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Strength Comparative Analysis of Mechanical and Cement Stabilized Laterite Soil Used as Sub-Base in Pavement Construction

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Abstract

The use of cement, asphalt, additives, and other conventional materials to stabilize the sub base and sub grade of pavement is far from being cost-effective due to the economic crisis, which has severely affected road construction in Nigeria and other developing countries. Hence this research: Strength Comparative Analysis of Mechanical and Cement Stabilized Laterite Soil used as Sub-Base in Pavement Construction. Soil samples were obtained from University of Benin burrow pit. Index properties and strength tests were carried out on the soil samples, while the strength tests were carried out on the stabilized soils for the purpose of strength comparison and evaluation of the suitability as sub base material. For the soil samples alone, the average results obtained for the specific gravity was 2.46; the liquid limit was 33.00%; plastic limit was 19.21% and plasticity index was 13.79% which indicates that the soil is of medium plasticity. From the sieve analysis, the soil was classified as an A-2-6 soil according to AASTHO (American Association of State Highway and Transportation) system of classification. The Optimum Moisture Content (OMC) and the Maximum Dry Density (MDD) were 12.2% and 1.76g/cm^3 respectively. The maximum value for soaked CBR was obtained as 15.69%. When the natural soil was stabilized with cement at different percentages from 2 – 10 %, the OMC ranged from 12.6% to 14.6%, the MDD ranged from 1.72g/cm^3 to 1.76g/cm^3 and from the CBR tests, the value for the soaked CBR ranged from 24.21% to 73.74%. When the soil was stabilized with quarry dust at percentages ranging from 15% - 75%, the OMC ranged from 9.6% to 12.8%, the MDD ranged from 1.73g/cm^3 to 1.81g/cm^3 and from the CBR tests, the value for the soaked CBR ranged from 3.32% to 3.71%. The optimum mix proportion was obtained as 75%. When the soil was stabilized with sharp sand at percentages from 20% - 100%, the OMC ranged from 11.00% to 12.8%, the MDD ranged from 1.73g/cm^3 to 1.78g/cm^3 and the CBR tests, the value for the soaked CBR ranged from 5.70% to 9.21%. The optimum mix proportion was obtained as 80%. Soil stabilization techniques with cement at percentages 6%,8% and 10% gave CBR values that met the requirements of a good subbase course of a pavement or road in accordance with the Federal Ministry of Works and Housing specification. Quarry dust and Sharp sand, did not meet the requirements, hence not suitable for a subbase course. They can be used to construct local roads to be more stable and they can also be suitable with the addition of cement or other effective binders.

1.0 Introduction

The performance of completed roads is not only dependent on the pavement structural design, the sub-base and sub-grade support conditions also play an important role in it. As the foundation of pavement's upper layers; the sub-base and sub-grade layers help to alleviate the severe effects of climate and static dynamic stress generated. Therefore, building a stable subgrade and sub-base is essential for constructing an effective and durable pavement system [1]. Stabilization by mechanical means involving the mixing or blending granular sub-base materials with wet subgrade soils and compaction can provide a stable working platform and foundation layer under pavements [2]. The mechanically stabilized layer can exhibit lower plasticity, lower frost heave potential and higher drainage characteristics. One typical example or kind of mechanical stabilization is gradation. Performance of gradation incorporating on site granular sub-base material with wet sub-grade soil is assessed by measuring the various in-situ engineering properties overtime [3]. Another form of stabilization is the chemical stabilization. Selection of stabilizers for a certain type of soil solely depends on the kind of soil, type of construction and availability of materials to be used in construction. Cement stabilized subgrade and sub-base pavement have an advantage of excellent strength and durability. Also, it is widely available hence is one of the best materials for stabilization of various soils. The hydrated product of cement binds with soil to give rise to the cement stabilized base or cement treated aggregate base. The strength of the stabilized soil will mainly depend on the amount of cement used in the soil. With the increase in cement quantity, the strength of cement stabilized soil increases [4].

Gradation, a form of mechanical stabilization is accomplished by mixing or blending soils of two or more grades of soils to obtain a material meeting the required specification [5]. In Nigeria and other tropical regions of the world, prevalent soil material available for the construction of sub-base course of pavements is the lateritic soil. This soil is used because of its abundance and cost effectiveness. [6], reported that there are some lateritic soils which do not require treatment to give them sufficient load bearing capacity, but most laterite soils require some sort of stabilization for use in road construction [7]. Retrogression of roads in Nigeria may be as a result of failed pavements, due to sub bases and subgrades not properly stabilized using the right materials. Failure of pavements can translate into the formation of pot holes and transport inefficiency. Therefore, averting these implications, the sub base and subgrade which is a major part of the road pavement must be well stabilized with the use of the best method which should be cost effective, hence the need for this paper. Many literatures have been reviewed on the effectiveness and to what percentage content of cement as a stabilizer to improve different problematic soils in different part of the world [8-11]. [12- 21] studied the utilization of quarry dust to improve the geotechnical properties of soils and the results showed that the geotechnical properties improved substantially by the addition of quarry.

2.0 Materials and Method

2.1 Materials

The materials are: laterite soil (plate 1), ordinary Portland cement (plate 2), quarry dust (plate 3) and sharp sand (plate 4).

Plate 1: Laterite Soil

Plate 2: Ordinary Portland Cement

Plate 3: Quarry Dust

Plate 4: Sharp sand

2.2 Laboratory Tests

According to the [22], the following tests were carried out on the laterite soil:
Bulk Density Test, Moisture Content Test, Specific Gravity Test, Sieve Analysis, Consistency limit Tests, Compaction Test (Proctor test) and California Bearing Ratio Test.
The soil samples were thereafter stabilized with Ordinary Portland Cement at different percentages of 2% - 10%. They were also stabilized with quarry dust at percentages ranging from 15% - 75% and finally stabilized with sharp sand at percentages ranging from 20% - 100%. These stabilized soils were passed through Compaction Test (Proctor test) and California Bearing Ratio Tests for the purposes of strength comparison.

3.0 Results and Discussion

3.1 Results of Laboratory Tests on the laterite soil only (Control Sample)

The summary of the results of the laboratory tests carried out on the control sample are as shown in Table 1.

Table 1: Summary of the laboratory test on the control sample

S/No.	Laboratory Test(s)		Result(s)
1.	**Bulk Density (g/cm^3)**		1.67
2.	**Natural Moisture Content (%)**		16.83
3.	**Specific Gravity**		2.46
4.	**Atterberg Limit**	**Liquid Limit (%)**	33.00
		Plastic Limit (%)	19.21
		Plasticity Index (%)	13.79
5.	**Sieve analysis**	**Sieve size (mm)**	**Percentage passing (%)**
		3.35	
		2.36	100
		2.00	100
		1.18	98.6
		0.60	85.1
		0.425	76.9
		0.3	58.0
		0.212	44.7
		0.15	40.6
		0.075	34.3
6.	**Compaction**	**OMC (%)**	12.2
		MDD (%)	1.76
7.	**CBR (Soaked)**	**Top (%)**	6.60
		Bottom (%)	15.69

The bulk density of the control sample (natural soil), was determined to be 1.67 g/cm^3. The moisture content of the control sample was obtained as 16.38%. [23] proposed that soils with natural moisture content (NMC) of 5%-15% are suitable or favorable engineering materials, NMC of 16%-19% are marginal favorable materials and soils with NMC values ranging from of 20%-35% are unfavorable engineering materials.
The results of the specific gravity (G_s), was determined as 2.46. Specific gravity test is an important index property of soils that is closely linked with mineralogy or chemical composition [9]. It is relatively important as far as the qualitative behavior of the soil is concerned. [24-25] observed that increase in specific gravity also increases the California Bearing Ratio strength of the subgrade materials used in road pavement design.
According to the sieve analysis, 34.3% of the sample passed the 0.075mm sieve, 76.9% passed the 0.425mm sieve, and 100.00% passed the 2.00mm sieve. The liquid limit is 33.00% and the plastic limit is 19.21% according to the Atterberg limit test, while the plasticity index is 13.79%. This indicates that the soil is of the clayey type and has medium plasticity. Given that less than 35% of the soil passed through a 0.075-mm screen, it is a granular soil. The soil is categorized as an A-2-6 soil when all other factors are taken into account. Soils of the A-2–6 class meet the requirements of [26] AASTHO System of Classification and are suitable for use as subgrade materials. The control sample is only appropriate for use as subgrade material but not for sub-base, as evidenced by the Soaked CBR of 15.69%. It must be strengthened or stabilized with additional materials if it is to be used as a subbase or base course.

3.2 Sample of Natural Soil and Ordinary Portland Cement

The results of the laboratory tests carried out on the soil stabilized with varying percentages of Portland Limestone Cement are presented in Table 2.

Table 2: Results of the geotechnical tests summarized (Sample of Natural Soil and Cement)

S/No.	Percentages (%)	Laboratory Test(s)		Result(s)
1.	**2**	**Compaction**	**OMC (%)**	13.80
			MDD (g/cm^3)	1.73
		SOAKED CBR (%)	24.21	
2.	**4**	**Compaction**	**OMC (%)**	13.40
			MDD (g/cm3)	1.76
		CBR (%)	26.75	
3.	**6**	**Compaction**	**OMC (%)**	12.60
			MDD (g/cm3)	1.75
		CBR (%)	35.48	
4.	**8**	**Compaction**	**OMC (%)**	12.70
			MDD (g/cm3)	1.73
		CBR (%)	39.37	
5.	**10**	**Compaction**	**OMC (%)**	14.6
			MDD (g/cm3)	1.72
		CBR (%)	73.74	

From Table 2, The OMC continued to reduce from 2% to 6% of cement added to the control sample with an increase at 10% of cement added. Considering the MDD, there was a continuous reduction from 6% to 10% of cement added. No sample stabilized with cement had a higher MDD than the control sample of 1.76g/cm^3; MDD at 4% cement was obtained as 1.76g/cm^3 which equaled that of the control. There was a linear relationship observed between increase in CBR and increase in the quantity of stabilizer (cement) added. According to the general requirements for subgrade, sub-base and base course in [27] Nigeria, provided in the Federal Republic of Nigeria highway manual (1997), CBR value for a standard sub base must be greater than 30, therefore CBR values at 6% to 10% cement can be used to achieve this.

3.3 Sample of Natural Soil and Quarry Dust

The results of the laboratory tests carried out on the soil stabilized with varying percentages of Quarry Dust are presented in Table 3

Table 3: Results of the geotechnical tests summarized (Sample of Natural Soil and Quarry Dust)

S/No.	Percentages (%)	Laboratory Test(s)		Result(s)
1.	15	Compaction	OMC (%)	12.00
			MDD (g/cm^3)	1.73
		CBR (%)	3.43	
2.	30	Compaction	OMC (%)	12.80
			MDD (g/cm3)	1.75
		CBR (%)	3.34	
3.	45	Compaction	OMC (%)	11.00
			MDD (g/cm3)	1.76
		CBR (%)	3.32	
4.	60	Compaction	OMC (%)	10.8
			MDD (g/cm3)	1.80
		CBR (%)	3.43	
5.	75	Compaction	OMC (%)	9.60
			MDD (g/cm3)	1.81
		CBR (%)	3.71	

From Table 3, the OMC reduced from 30% to 75% quarry dust and control sample. There was a linear relationship observed between increase in MDD and increase in the quantity of stabilizer (quarry dust); with highest MDD in the sample with 75% quarry dust. Maximum OMC was obtained in the sample with 30% quarry dust with a value of 12.80%.

No linear relationship was observed between CBR and increase in the quantity of stabilizer added. In carrying out soaked CBR, sample is to be left in water (soaked) for 96 hours. Due to logistics in the laboratory, the required time for soaking was exceeded. This represented an extreme case e.g. Cases in Anambra, Bayelsa, Kogi etc. where roads were completely submerged in water, hence the nonlinear relationship.

3.4 Sample of Natural Soil and Sharp Sand

The results of the laboratory tests carried out on the soil stabilized with varying percentages of Sharp Sand are presented in Table 4.

Table 4: Results of the geotechnical tests summarized (Sample of Natural Soil and Sharp Sand)

S/No.	Percentages (%)	Laboratory Test(s)		Result(s)
1.	20	Compaction	OMC (%)	12.80
			MDD (g/cm^3)	1.76
		CBR (%)	5.87	
2.	40	Compaction	OMC (%)	12.00
			MDD (g/cm3)	1.78
		CBR (%)	7.01	
3.	60	Compaction	OMC (%)	11.40
			MDD (g/cm3)	1.78
		CBR (%)	7.59	
4.	80	Compaction	OMC (%)	11.60
			MDD (g/cm3)	1.73
		CBR (%)	9.21	
5.	100	Compaction	OMC (%)	11.00
			MDD (g/cm3)	1.78
		CBR (%)	5.70	

From Table 4, there was an increase in CBR value with an increase in the quantity of stabilizer added from 20% to 80% percent and a decrease at 100%, due to mass of stabilizer equaling mass of soil sample. Maximum CBR value was obtained in the sample with 80% of sharp sand.

4.0 Conclusion

The following conclusions have been drawn, from the critical examinations and analyses:
The use of appropriate mix ratio of cement to reinforce natural lateritic soil, should be used to meet standards or requirements of a good sub base course as provided by Federal Ministry of Works and Housings. CBR values obtained from natural lateritic soil reinforced with quarry dust cannot be compared with that of cement and hence, not a suitable material for stabilizing or constructing a sub base of a pavement. Quarry dust can be used on local roads to make it more stable than it is supposed to be originally. Even with an improvement in the CBR value of natural lateritic soil reinforced with sharp sand, it is not a suitable material for stabilizing sub bases. It can be applied to local roads, to make them stable. Cement or any other strong binder can be added to make it suitable for its use in the subbase and base course of roads and pavements.

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