layers as this is a major concern in sub-grade and pavement system failure. (Cedergren, 1987)

Based on the functionality of the sub-grade as a platform that enables subsequent structural layers to be adequately compacted during construction and as a foundation unit that determines the integrity of the pavement system, proper Subgrade assessment should be accompanied by appropriate pavement system designs. The study within the area reveals minimum pavement systems design thickness based on trunk Road category with minimum wheel load of 15000Ib; Capping (minimum thickness 150mm), Moisture-insensitive free draining sub-base (minimum thickness 200mm) Moisture-insensitive free draining base (minimum thickness 150mm) surface (minimum thickness 50mm). For and Express Road category with minimum wheel load of 15000Ib; Capping (minimum thickness 150mm) Moisture-insensitive free draining sub-base (minimum thickness 200mm) Moisture-insensitive free draining base (minimum thickness 200mm) surface (minimum thickness 50mm)

VI. CONCLUSIONS

The study within the area reveals A-2-4 to A-2-7 subgrade soils with a CBR < 10%, MDD > 1.965, Moisture content less than OMC, Fines Fraction > 18%. These parameters will necessitate capping with compacted material of fines < 35% and at least a soaked CBR value > 8%; this should be accompanied by subsequent cumulative thickness of pavement layers not less than 400mm. with respect to their relative CBR values of each layer. This will provide increase functionality as a foundation platform for subsequent compaction and increased the overall depth to water table from the surface or bounds layers.

For distress and failure mitigation on pavements, Relative compaction > 95% should be ensured based on test methods for sub-grade soils. This will reduce the permeability, reduction of subsequent deformation and increase the Engineering Properties of the Soil. All components in the pavement system should be properly design especially the **thickness** due to the poor quality sub-grade observed within the study area, else its failure will lead to reduce serviceability or premature failure of the entire system. Adequate drainage systems, cross slopes for rapid runoff, regular surface maintenance to mitigate moisture infiltration and subgrade stabilization are ways to improve pavement performance in the study area.

REFERENCES

- [1] Arumala, J.O. and Akpokodje, E.G (1987). Soil Properties and Pavement Performance in the Niger Delta. Journal of Engineering Geology, London Vol. 20 pp. 287- 296.
- [2] Cedergren, H.R. (1987). Drainage of Highway and Airfield Pavements, Robert E. Krieger Publishing Co. Inc., Malabar, FL
- [3] Newcombe, D.A., and B. Birgisson (1999). "Measuring In-situ Mechanical Properties of Pavement Subgrade Soils," NCHRP Synthesis 278, Transportation Research Board, Washington, D.C.
- [4] Novikov E, Miskovsky K (2010). Capillary of Base Course Aggregates. J. Transport. Safety. 7(1): pp24-30.
- [5] Islam MT (2011). Evaluation of Existing Sylhet-Sherpur Highway by Dynamic Cone Penetrometer and Computer Based The AASHTO Software. J. Sci. Res., 3(2): 13-20.
- [6] Kiehl JT, Briegleb BP (2011). Pavement Surface Condition Field Rating Manual for Asphalt Pavement. ARPN. J. Sci. Technol., 2(1): 17-25.

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: www.ijirset.com

Vol. 7, Issue 8, August 2018

- [7] Ogundipe R, Olumide M (2012). Road Pavement Failure Caused by Poor Soil Property. Int. J. Eng. Technol., 2(1): 7-15.
- [8] Talukder MJ (2009). Evaluation of Existing Pavement of Sylhet-Sunamganj Road by Dynamic Cone Penetrometer. The institution of Engineers, Bangladesh. Penetrometer. J. Civil Eng., 35(1): 51-59.
- [9] M. Y. Ahmed, A. H. Nury, F. Islam¹ and M. J. B. Alam¹ (2012). Evaluation of geotechnical properties and structural strength enhancing road pavement failure along Sylhet-Sunamganj Highway, Bangladesh Journal of Soil Science and Environmental Management Vol. 3(5), pp. 110-117
- [10] Road Note 31, 1971 . A Guide to the structural design of bitumen-surfaced roads in tropical and sub – tropical countries , 3rd edn. Transport and Road Research Laboratory . Department of the Environment , Her Majesty's Service Organisation, London.
- [11] NHI-05-037