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Cement Stabilization Characteristics of Shale Subgrade of parts of the Lower Benue Trough, Southeastern Nigeria

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ABSTRACT

The effects of weathered shale subgrade and cement stabilization on road pavement durability [incessant failure] within the Lower Benue Trough were investigated. The soils classified as A-2-4, A-2-6, A-2-7, A-4 and A-7-6 on the AASHTO classification scheme with maximum dry density (MDD) and optimum moisture content (OMC) values of 1.76 - 2.03 gcm^{-3} and 12 - 19% respectively. The plasticity recorded values between 20 and 66% for the liquid limits, 6.7 – 24% for the plastic limits and between 7.6 and 43% for the plasticity index. The soaked CBR ranged between 3.5% - 38.0% which classifies the samples as non-weak soils. Although the results of the CBR may suggest that the materials meet the Nigerian national standard pavement design specification, the liquid limit and plasticity index values exceed recommended values, which most probably explain the widespread pavement failures observed within the area. The range of the soaked unconfined compressive strength (UCS) is 0.01 - 0.14Nmm^{-2} for various percentages of cement (3 – 12%). The soils showed some level of improvement when treated with 10 - 12% cement.

Keywords: *Pavement, failure, stabilization, cement, unconfined compressive strength, California Bearing Ratio, plasticity*

I. INTRODUCTION

Widespread pavement failure has been observed in parts of the Anambra Basin within the Lower Benue Trough, and these pavement failures are associated with the shale subgrade (Akpokodje, 1985 and Uduji et. al, 1994). Observation showed that efforts to rehabilitate these failed sections have not been very successful. Several reasons may be responsible and these include substandard construction materials, poor design specifications and supervision. The observed failure pattern suggests that one or two or even a combination of all the above may be responsible.

The sections of road within the area under study run through several shale formations (e.g. Imo, Awgu, Nkporo and Enugu) of varying ages and degree of weathering. The imminent poor quality of shales in view of road construction gave the impetus for this study, with a view to establishing the level of improvement that can be achieved on the quality of these shales upon stabilization using various percentages of cement.

Stabilization entails the improvement of the engineering properties of soils used for pavement base courses, sub-base courses, and subgrades by using additives to effect the desired improvement. The appropriate type of additive with different soil types can be determined by following procedures recommended by the Department of The Army, The Navy, and The Air Force (1994).

Portland cement, which was used in this study, was mixed and pulverised with soils, for increasing their strength, durability and also to minimise moisture variations. All other soils except the highly organic clays, show improvement on being stabilised with cement (Garg, 2009). Cement has been found to be effective in stabilizing a wide variety of soils, including granular materials, silts, and clays; by-products such as slag and fly ash; and waste materials such as pulverized bituminous pavements and crushed concrete. These materials are used in pavement base, sub base, and subgrade construction (http://onlinepubs.trb.org/onlinepubs/millennium/00016.pdf).

II. THE STUDY AREA

The study was carried out along sections of the Port Harcourt – Enugu expressway underlain by shales within the Anambra Basin of the Lower Benue Trough, South Eastern Nigeria. The study area is located within the geographical coordinates of between 5º40’ and 6 º 25’N and between 7 º 15’ and 8 º 23’E (Fig. 1).

III. GEOLOGY OF THE AREA

The geology of the area has been severally described (Reyment, 1965; Short and Stauble, 1967; Burke et.al, 1970; Kogbe, 1976; Agagu *et.al*, 1985; etc.), and is believed to be associated with the tectonic activities that were recorded during the Cenomanian. These tectonic activities produced an uplift that had a NE-SW trend. This gave way to the tectonic activities that took place in Santonian times (i.e. the second tectonic activity of the Lower Benue Trough), which resulted in the folding and uplifting of the Abakaliki Sector of the Trough and the subsidence of Anambra platform. The latter event led to the formation of the Anambra Basin (Table 1), which constituted a major depocenter of clastic sediments and deltaic sequences.

Table 1: Stratigraphic sequence of the Anambra Basin

UNITS	LITHOLOGY	AGE
Coastal Plain Sand (Benin Formation)	Medium – Coarse Sand with Silt and Clay streaks	Miocene to Recent
Ogwashi-Asaba Formation	Unconsolidated sands with prominent Lignite seams	Oligocene
Nanka Formation	Coarse – medium unconsolidated Sands	Eocene
Bende – Ameki Fm	Grey clayey sandstones and claystone	Eocene
Imo Shale	Laminated clayey shale with sandstone lenses	Eocene
Nsukka Formation	Sandstone intercalated with coal seam and clay	Maastrichtian
Ajali Sandstone	Poorly consolidated cross-bedded Sandstone, with minor clay intercalations	Maastrichtian
Mamu Fm	Shales with subordinate sandstones and coal seams	Maastrichtian
Enugu Shale	Fissile shales with mudstone interbeds	Campanian
Awgu Shale	Fissile shale with minor intercalations of limestone and calcareous Sandstone	Coniacian

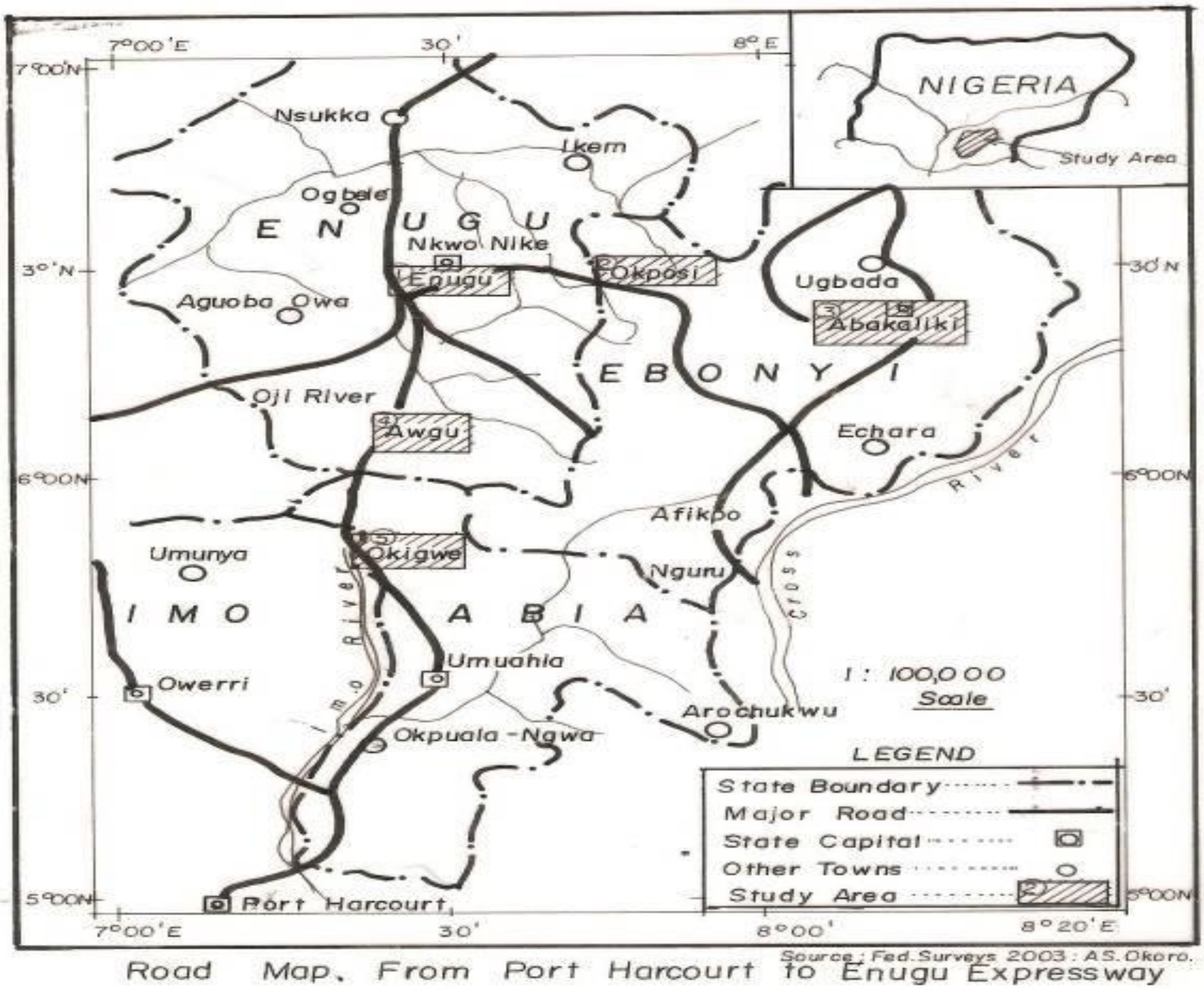

Fig. 1: Location Map

In this part of the Benue Trough, the stratigraphic succession begins with the Albian Abakaliki Formation. The Abakaliki Formation is said to be about 3000m thick and lies unconformably on an older basement complex (Likkason *et.al*. 2005). The marine Abakaliki is overlain with a transitional contact by the Keana and Awe Formations. The Keana and Awe Formations were deposited as (near) coastal sediments during the Early Cenomanian regression. The Ezeaku Formation lies conformably on the Keana and Awe Formations. This formation was deposited in marine environments during the beginning of marine transgression in the Late Cenomanian (Obaje *et.al.*, 1999*)*.

The age of the sediments in the Basin ranges from Pre-Cretaceous to Recent. Awgu shales which were deposited during the Coniacian times are the oldest formation in the Anambra basin section of the study area. It overlies the Eze-Aku Group and its lateral equivalent, the Agbani Sandstone. The deposition of the Awgu Formation marks the end of fully marine sedimentation in this part of the Benue Trough. The Awgu Formation is made up of bluish-grey to dark-black carbonaceous shales, calcareous shales, shaley limestones, siltstones and coal seams. This suggests rapid changes in the depositional environments (Obaje *et.al.* 1994, in Obaje *et.al.*, 1999). This erosion of the Abakaliki uplifted and folded belts resulted in the development of a Proto-Niger Delta sequence consisting of Enugu shale, Mamu, Ajali and Nsukka Formations. The third and last depositional cycle of the Lower Benue Trough started with a major transgression that deposited the marine Imo shales in the Anambra basin, during the Palaeocene Period. This was followed by a regression that started during the Eocene and continued to the present day with the deposition of the sediments of the Tertiary Niger Delta. The sediments deposited during this period included the Bende – Ameki, Nanka, Ogwashi – Asaba and the Coastal Plain Sands (Benin) Formations in that sequence.

IV. METHOD OF STUDY

Samples were collected from the natural soils at the failed sections of the road and were taken to the laboratory for the various kinds of analysis, which include plasticity, grain size distribution, California Bearing Ratio and unconfined compressive strength determination.

Plasticity

The plasticity of the samples was determined adopting the American Society for Testing and Materials (ASTM, 1975) method “for determination of properties of soils and rocks”.

California Bearing Ratio (CBR)

The California Bearing Ratio (CBR) which was developed by the California State Highways Department evaluates the strength of road subgrades. The basic CBR test, which was carried out on compacted samples in the laboratory, both in soaked as well as unsoaked states, consists of causing a plunger of standard area to penetrate a sample. The load required to cause the penetration is plotted against measured penetration, the readings noted at regular intervals of time. The information is plotted on a standard graph where the plot of the test data showed the CBR result. The analysis was carried out according to BS 1377: Soils for civil engineering purposes: Part 4, Compaction related tests.

Stabilization Test

The stabilization test establishes criteria for improving the engineering properties of soils used for pavement base courses, sub-base courses, and subgrades by the use of additives which are mixed into the soil to effect the desired improvement. It establishes the appropriate type of additive to be used with different soil types, procedures for determining a design treatment level for each type of additive, and recommended construction practices for incorporating the additive into the soil (Department of The Army, The Navy, The Airforce, 1994).

Particle Size Distribution (PSD)

The stabilization criteria adopted were consequent upon the classification of the samples using the American Association of State Highway and Transportation Officials (AASHTO) 2010 Classification system.

V. RESULTS AND DISCUSSION

Particle Size Distribution and Plasticity

The particle size distribution result classified the samples as A-2-4, A-2-6,

A-2-7, A-4 and A-7-6 on the American Association of State Highway and Transportation Officials (AASHTO) classification scheme. The plasticity values obtained are liquid limits 20 - 66%, plastic limits 6.7 – 24% and plasticity index 7.6 and 43%. It is important to note that earth materials that possess low cation exchange capacities (CEC) will have low water holding capacity and by implication low plasticity. Sandy soils fall within this description while the reversed state will have clays as instances. The studied samples were partly weathered shale which was not completely broken down into individual grains and as a result, yielded apparently low quantity of fines.

Half of the samples have liquid limit results above the FGN specification (Table 2). It is important to note that other parameters such as the bearing capacity, traffic volume and compressibility should be considered in assessment of the overall strength properties of road pavement materials. It is noted that while the liquid limit and plasticity index of the samples suggest probable failure, other factors may cause actual failure. These factors include inadequate water - proof running surface/bituminous running surface, as the soils which were derived from shales tend to loose strength significantly with increase in moisture content. This explains the extensive failures mostly during the rainy season in sections where the running surface is damaged.

Compaction, California Bearing Ratio (CBR)

CBR and unconfined compressive strength indicate the most effective measures of effectiveness of cement stabilization (Ingles and Metcalf, 1972). The CBR quantitatively evaluates the inherent strength of a subgrade in order for a road pavement to be designed for a particular strength of subgrade. It is a point load test that can be carried out on almost all kinds of soils, ranging from clay to gravel (Garg, 2009). The results are presented in Table 2 and Figure 2.

The overall averaged soaked CBR results ranged between 5.5 and 15.4 which according to Omotosho (2006) classifies the samples as non-weak soils. The range of the overall unsoaked CBR is 5.5 - 10.9%. Though the results of the CBR partly meet the specifications of the Federal Government standard for pavement design (Table 2), the liquid limit and plasticity indices of over 50% of the samples far exceed those specified by the Federal Government. This explains the widespread failure observed within the area.

Unconfined Compressive Strength

Ground improvement by treating soft soil with various types of binders is an attractive alternative and is often economical compared to other ground improvement methods (Hassan, 2009). The results of cement stabilization on the unconfined compressive strength of the various soils are presented in Table 2 and Figure 3).

The soaked unconfined compressive strength (UCS) recorded very low values of between 0.01 and 0.14Nmm^{-2} while the unsoaked UCS values were between 0.01 and 0.19Nmm^{-2} for various cement levels. The strength increased linearly with cement content (Figure 3 and 4) in line with Ingles and Metcalf (1972)

The cement stabilization results show that detectable improvements were achieved in samples A-2-6, A-2-7 and A-7-6 with cement proportions above 6% whilst not significant improvements were recorded in the A-4 and A-2-4 soil types. This recorded improvement is occasioned by the reduction in the permeability of the samples. Further improvement can be achieved with increased levels of cement binders. This however has the inherent problem of hydration which ultimately will initiate cracks and the attendant failure of the soil.

VI. CONCLUSION

From the foregoing, it could be observed that stabilization using 8-12% cement achieved some level of improvement but not high enough to guarantee an all-season stability and durability.

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Table 2: Summary of Results

SAMPLE IDENTITY		(A)				(B)				(C)				(D)				(E)				FGN 1997
AASHTO GROUP		A – 7 – 6				A – 2 – 7				A – 2 – 6				A – 4				A – 2 – 4				
LIQUID LIMIT (%)		65.5				43				20				29				32.5				30
PLASTIC LIMIT (%)		23.1				20.5				6.7				21.4				22.7				-
PLASTICITY INDEX (%)		42.4				22.5				13.3				7.6				9.8				13
NMC (%)		25.8				12.2				7.7				9.9				13.4				-
% FINER 75mm		43.8				21.5				22.3				43.1				28.3				-
MDD (G/CM3)		1.76				1.95				2.03				2.0				1.88				-
OMC (%)		19				15				12				15				17				-
CEMENT CONTENT %		0	8	10	12	0	3	4.5	6	0	3	4.5	6	0	5	7	9	0	3	4.5	6	-
CBR (%) Soaked	Min		28	30	31		6	12.8	31		6.8	11	18	nd	4.5	6	8.1	nd	3.5	4.5	6	5-11
	Max		30	33	37		7.3	14	38		8	14	25	nd	5.1	7.3	9.6	nd	3.8	5.1	8.4	
	Mean	10.7	29.2	31.3	34	7.1	6.8	13.3	35	5.5	7.3	12.4	21.6	nd	4.8	6.7	8.7	nd	3.6	4.8	7.2	
UCS N/MM2 Soaked	Min		0.1	0.12	0.14		0.01	0.07	0.12		0.04	0.07	0.1		0.02	0.04	0.05		0.02	0.03	0.04	-
	Max		0.12	0.13	0.14		0.03	0.08	0.13		0.05	0.07	0.1		0.02	0.04	0.05		0.02	0.04	0.05	-
	Mean		0.11	0.12	0.14		0.02	0.07	0.13		0.05	0.07	0.1		0.02	0.04	0.05		0.02	0.03	0.04	-
UCS N/MM2 Unsoaked	Min		0.12	0.16	0.19		0.01	0.09	0.15		0.02	0.08	0.11		0.02	0.04	0.05		0.01	0.03	0.04	-
	Max		0.14	0.17	0.19		0.04	0.1	0.15		0.04	0.08	0.11		0.02	0.04	0.06		0.02	0.03	0.05	-
	Mean		0.13	0.17	0.19		0.03	0.09	0.15		0.03	0.08	0.11		0.02	0.04	0.06		0.02	0.03	0.04	-

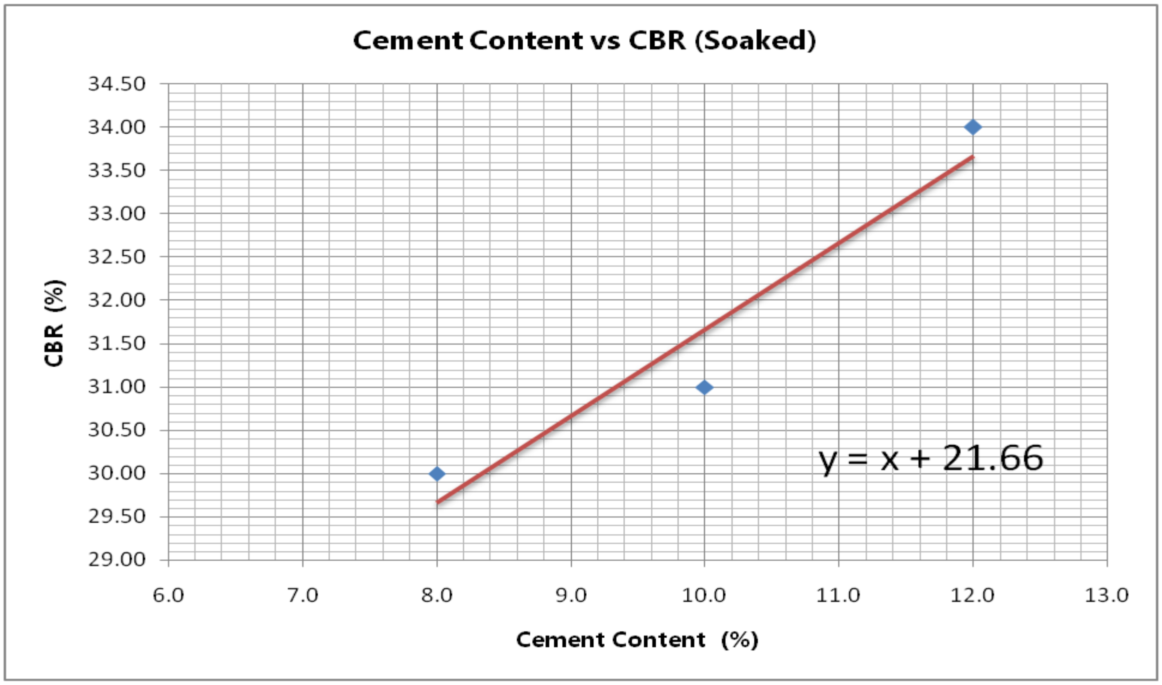

Figure 2: Typical plot showing relation between CBR and cement content

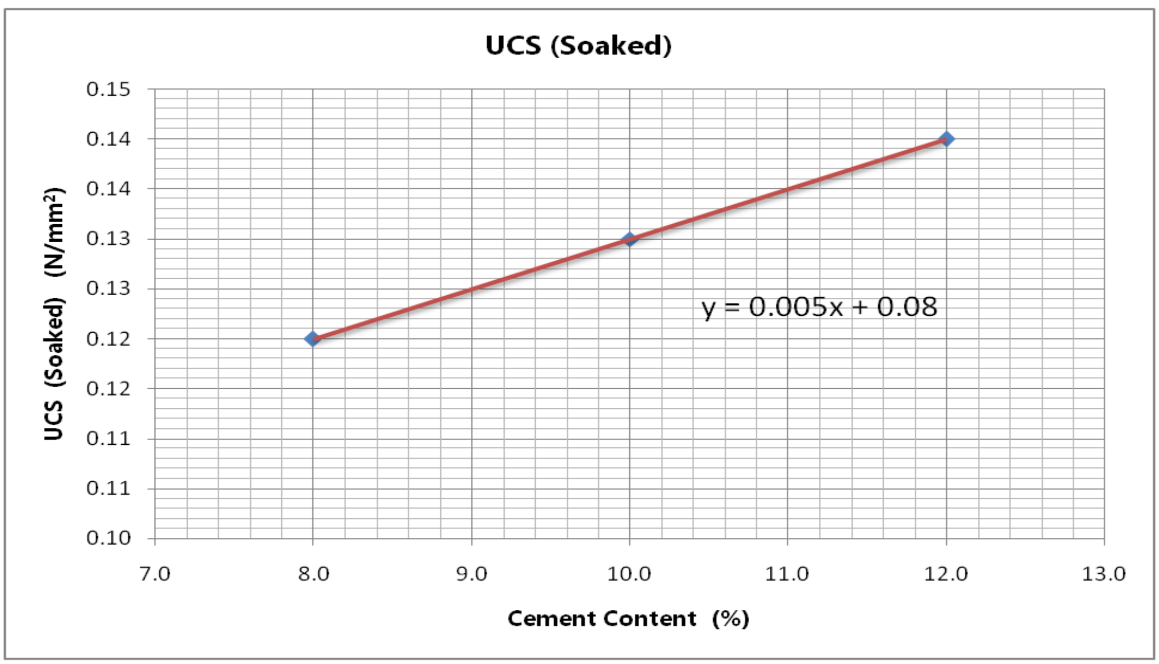

Figure 3: Plot of relation between cement content and compressive strength