Chemical Stabilization of Laterite Soils for Road construction

CASE STUDY: THE LATERITE SOILS AT LEGON

Dr. Francis Achampong[1*], Reginald Adjetey Anum[2], Prof. Fred Boadu[3], Nene Boso Djangmah[4], Dr. L.P. Chegbele[5]

1*. Corresponding author, Civil/ Geological/ Geotechnical/Environmental Engineer,Achampongf@yahoo.com

2. Assistant Researcher, Earth Science Department, University of Ghana.
3. Associate professor, Duke University, United State of America.
4. Teaching assistant, Earth Science Department, University of Ghana.
5. Lecturer, Earth Science Department, University Ghana.

ABSTRACT

Most roads in Accra (Ghana) don't stand the test of time and don't live out their designed life span due to inferior soils used as sub-base in their construction. Presently, engineers and contractors deal with such soils by removing them and replacing them with superior materials such as imported gravels to help improve the strength of the soils. The importation of these desirable materials for construction is very costly. More efficient method which uses less energy and is less expensive in dealing with poor soils for road construction is chemical stabilization. The objective of this project therefore is to chemically stabilize poor sub-base soil to be used for road construction using lime and cement as additives.

The soil sample was laterite collected from an exposed trench during a construction project near the University of Ghana. This sample was subjected to various tests including grading, Atterberg limits, swelling as well as compaction and California Bearing Ratio (CBR) tests. Results from the tests showed that: the soil was well graded, with all the soil fractions being retained on each of the sieves used, the soil contained a minimal amount of clay evidenced by the increased of 1ml in the swelling test, and the compaction test for the raw sample yielding Maximum Dry Density (MDD) of 1869kg/m^3 and Optimum Moisture Content (OMC) of 13.9%.For the lime stabilized sample, PI was 11, 7 and 0; LL was 34, 30 and 0 and CBR of 28%, 31% and 126% all for 2%, 4% and 6% lime addition to the raw sample respectively. For the cement stabilized sample, PI was 15, 14 and 11; LL was 37. 34 and 31and CBR was 14%, 74% and 236% all for 2%, 4% and 6% cement addition to the raw sample respectively. Hence it was concluded that only 6% lime addition was the most suitable for stabilizing the soil when the results were compared to the specifications of the Ghana Highway Authority (GHA). It is recommended that the economic implications of the use of lime for chemical stabilization in Accra, Ghana should b encouraged.

KEYWORDS: **Sub-grade; Stabilization; Lime; Cement; Laterites; Grading; Atterberg limits; Swelling; Compaction; California Bearing Ratio (CBR);Ghana Highway Authority (GHA).**

1. INTRODUCTION

1.1 Statement of the problem.

Inspection of road surfaces in Ghana shows that nearly all the roadways are in poor condition due to weak sub-base (fig 1.1) soils. Weak sub-base soils promote rutting or longitudinal grooves in a road surface leading to premature failures. Driving on poor road surface is a public safety hazard and also costs vehicle owners millions of cedis annually in extra vehicle repairs (Achampong, 2013). Many soil encountered in many areas of Accra do not meet engineering required for use in construction. Soil with desirable engineering properties must be transported using large haulage vehicle. The transportation of large quantities of building material to replace unsuitable in-situ soils has negative impact on the environment by the introduction of CO gas from vehicle exhaust and dust which causes respiratory disorders. Also, the cost of importing these desirable materials is expensive. The Ghana Highways Authority is looking for alternative methods for the design and construction of roads. The goal of this research work is to use the most appropriate stabilization methods to economically stabilize soils of marginal quality for use on roads, highways, and other similar applications.

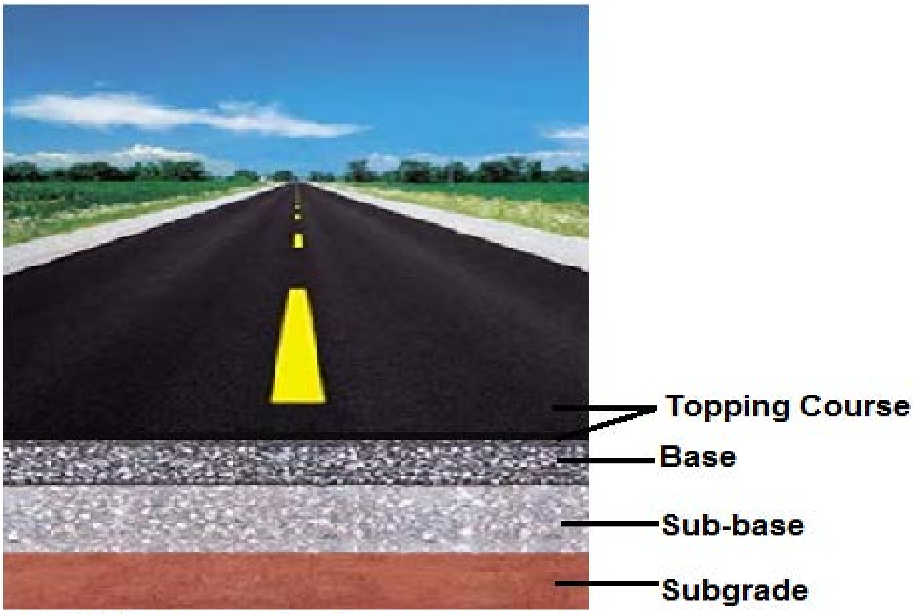


Fig. 1.1 Cross-section of an engineered road pavement.

ISSN 2229-5518

1.2 Background of the study

The long-term performance of any construction project depends on the engineering competence of the underlying soils. In the construction and maintenance of transportation facilities, geomaterials (soils and rocks) must be stabilized through chemical and mechanical processes. The main purpose of stabilization is to improve the soil strength, bearing capacity, durability under adverse moisture and withstand both static and dynamic stress. Stabilization of the geomaterials can aid in dust control on roads and highways, particularly unpaved roads, in water erosion control, and in fixation and leaching control of waste and recycled materials.

1.2.1 *Chemical stabilization*

Chemical stabilization includes the use of admixtures (chemicals and emulsions) as cementing agents, modifiers, water proofing, water retaining and miscellaneous chemicals to improve the engineering properties of undesirable soils. The behavior of each of these admixtures differs vastly from the others; each has its particular use and conversely each has its own limitations (Gidigasu, 1976). The main admixtures to be considered in this work are cement and lime. Cement and lime stabilization modifies the physiochemical properties of cohesive soils as well as improve the static and dynamic strength.

Cement stabilization mechanism is mainly controlled by hydrolysis and hydration. Factors which affect physical properties of soil-cement include:

- Soil type(particle size distribution, grain shape, mineralogy)
- Proportion of soil , cementitious material and water content
- Quantity of cement
- Degree of mixing
- Time of curing and
- Density of the of the compacted mixture
  (Road Research laboratory, 1952; yonder, 1957).

Cement stabilization usually result in decreased density, increased compressive strength, decreased plasticity, decreased volume change characteristics of expansive clays when compared to the natural soil (PCA, 1992).

Lime is generally restricted to the warm to moderate climates, since lime-stabilized soils are susceptible to breaking under freezing and thawing. Lime stabilization will generally bring about a decrease in the density a change in the plasticity of the soil and an increase in the soil strength. The action of lime in soil stabilization may be reduced to three basic reactions (Gillot, 1968):

- Alteration of water film through cation exchange.
- Flocculation-agglomeration
- Lime reaction with clay crystal edges producing accumulation of cementitious materials which aid in the formation of new chemicals.

1.2.2 *Laterite*

Laterite is a group of highly weathered soils formed by the concentration of hydrated oxides of iron and aluminum (Thagesen, 1996). Other definitions have been the ratio of silica (SiO_2) and sesquioxides (Fe_2O_3 + Al_2O_3). In laterites the ratios are less than 1.33.

Those between 1.33 and 2.0 are indicative of laterite soils, and those greater than 2.0 are indicative of non-lateritic soils (Bell, 1993). Experience has shown that lime works well with medium, moderately fine, and fine-grained clay soils. Attempts have been made to stabilize laterite soils for engineering purposes (eg. Winterkon and Chandrasekaran, 1951; Remillon, 1955). Most laterite gravels and gravelly soils are easy to win and distribute during construction, and give high laboratory and field compaction densities (Evans, 1958; Daniel and Newill, 1959), however, their performance has been found to be poor under adverse traffic and moisture conditions (Nanda and Krisnamachari, 1958; Arulanandan and Tunbridge, 1969). There have been studies into the effect of chemical composition on the stabilization of laterite soils (eg., Winterkon and Chandrasekaran, 1951). The engineering properties of stabilized laterite soils depend on:

- Genetic characteristics
- Compositional factors, such as particle-sixe distribution, organic matter content, chemical and mineralogical composition, and physico-chemical characteristics etc. and
- Method of sample preparation prior to stabilization and the stabilization procedures

This research work sought to investigate the influence of lime and cement stabilization on the engineering properties of Laterite soils in Accra. Specific objectives covered are outlined below.

1.3 Objectives of the studies

The objectives of the studies are as follows:

- To establish the effectiveness of lime and cement stabilization on the sample collected.
- To compare the strength of the stabilized soils to the raw sample collected.

In order to effectively achieve the above objectives a rational work program was conducted. First, a comprehensive desk study was conducted in order to gather available relevant information, techniques, specification and parameter data on lime and cement. Procedures were followed to categorize the type of poor soil encountered. Tests were then performed to investigate the properties of the soil before and after stabilization; this was to potential for its applicability in Accra or make up for where data in the literature was not adequate.

1.4 Study area

The study area is Legon in Accra,Ghana. From Kesse ( ), they all form part of the Precambrian Togo series, which occur at the south eastern part of Ghana. The geology is dominantly metamorphosed and highly folded arenaceous and argillaceous group of rocks, in which the predominant rock types are quartzites and phyllites (Anum, 2013). Structures present are basically foliations and joints. The soil type is laterite.The coordinates include, $05^0 39' 25.3''$ (N) and $000^0 10' 43''$(w) with elevation 92m.

2. METHODOLOGY

The study covered representative sampling of the soils from the various locations, laboratory tests to stabilize the poor soils for engineering works (road works) and the determination from the results gained of which of the soils sampled was the most favorable in terms of maximum strength gained after stabilization. Testing was done in accordance with specifications from the Ghana Highway Authority. Tests done included, but were not limited to, the following:

- Grading test
- Atterberg limit test
- Compaction Test
- California bearing ratio

2.1 Sample collection and preparation

Samples were collected as per Ghana Highway Authority standards for soil stabilization tests. At the laboratory, the samples were mixed thoroughly in order to achieve a state where by any amount sample taken is representative of the entire sample and, by extension, the soil in the field. This was done by a process called refilling. Refilling is done by first dividing the sample into two equal parts using a set of equipment collectively known as the refilling box. Then one part is again divided into two equal parts. This process is continued until one is satisfied with the level of mixing.

2.2 Laboratory Test

2.2.1 *Gradation analysis*

This method is used primarily to determine the grading of materials proposed for use as aggregates or being used as aggregates. The results are used to determine compliance of the particle size distribution with applicable specification requirements and to provide necessary data for control of the production of various aggregate products and mixtures containing aggregates. Essentially, it is a practice or procedure used (commonly in civil engineering) to assess the particle size distribution of a granular material. The procedure according to Ghana Highway Authority standards requires that, after refilling, two small quantities of the sample should be taken and put into two pans: one for washing of the sample and one for moisture content weight determination.

Apparatus: Two pans, 19.0mm, 9.5mm, 4.75mm, 2.0mm, 1.00mm, 0.425mm, 0.300mm, 0.150mm, 0.075mm sieves, washing bowl, balance/scale, vibrator.

Procedure: The masses of the two pans A and B were recorded. An appreciable amount of the sample was then taken and placed into pan A and weighed to obtain the weight of the moist sample plus the pan. It is then placed in an oven for 24 hours. This is for the moisture content determination. A smaller amount of the sample was placed into pan B and soaked in water for 24 hours. After 24 hours, the sample in pan A was removed from the oven and weighed to obtain the dry mass plus the pan. Then the sample in pan B was poured into a bowl and washed under a running tap by pouring the water through the 0.075mm sieve so that not all the soil is washed away (fig. 3.4). The useful ones were retained on the sieve whiles those that passed through the sieve were unwanted. Washing was done to take the dust or the unwanted particles out of the whole sample. This was done several times until the water used to wash the sample became clear (fig. 3.5). Then the sample was poured back into pan B, drained and put into the oven to dry. After 24 hours, pan B was removed from the oven and the washed dry sample was then weighed.

The gradation analysis of the dry washed samples was done using the sieves and the pan. The samples were then poured into the sieves arranged according to the largest sieve to the smallest sieve. The sieves containing the samples were placed under a vibrator (fig. 3.6). The vibrator shook the sieve for about 5 to 10 minutes to ensure that the samples passed through the sieves in order to obtain the various size fractions of the soil sample (fig. 3.7). The soil retained on each of the sieves were then poured to a plate and weighed. Values were recorded on the data sheet.

The sieves were nested in order of decreasing size of opening from top to bottom and the sample was placed on the top sieve. The sieves were agitated by the vibrator until meeting the criteria for adequacy of sieving i.e. for about 10 minutes and then removed from the vibrator. The top sieve was removed and the retained material was brushed into a pan, which is then weighed and recorded. Each sieve cleaned thoroughly. This process was repeated with each succeeding sieve; brushing the material into individual pans, and recording the non-cumulative weights.

2.2.2 ***Atterberg limit test***

Apparatus: 0.425mm sieve, pans, mortar, pestle, Cassagrande device, Grooving tool, Balance, Spatula, Distilled water, Wash bowl, Glass Plate, alluminium.

Procedure: 200g of the total sample was obtained by first breaking down the sample into smaller pieces (fig. 3.8) before passing it through the 0.425mm sieve (fig. 3.9). The raw sample was divided into two equal parts; one part for Liquid Limit test (LL) and the other for Plastic Limit test (PL). Two empty cans were weighed. The soil was moulded after adding water. Then 20g of the moulded sample was weighed and divided into two pans to be weighed again. The readings wererecorded. The raw sample was placed on the glass plate and distilled water was added in small amounts to adjust the water content of the mixture if it was too dry. The mixture was also allowed to dry at room temperature while mixing on a glass plate if it was too wet. This was done until a consistent mixture was achieved. A portion of the previously mixed sample was placed into the cup of the Liquid Limit of the point where the cup rests on the base. Air pockets were eliminated by squeezing the soil sample down and spreading it into the cup in the Cassagrande device to a depth of about 10mm at its deepest point. The sample formed an approximately horizontal surface. The grooving tool was then used to carve a space down the centre of the cup of the Cassagrande device (fig. 3.10). The cup was repeatedly dropped 10 mm onto a hard rubber base at a rate of 27-30 for the first blows. For example, when the first blows numbered less than 27, then there was less water in the sample and therefore distilled water was added. When the blows were greater than 27 then it was an indication that there was more water in the sample. When the required number of blows was achieved, the spatula was used to take some of the sample and placed it on the pan to be weighed and recorded. The sample was then placed in an oven for at least 16 hours. The remaining sample was remixed by adding small amount of distilled water to increase the water content. The previous steps were repeated for one additional trial to produce successively lower number of blows to close up the grove so that the number of blows will decrease: 23-27 for the second blows and 15-23 for the third blows.

2.2.3 ***Swelling test***

Apparatus: two test tubes, 0.075mm Sieve, Mortar, Pestle, Pan, Distilled water, Salt, Kerosene.

Procedure: Using the mortar and pestle, the samples were broken down into smaller fractions. An appreciable amount of the sample was then sieved through 0.075mm. 10ml each of the samples was then poured into two different tests tubes. Salt solution was poured into one of the test tubes containing 10ml of the sample. In the other test tube, an appreciable amount of Kerosene was poured into the other test tube with the 10ml sample (fig 3.11). The test tubes are left for 24 hours for the swell to develop fully.

2.2.4 ***Compaction test***

ISSN 2229-5518

Apparatus: 19mm Sieve, Refilling box, Balance, Bucket, Mould, Filter Paper, Pan, Rammer (fig. 12), Scoop, Cutter, And Calibrated Test Tube.

Procedure: The sample was sieved through 19mm. It was then poured into a bucket and weighed to a total of 5040g. The weight and the label of the mould (fig 3.12) were recorded as well. A filter paper was placed in the mould to serve as a separating membrane (fig. 3.15). Using the calibrated test tubes, the amount of water to be added to the samples was measured. Water was added in percentages 4%, 6%, 8%, 10% and 12% of the total sample weight of 5040g. Part of the sample was scooped from the bucket into the mould to serve as the first layer in the compaction sequence (fig. 3.13). Using the rammer, the soil was compacted to a total of five layers, each of 56 blows according to Ghana Highway Authority (GHA) standards (fig. 3.16). The rammer was removed and Highway Authority (GHA) standards (fig. 3.16). The rammer was removed and the cutter was used to level the compacted sample in the mould before it was weighed (fig 3.14).Graphs were then drawn to obtain the maximum dry density and the optimum moisture content, which was necessary for the CBR test.

2.2.5 ***California bearing ratio (CBR) test***

Apparatus: mould, rammer, scoop, Pan, 7 buckets, balance, calibrated test tube, 19mm sieve, filter paper, cutter, CBR machine, lime and cement, surcharges.

Procedure: The samples were sieved through 19mm. The weight and the label of the mould were recorded. A filter paper was placed in the mould to serve as a separating layer. 5040g of the soil sample was put into one bucket without any additives to serve as a control for the test. The additives were then added in this manner: 101g lime/cement (2%) to 4939g of the sample taken, 202g lime/cement (4%) to 4838g of the sample taken and 302g lime/cement (6%) to 4738g of the sample taken. The addition of the samples and the lime gave a total of 5040g for each mould. From the compaction graph, the optimum moisture content determined was used to estimate the amount of water to be added and then the calibrated test tubes were used to measure the appropriate volume of water. The samples, lime/cement (figs. 3.18 &3.19) and water were then thoroughly mixed. The sample plus the additives were put into each mould and compacted in layers, with one scoop representing one layer. The sample was compacted in five layers with 56 blows for each layer. The sample was then leveled using the cutter. Surcharges were placed on the moulds and they were submerged underwater for 4 days. After that the moulds with the surcharges on them were removed and placed down to drain. Each of the moulds was then placed on the CBR machine (fig. 3.17) or the penetration piston and a surcharge lead of 10Ib placed. The lead was applied and the penetration lead value was taken. A graph between the penetration (inches) and penetration load (inches) was drawn and the CBR value was found. A graph between percentage CBR and Dry Density and the CBR at the require degree of compaction were found.

Fig. 2.1 The Cassagrande device

Fig. 2.2 The CBR machine

3. RESULTS

3.1. GRADING TEST RESULTS – Table 3.1

CENTRAL MATERIALS LABORATORY

WASHED SIEVE ANALYSIS

DATE:	18-04-13	TECHNICIAN:	
SAMPLE NO:	2		
SAMPLE LOCATION:	LEGON ROAD CONSTRUCTION SITE		
SAMPLE DESCRIPTION:	LATERITE		
MASS SAMPLE RECEIVED:	8871 g		

SIEVE APERTURE	MASS RETAINED	DRY MASS	PERCENT RETAINED	PERCENT PASSING
75.0				
53.0				
37.5				
26.5				
19.0				
PAN				
TOTAL DRY MASS				

AIR-DRY MOISTURE CONTENT

	PASSING 19.00 mm	RETAINED 19.00mm
CONTAINER NO:	OLV-1	
MASS MOIST AGG+CONT:	2107.86	2545.98
MASS DRY AGG+CONT	2081.04	2544.93
MASS OF CONTAINER	922.96	957.68
MASS OF WATER	26.82	1.05
MASS OF DRY AGGREGATE	1158.08	1587.25
MOISTURE CONTENT	2.32	0.07

GRADING OF MINUS 19mm FRACTION

BOWL NO:	KAM 30
MASS OF BOWL	931.41
MASS BOWL + AIR-DRY(MOIST) SUB SAMPLE	1442.11
MASS AIR-DRY(MOIST) SUB SAMPLE	510.70
MASS DRY SUB SAMPLE	499.14
MASS BOWL + DRY SAMPLE AFTER WASHING	1266.71
MASS DRY SAMPLE AFTER WASHING	335.30
MASS MINUS 0.075 WASHED AWAY	163.84

SIEVE APERTURE (mm)	MASS RETAINED (g)	% RETAINED (%)	% PASSING MINUS 19mm	%PASSING TOTAL SAMPLE
19.000			100.00	
9.500	11.39	2.28	97.72	
4.750	13.76	2.76	94.96	
2.000	27.77	5.57	89.39	
1.000	26.61	5.33	84.06	
0.425	33.35	6.69	77.37	
0.300	23.14	4.64	72.73	
0.150	77.44	15.52	57.21	
0.075	98.09	19.66	37.55	
PAN +	23.47	4.70		
MASS WASHED AWAY	163.84	32.84		
TOTAL - 19mm	498.86	100.00		

3.2. Atterberg limits test results.

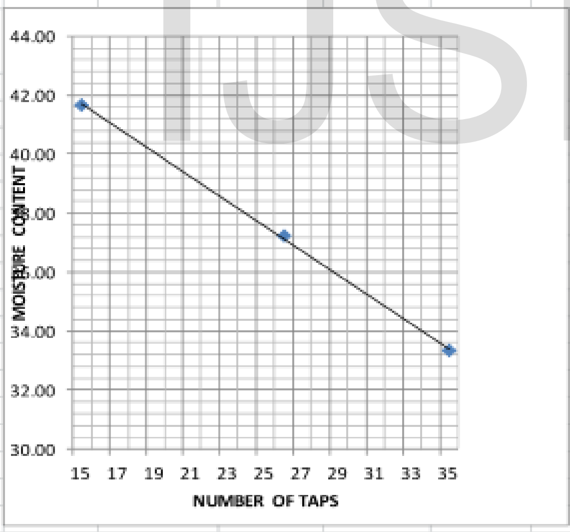
3.2.1 *Raw sample* – Table 3.2

GHANA HIGHWAY AUTHORITY	DRAFT FORM S6	DATE:	09-04-13
CENTRAL MATERIALS	ATTERBERG LIMITS		
LABORATORY	OF		
	SOIL FINES		

SAMPLE NUMBER	: L-0	OPERATOR:	
SAMPLE LOCATION	: LEGON		
SAMPLE DESCRITION	LATERITE		
MASS AIR-DRY SAMPLE	:	PREPARATION A / PREPARATION B / AIR-DRY	
MAKING BOWL NUMBER	:	PI TUB NUMBER	
SETTLEMENT BOWL NUMBER	:	EVAPORATION PAN NO.	

MOISTURE CONTENT DETERMINATIONS

TYPE OF TEST	CASAGRANDE CUP LIQUID LIMIT			B.S. CONE LIQUID LIMIT			PLASTIC LIMIT	
TEST NUMBER	1(27-35)	2(23-27)	3(15-23)	1(15-18)	2(18-22)	3(22-25)	1	2
NO. BLOWS - CONE PENETRATION	35	26	15					
CONTAINER NUMBER								
MASS OF WET SOIL + CONTAINER	27.71	29.64	31.54				19.53	19.42
MASS OF DRY SOIL + CONTAINER	23.11	24.13	25.04				17.74	17.65
MASS OF CONTAINER	9.31	9.33	9.44				9.44	9.34
MASS OF WATER	4.6	5.51	6.5				1.79	1.77
MASS OF DRY SOIL	13.8	14.8	15.6				8.3	8.31
MOISTURE CONTENT	33.33	37.23	41.67				21.57	21.30



Number of blows	Factor
15	0.95
16	0.96
17	0.96
18	0.97
19	0.97
20	0.98
21	0.98
22	0.99
23	0.99
24	0.99
25	1.00
26	1.00
27	1.01
28	1.01
29	1.01
30	1.02
31	1.02
32	1.02
33	1.02
34	1.03
35	1.03

CASANGRANDE CUP LIQUID LIMIT:	38	B.S. CONE LIQUID LIMIT:	
SHRINKAGE MOULD NO.	SHRINKAGE:	SHRINK MLD NO.	SHRINKAGE: mm; %
AVERAGE PLASTIC LIMIT:	21		
PLASTICITY INDEX; CASANGRANDE:	16	PLASTICITY INDEX; BS CONE:	

ISSN 2229-5518

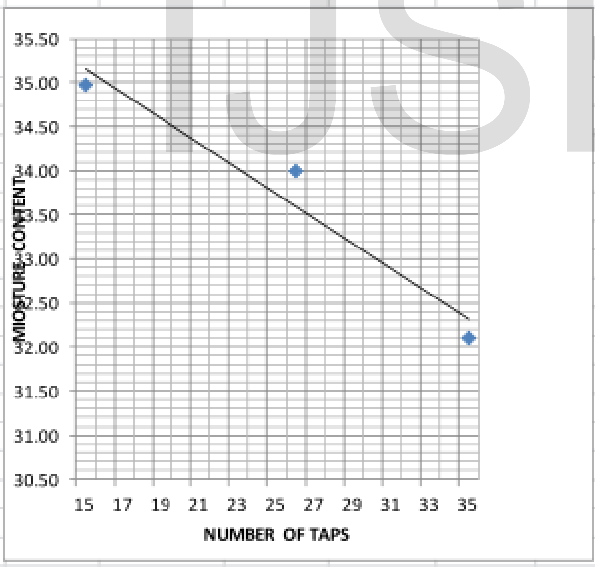
3.2.2 *2% lime addition* – Table 3.3

GHANA HIGHWAY AUTHORITY		DRAFT FORM S6	DATE:	18-04-13
CENTRAL MATERIALS		ATTERBERG LIMITS		
LABORATORY		OF		
		SOIL FINES		

SAMPLE NUMBER	: LL-2	OPERATOR:	
SAMPLE LOCATION	: LEGON		
SAMPLE DESCRITION	LATERITE		
MASS AIR-DRY SAMPLE	:	PREPARATION A / PREPARATION B / AIR-DRY	
MAKING BOWL NUMBER	:	PI TUB NUMBER	
SETTLEMENT BOWL NUMBER	:	EVAPORATION PAN NO.	

MOISTURE CONTENT DETERMINATIONS

TYPE OF TEST	CASAGRANDE CUP LIQUID LIMIT			B.S. CONE LIQUID LIMIT			PLASTIC LIMIT	
TEST NUMBER	1(27-35)	2(23-27)	3(15-23)	1(15-18)	2(18-22)	3(22-25)	1	2
NO. BLOWS - CONE PENETRATION	35	26	15					
CONTAINER NUMBER								
MASS OF WET SOIL + CONTAINER	18.64	20.72	22.94				13.86	13.64
MASS OF DRY SOIL + CONTAINER	14.91	16.31	17.84				11.95	11.77
MASS OF CONTAINER	3.29	3.34	3.26				3.63	3.63
MASS OF WATER	3.73	4.41	5.1				1.91	1.87
MASS OF DRY SOIL	11.62	12.97	14.58				8.32	8.14
MOISTURE CONTENT	32.10	34.00	34.98				22.96	22.97



Number of blows	Factor
15	0.95
16	0.96
17	0.96
18	0.97
19	0.97
20	0.98
21	0.98
22	0.99
23	0.99
24	0.99
25	1.00
26	1.00
27	1.01
28	1.01
29	1.01
30	1.02
31	1.02
32	1.02
33	1.02
34	1.03
35	1.03

CASANGRANDE CUP LIQUID LIMIT:	34	B.S. CONE LIQUID LIMIT:			
SHRINKAGE MOULD NO.	SHRINKAGE:		SHRINK MLD NO.	SHRINKAGE:	mm; %
AVERAGE PLASTIC LIMIT:	23				
PLASTICITY INDEX; CASANGRANDE:	11	PLASTICITY INDEX; BS CONE:			

ISSN 2229-5518

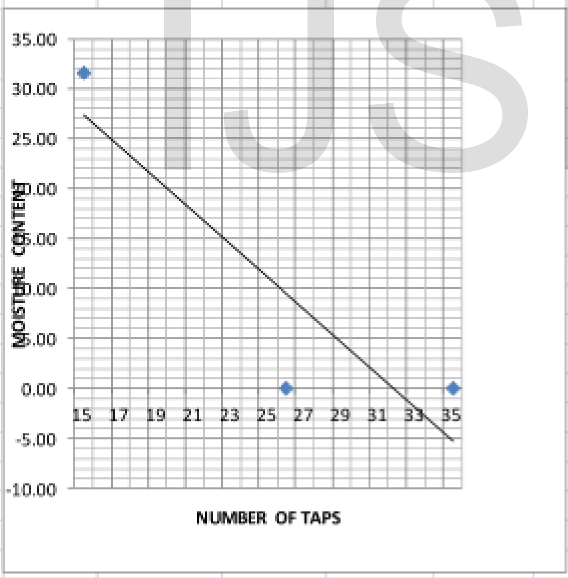
3.2.3 *4% lime addition* – Table 3.4

GHANA HIGHWAY AUTHORITY	DRAFT FORM S6	DATE:	18-04-13
CENTRAL MATERIALS	ATTERBERG LIMITS		
LABORATORY	OF		
	SOIL FINES		

SAMPLE NUMBER	: LL-4	OPERATOR:	
SAMPLE LOCATION	: LEGON		
SAMPLE DESCRITION	LATERITE		
MASS AIR-DRY SAMPLE	:	PREPARATION A / PREPARATION B / AIR-DRY	
MAKING BOWL NUMBER	:	PI TUB NUMBER	
SETTLEMENT BOWL NUMBER	:	EVAPORATION PAN NO.	

MOISTURE CONTENT DETERMINATIONS

TYPE OF TEST	CASAGRANDE CUP LIQUID LIMIT			B.S. CONE LIQUID LIMIT			PLASTIC LIMIT	
TEST NUMBER	1(27-35)	2(23-27)	3(15-23)	1(15-18)	2(18-22)	3(22-25)	1	2
NO. BLOWS - CONE PENETRATION	35	26	15					
CONTAINER NUMBER								
MASS OF WET SOIL + CONTAINER			19.80				13.86	13.64
MASS OF DRY SOIL + CONTAINER			15.85				11.95	11.77
MASS OF CONTAINER	3.33	3.29	3.35				3.63	3.63
MASS OF WATER			3.95				1.91	1.87
MASS OF DRY SOIL			12.5				8.32	8.14
MOISTURE CONTENT			31.60				22.96	22.97



Number of blows	Factor
15	0.95
16	0.96
17	0.96
18	0.97
19	0.97
20	0.98
21	0.98
22	0.99
23	0.99
24	0.99
25	1.00
26	1.00
27	1.01
28	1.01
29	1.01
30	1.02
31	1.02
32	1.02
33	1.02
34	1.03
35	1.03

CASANGRANDE CUP LIQUID LIMIT:	30	B.S. CONE LIQUID LIMIT:			
SHRINKAGE MOULD NO.	SHRINKAGE:		SHRINK MLD NO.	SHRINKAGE:	mm; %
AVERAGE PLASTIC LIMIT:	23				
PLASTICITY INDEX; CASANGRANDE:	7	PLASTICITY INDEX; BS CONE:			

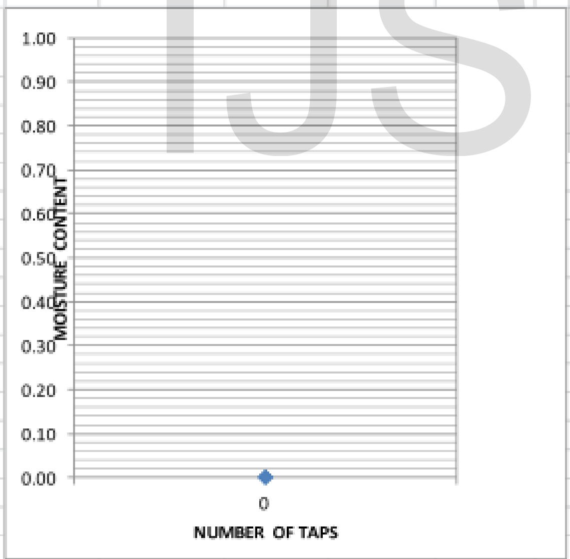
3.2.4 *6% lime addition* – Table 3.5

GHANA HIGHWAY AUTHORITY	DRAFT FORM S6	DATE:	18-04-13
CENTRAL MATERIALS	ATTERBERG LIMITS		
LABORATORY	OF		
	SOIL FINES		

SAMPLE NUMBER	: LL-6	OPERATOR:
SAMPLE LOCATION	: LEGON	
SAMPLE DESCRITION	LATERITE	
MASS AIR-DRY SAMPLE	:	PREPARATION A / PREPARATION B / AIR-DRY
MAKING BOWL NUMBER	:	PI TUB NUMBER
SETTLEMENT BOWL NUMBER	:	EVAPORATION PAN NO.

MOISTURE CONTENT DETERMINATIONS

TYPE OF TEST	CASAGRANDE CUP LIQUID LIMIT			B.S. CONE LIQUID LIMIT			PLASTIC LIMIT	
TEST NUMBER	1(27-35)	2(23-27)	3(15-23)	1(15-18)	2(18-22)	3(22-25)	1	2
NO. BLOWS - CONE PENETRATION								
CONTAINER NUMBER								
MASS OF WET SOIL + CONTAINER								
MASS OF DRY SOIL + CONTAINER								
MASS OF CONTAINER	6.52	6.52	6.53				6.33	6.52
MASS OF WATER								
MASS OF DRY SOIL								
MOISTURE CONTENT							0.20	0.10



Number of blows	Factor
15	0.95
16	0.96
17	0.96
18	0.97
19	0.97
20	0.98
21	0.98
22	0.99
23	0.99
24	0.99
25	1.00
26	1.00
27	1.01
28	1.01
29	1.01
30	1.02
31	1.02
32	1.02
33	1.02
34	1.03
35	1.03

CASANGRANDE CUP LIQUID LIMIT:		B.S. CONE LIQUID LIMIT:			
SHRINKAGE MOULD NO.	SHRINKAGE:		SHRINK MLD NO.	SHRINKAGE: mm;	%
AVERAGE PLASTIC LIMIT:	0				
PLASTICITY INDEX; CASANGRANDE:		PLASTICITY INDEX; BS CONE:			

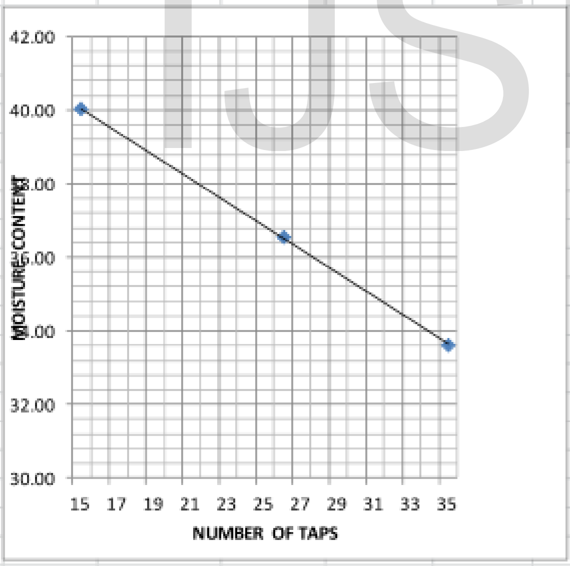
3.2.5 *2% cement addition* – Table 3.6

GHANA HIGHWAY AUTHORITY	DRAFT FORM S6	DATE:	19-04-13
CENTRAL MATERIALS	ATTERBERG LIMITS		
LABORATORY	OF		
	SOIL FINES		

SAMPLE NUMBER	: LC-2	OPERATOR:	
SAMPLE LOCATION	: LEGON		
SAMPLE DESCRITION	LATERITE		
MASS AIR-DRY SAMPLE	:	PREPARATION A / PREPARATION B / AIR-DRY	
MAKING BOWL NUMBER	:	PI TUB NUMBER	
SETTLEMENT BOWL NUMBER	:	EVAPORATION PAN NO.	

MOISTURE CONTENT DETERMINATIONS

TYPE OF TEST	CASAGRANDE CUP LIQUID LIMIT			B.S. CONE LIQUID LIMIT			PLASTIC LIMIT	
TEST NUMBER	1(27-35)	2(23-27)	3(15-23)	1(15-18)	2(18-22)	3(22-25)	1	2
NO. BLOWS - CONE PENETRATION	35	26	15					
CONTAINER NUMBER								
MASS OF WET SOIL + CONTAINER	21.29	23.25	25.29				14.63	14.55
MASS OF DRY SOIL + CONTAINER	17.27	18.42	19.54				12.83	12.79
MASS OF CONTAINER	5.31	5.21	5.17				4.50	4.50
MASS OF WATER	4.02	4.83	5.75				1.8	1.76
MASS OF DRY SOIL	11.96	13.21	14.37				8.33	8.29
MOISTURE CONTENT	33.61	36.56	40.01				21.61	21.23



Number of blows	Factor
15	0.95
16	0.96
17	0.96
18	0.97
19	0.97
20	0.98
21	0.98
22	0.99
23	0.99
24	0.99
25	1.00
26	1.00
27	1.01
28	1.01
29	1.01
30	1.02
31	1.02
32	1.02
33	1.02
34	1.03
35	1.03

CASANGRANDE CUP LIQUID LIMIT:	37	B.S. CONE LIQUID LIMIT:			
SHRINKAGE MOULD NO.	SHRINKAGE:		SHRINK MLD NO.	SHRINKAGE:	mm; %
AVERAGE PLASTIC LIMIT:	21				
PLASTICITY INDEX; CASANGRANDE:	15	PLASTICITY INDEX; BS CONE:			

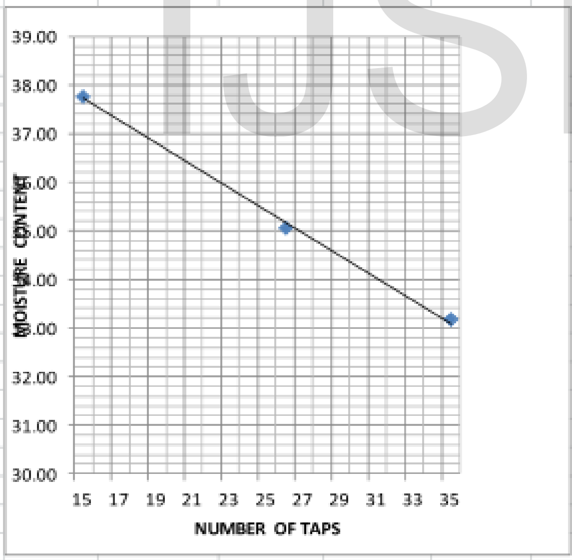
3.2.6 *4% cement addition* – Table 3.7

GHANA HIGHWAY AUTHORITY	DRAFT FORM S6	DATE:	19-04-13
CENTRAL MATERIALS	ATTERBERG LIMITS		
LABORATORY	OF		
	SOIL FINES		

SAMPLE NUMBER	: LC-4	OPERATOR:	
SAMPLE LOCATION	: LEGON		
SAMPLE DESCRITION	LATERITE		
MASS AIR-DRY SAMPLE	:	PREPARATION A / PREPARATION B / AIR-DRY	
MAKING BOWL NUMBER	:	PI TUB NUMBER	
SETTLEMENT BOWL NUMBER	:	EVAPORATION PAN NO.	

MOISTURE CONTENT DETERMINATIONS

TYPE OF TEST	CASAGRANDE CUP LIQUID LIMIT			B.S. CONE LIQUID LIMIT			PLASTIC LIMIT	
TEST NUMBER	1(27-35)	2(23-27)	3(15-23)	1(15-18)	2(18-22)	3(22-25)	1	2
NO. BLOWS - CONE PENETRATION	35	26	15					
CONTAINER NUMBER								
MASS OF WET SOIL + CONTAINER	28.28	30.38	32.45				19.65	19.39
MASS OF DRY SOIL + CONTAINER	23.59	24.92	26.09				17.88	17.64
MASS OF CONTAINER	9.45	9.35	9.25				9.55	9.43
MASS OF WATER	4.69	5.46	6.36				1.77	1.75
MASS OF DRY SOIL	14.14	15.57	16.84				8.33	8.21
MOISTURE CONTENT	33.17	35.07	37.77				21.25	21.32



Number of blows	Factor
15	0.95
16	0.96
17	0.96
18	0.97
19	0.97
20	0.98
21	0.98
22	0.99
23	0.99
24	0.99
25	1.00
26	1.00
27	1.01
28	1.01
29	1.01
30	1.02
31	1.02
32	1.02
33	1.02
34	1.03
35	1.03

CASANGRANDE CUP LIQUID LIMIT:	35	B.S. CONE LIQUID LIMIT:	
SHRINKAGE MOULD NO.	SHRINKAGE:	SHRINK MLD NO.	SHRINKAGE: mm; %
AVERAGE PLASTIC LIMIT:	21		
PLASTICITY INDEX; CASANGRANDE:	14	PLASTICITY INDEX; BS CONE:	

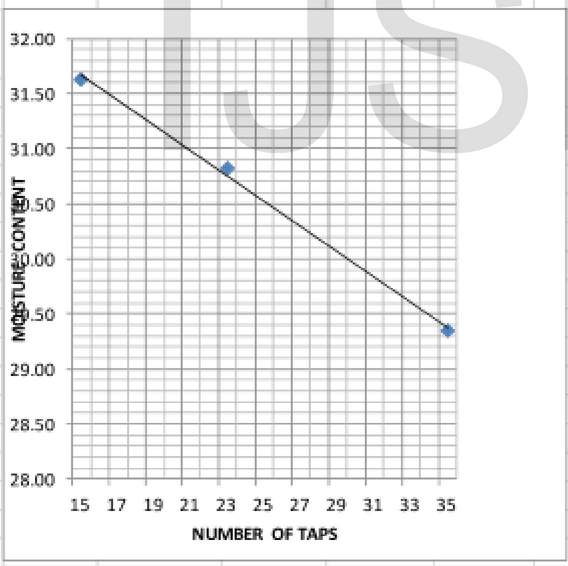
3.2.7 *6% cement addition* – Table 3.8

GHANA HIGHWAY AUTHORITY	DRAFT FORM S6	DATE:	19-04-13
CENTRAL MATERIALS	ATTERBERG LIMITS		
LABORATORY	OF		
	SOIL FINES		

SAMPLE NUMBER	: LC-6	OPERATOR:	
SAMPLE LOCATION	: LEGON		
SAMPLE DESCRITION	LATERITE		
MASS AIR-DRY SAMPLE	:	PREPARATION A / PREPARATION B / AIR-DRY	
MAKING BOWL NUMBER	:	PI TUB NUMBER	
SETTLEMENT BOWL NUMBER	:	EVAPORATION PAN NO.	

MOISTURE CONTENT DETERMINATIONS

TYPE OF TEST	CASAGRANDE CUP LIQUID LIMIT			B.S. CONE LIQUID LIMIT			PLASTIC LIMIT	
TEST NUMBER	1(27-35)	2(23-27)	3(15-23)	1(15-18)	2(18-22)	3(22-25)	1	2
NO. BLOWS - CONE PENETRATION	35	23	15					
CONTAINER NUMBER								
MASS OF WET SOIL + CONTAINER	19.22	21.82	23.91				15.00	16.09
MASS OF DRY SOIL + CONTAINER	16.08	17.93	19.45				13.43	14.36
MASS OF CONTAINER	5.38	5.31	5.35				5.34	5.39
MASS OF WATER	3.14	3.89	4.46				1.57	1.73
MASS OF DRY SOIL	10.7	12.62	14.1				8.09	8.97
MOISTURE CONTENT	29.35	30.82	31.63				19.41	19.29



Number of blows	Factor
15	0.95
16	0.96
17	0.96
18	0.97
19	0.97
20	0.98
21	0.98
22	0.99
23	0.99
24	0.99
25	1.00
26	1.00
27	1.01
28	1.01
29	1.01
30	1.02
31	1.02
32	1.02
33	1.02
34	1.03
35	1.03

CASANGRANDE CUP LIQUID LIMIT:	31	B.S. CONE LIQUID LIMIT:			
SHRINKAGE MOULD NO.	SHRINKAGE:		SHRINK MLD NO.	SHRINKAGE:	mm; %
AVERAGE PLASTIC LIMIT:	19				
PLASTICITY INDEX; CASANGRANDE:	11	PLASTICITY INDEX; BS CONE:			

ISSN 2229-5518

3.3 Swelling test results – Table 3.9

Sample	Initial (ml)	Final (ml)
Legon Laterite	12	13

3.4 Compaction test results – Table 3.10

GHANA HIGHWAY AUTHORITY FORM S2/2. DATE: 1

CENTRAL MATERIALS LABORATORY

MOISTURE DENSITY RELATIONSHIP

MINUS 19mm FRACTION

ESPECTED WEIGHT:

SAMPLE NUMBER: L-0

	MASS MINUS 19mm	MASS PLUS 19mm:		TOTAL MASS:			
ROW	PARAMETER	SPECIMEN 1	SPECIMEN 2	SPECIMEN 3	SPECIMEN 4	SPECIMEN 5	SPECIM
1	CONTAINER NO.						
2	MASS AIR-DRY SAMPLE(g)	7000	7000	7000	7000	7000	
3	MASS WATER ADDED (g)						
4	PERCENT WATER ADDED (%)	4.0	6.0	8.0	10.0	12.0	
5	ESTIMATED AIR-DRY MC(%)						
6	EST. COMPACTION MC. (%)(4) + (5)	4	6	8	10	12	
7	MOULD NUMBER	Z-8	Z-8	Z-8	Z-8	Z-8	
8	MOULD FACTOR	0.4727	0.4727	0.4727	0.4727	0.4727	
9	MASS OF MOULD(g)	4285	4285	4285	4285	4285	
10	MASS MOULD + WET SOIL. (g)	7985	8702	8762	8690	8471	
11	MASS WET SOIL. (g). (10) - (9)	3700	4417	4477	4405	4186	
12	WET DENSITY. Kg/cu. M. (11) * (8)	1749	2088	2116	2082	1979	
13	APPROX. DRY DENSITY. 100 *(12)/(100+(6))	1682	1970	1960	1893	1767	
	MOISTURE CONTENT DETERMINATION						
14	OVEN- PAN NUMBER	FW-160	D-11	N-3	BL-11	KO	
15	MASS OVEN-PAN. (g)	914.09	1012.18	971.86	993.81	928.87	
16	MASS OVEN-PAN + WET SOIL. (g)	1225.56	1297.90	1335.42	1337.49	1345.24	
17	MASS OVEN-PAN + DRY SOIL. (g)	1194.36	1264.51	1286.12	1285.92	1277.94	
18	MASS OF WATER. (g) (16) - (17)	31.20	33.39	49.30	51.57	67.30	
19	MASS DRY SOIL. (g). (17) - (15)	280.27	252.33	314.26	292.11	349.07	
20	MOISTURE CONTENT(%). (18)/(19)*100	11.1	13.2	15.7	17.7	19.3	
21	BACK CALC. AIR-DRY MC. (%) (20) - (4)	7.13	7.23	7.69	7.65	7.28	
22	DRY DENSITY. 100 * (12) / (100 + (20))	1574	1844	1829	1770	1659	
				RELATIVE COMPACTION			

Fig. 3.1: Compaction graph for approximate MDD and estimated OMC

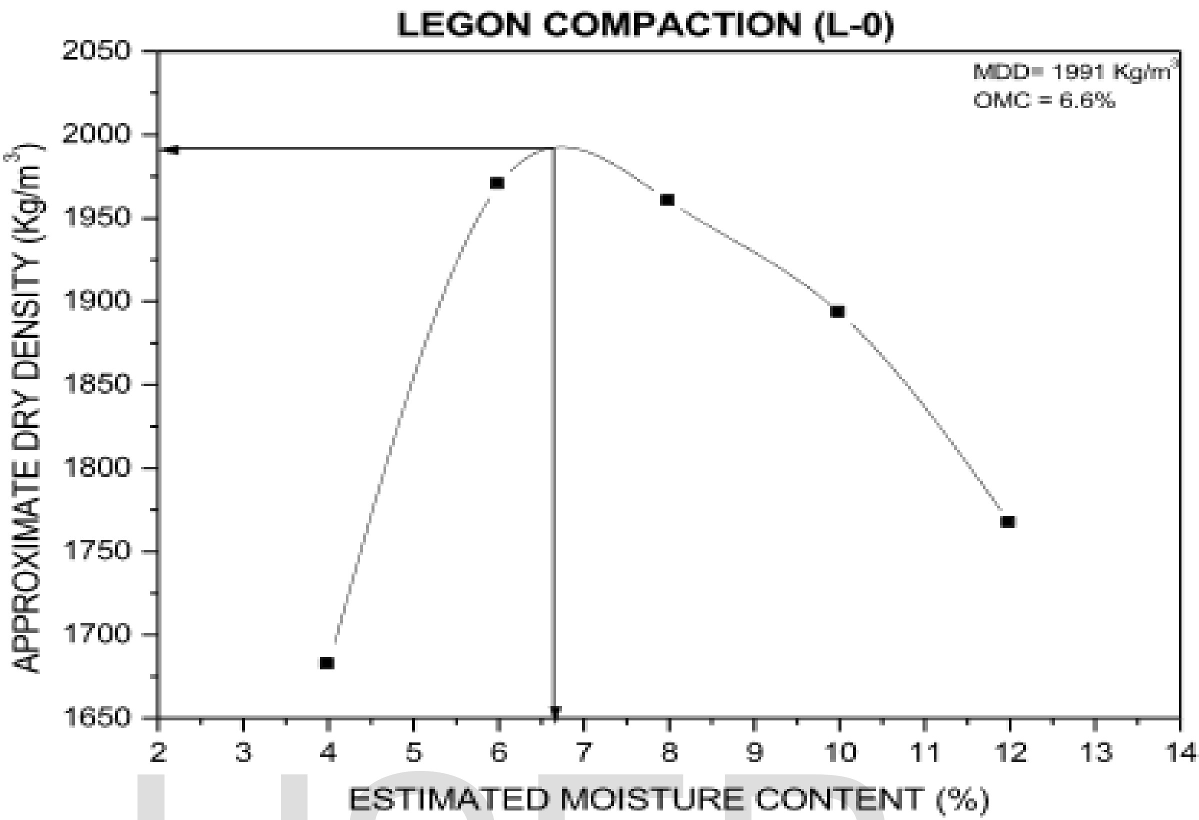
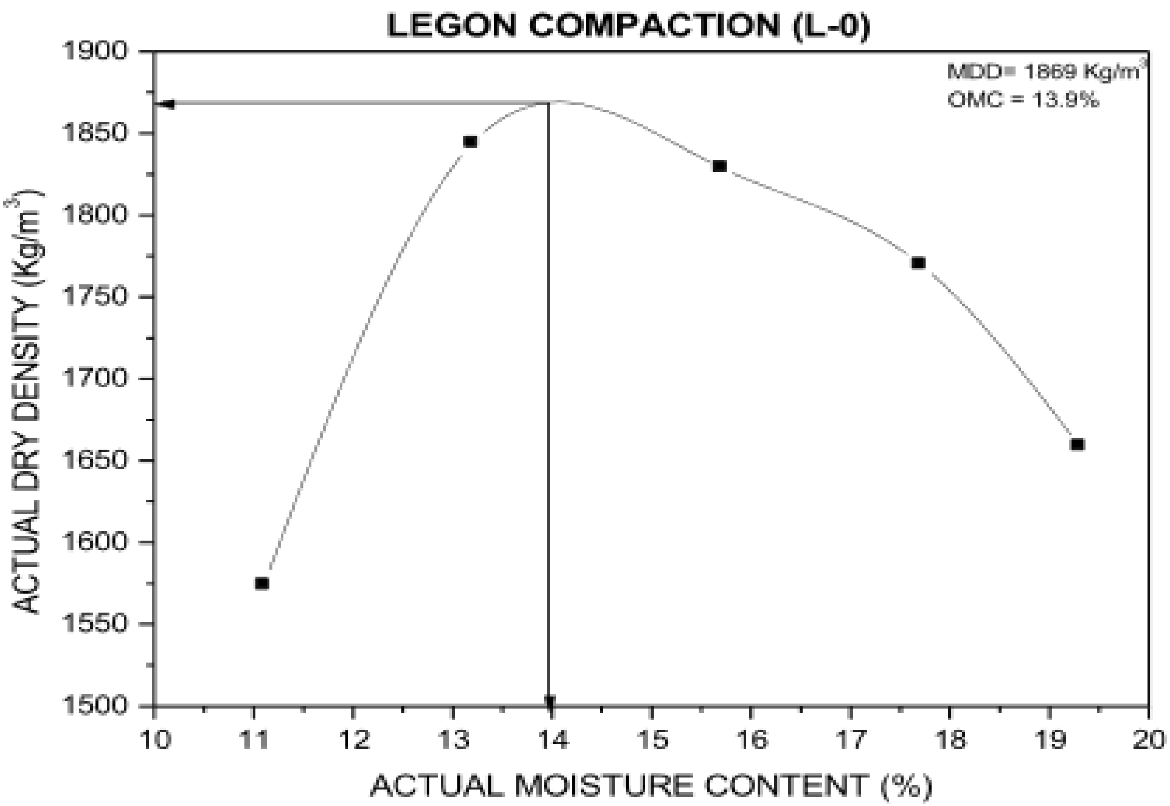


Fig. 4.2 Compaction graph for actual MDD and OMC



3.5 CALIFORNIA BEARING RATIO (CBR) TEST RESULTS

3.5.1 LIME STABILIZATION – Table 3.11

GHANS HIGWAYS AUTHORITY	FORM S2/S	DATE COMPACTED: 12/04/2013
CENTRAL MATERIALS LABORATORY	CBR LOAD - PENETRATION	
	DATA RECORD	
		DATE PENETRATED: 16/04/2013

SAMPLE NUMBER

CBR LOAD RING NUMBER:	LOAD RING FACTOR: (kN/Div.);
STANDARD LOAD @ 0.1 in. Pen. 13.344KN	STANDARD LOAD @ 0.2 in. Pen. 20.016 KN

PLUNGER PENETRATION (INCHES)	0% MOULD NO. : A-30			2% LIME MOULD NO. : A-19			4% LIME MOULD NO. : A-4			6% LIME MOULD NO. : M-6		
	LOAD RING DIAL DIVS	CORRECTED DIAL DIVS	CBR%	LOAD RING DIAL DIVS	CORRECTED DIAL DIVS	CBR%	LOAD RING DIAL DIVS	CORRECTED DIAL DIVS	CBR%	LOAD RING DIAL DIVS	CORRECTED DIAL DIVS	CBR%
0.00	0			0			0			0		
0.02	4			13			27			2		
0.04	5			44			52			50		
0.06	7			66			75			161		
0.08	8			83			88			243		
0.100	8		3	90		28	97		31	335	400	126
0.12	9			93			108			385		
0.14	9			97			119			423		
0.16	10			100			127			450		
0.18	10			104			131			470		
0.200	10		2	107		22	147		31	501	538	113
0.22	11			111			167			528		
0.24	11			116			180			546		
0.26	11			119			198			563		
0.28	11			125			224			583		
0.30	12			129			236			596		
			3			28			31			126

3.5.2 CEMENT STABILIZATION – Table 3.12

GHANS HIGWAYS AUTHORITY	FORM S2/S	DATE COMPACTED: 12/04/2013
CENTRAL MATERIALS LABORATORY	CBR LOAD - PENETRATION	
	DATA RECORD	
		DATE PENETRATED: 16/04/2013

SAMPLE NUMBER

CBR LOAD RING NUMBER:	LOAD RING FACTOR: (kN/Div.);
STANDARD LOAD @ 0.1 in. Pen. 13.344KN	STANDARD LOAD @ 0.2 in. Pen. 20.016 KN

PLUNGER PENETRATION (INCHES)	0% MOULD NO. : A-30			2% CEMENT MOULD NO. : Z-10			4% CEMENT MOULD NO. : BOIN			6% CEMENT MOULD NO. : Z-3		
	LOAD RING DIAL DIVS	CORRECTED DIAL DIVS	CBR%	LOAD RING DIAL DIVS	CORRECTED DIAL DIVS	CBR%	LOAD RING DIAL DIVS	CORRECTED DIAL DIVS	CBR%	LOAD RING DIAL DIVS	CORRECTED DIAL DIVS	CBR%
0.00	0			0			0			0		
0.02	4			16			51			189		
0.04	5			27			119			410		
0.06	7			33			176			610		
0.08	8			38			209			684		
0.100	8		3	43		14	235		74	750		236
0.12	9			47			258			773		
0.14	9			55			277			790		
0.16	10			57			292			796		
0.18	10			62			306			810		
0.200	10		2	65		14	320		67	816		171
0.22	11			67			329			821		
0.24	11			72			333			827		
0.26	11			74			336			832		
0.28	11			76			338			852		
0.30	12			80			342			863		
			3			14			74			236

ISSN 2229-5518

4. ANALYSIS AND DISCUSSION

4.1 Grading test

Results obtained from the test indicated that the sample was quite well graded with the percentage retained on each sieve ranging from 2.28% to 6.69%, with the exception of the 0.150mm and 0.075mm sieves retaining 15.52% and 19.66% respectively, although a large percentage of the sample (32.84%) was washed away.

4.2 Swelling test

The volume of the sample rose from 10ml to 12ml 24 hours after the kerosene was poured into one of the test tubes. This represented the actual height of the sample and acted as the control for the test. 24 hours after the water was added to the other test tube, the volume of the sample rose from 10ml to 13ml. this resulted in a 1ml difference in volume between the test tubes used for the test after 24 hours. Since the swelling test shows an indication of the clay content, the marginal increase in volume of the sample with water shows that there is a very small amount of clay in the laterite.

4.3 Standards of the Ghana highway authority

Road construction typically occurs in layers depending on the type of road i.e. either a flexible pavement or a rigid pavement. Most roads in Ghana are flexible pavements and as such this report concentrates on their characteristics. A flexible basically consist of the sub-grade, sub-base, base and topping courses. The sub-grade is the naturally occurring soil of the area upon which the road is built. It must be stable enough to support the road. The sub-base and the base are the "foundations" of the road and as such must be the strongest of the road layers/courses. If they are not, the road eventually suffers from warping as well as differential settlement or expansion.

It is for this reason that the GHA has specified minimum and maximum values for PI, LL and CBR of soil samples for both base and sub-base to be used for road construction. Non-compliance to these standards most certainly results in premature road failures.

4.4 Atterberg limits test

Table 4.1 Summary of Atterberg Limits Results

Lime	0% (Raw sample)	2%	4%	6%
Plasticity index (PI)	16	11	7	0 (non-plastic)
Liquid limit (LL)	38	34	30	0 (non-plastic)
Plastic limit (PL)	22	23	23	0
Cement	0%	2%	4%	6%
Plasticity index	16	15	14	11
Liquid limit	38	37	34	31
Plastic limit	22	22	20	20

Table 4.2 Ghana Highway Authority specification for LL and PI

	LL	PI
Specs base	25 (max)	10 (max)
Specs sub-base	34 (max)	14(max)

Both the PI and the LL summary graphs show that lime stabilization was better at reducing the clay content of the sample than the cement stabilization, with the most reduction occurring at the 6% lime addition. Specifications from GHA require that the PI and LL obtained from Atterberg Limits tests fall within their standards. The PL parameter is not considered in this analysis.

The summary tables show that the raw sample clearly does not meet the standards of the GHA for both PI and LL with respect to both the base and sub-base.

For the lime stabilization, the PI test passed for 4% and 6% stabilization and the LL test passed for only 6% stabilization with respect to the base course, whiles the PI test passed for 2%, 4% and 6% stabilization and the LL test passed for 4% and 6% stabilization with respect to the sub-base course. For the cement stabilization, both the PI and LL tests did not pass the specification with respect to the base course, whiles the PI test passed for 4% and 6% stabilization and the LL test did not pass the specification with respect to the sub-base course.

4.5 Compaction test

The results of the compaction test indicated that the sample achieved an actual maximum dry density (MDD) of 1869kg/m , but, more importantly, attained actual optimum moisture content (OMC) of 13.9%. This means that if the moisture content of the soil increases beyond this value during road construction the soil is most likely to fail due to oversaturation. The OMC obtained was used in the CBR test of the sample.

4.6 California bearing ratio test

Table 4.3 Summary of CBR test results

LIME	0% (Raw samle)	2%	4%	6%
CBR (%)	3	28	31	126
CEMENT	0% (Raw sample)	2%	4%	6%
CBR (%)	3	14	74	236

	CBR (%)
Specs Base	80 minimum
Specs Sub-base	40 minimum

Table 4.3 shows that there is a significant increase in the strength of the soil Irrespective of the additive used. At 2% addition, the lime stabilization was slightly better than the cement stabilization, but the cement stabilization became better than the lime stabilization at 4% addition and then much better at 6% stabilization. The summary tables show that the raw sample clearly does not meet the standards of the GHA for % CBR with respect to both the base and sub-base.
For the lime stabilization, the CBR test passed for only 6% stabilization with respect to both the base and sub-base courses. For the cement stabilization, the CBR test passed for only 6% stabilization with respect to the base course whiles the same test passed for both 4% and 6% stabilization with respect to the sub-base course.

5 CONCLUSION

From the analyses and discussions from the previous chapter, it can be inferred that 6% addition of lime to the sample resulted in PI, LL and CBR values that passed GHA specifications for both base and sub-base courses. It is therefore concluded that both lime and cement stabilization improved the engineering properties of the sample, but lime stabilization is the most suitable for Legon laterite soil for road construction.

ACKNOWLEDGEMENT
Glory be to God almighty, the maker of all things. We extent our heartfelt appreciation to multigeoconsult for contributing greatly to the success of this research work through professional consulting as well being the sole funder. We would like to extend our profound gratitude to the entire teaching staff of Earth Science Department (University Of Ghana) for their persistent review and thereby making immense contributions where necessary. In addition, a thank you to the technicians of the Ghana Highway Authority (GHA) for availing their resources in running this research.
We also give sincere thanks to Ama Achampong (University of North Carolina, U.S.A) and Akua Achampong (Princeton University, New Jersey, United States.)

for their valuable and constructive suggestions during the planning and development of this research work. To Mrs. Priscilla Anum (Bodo University, Norway) and Pastor. Samuel Adjei (Bethel International Church, Trondheim-Norway), we are extremely grateful for your financial support and encouragement throughout the research work. Finally we extend our heartfel appreciation to all friends and relatives who contributed to this research work.

REFERENCES

- Achampong, F. (1996).Evaluation of Resilient Modulus for lime and cement stabilized synthetic cohesive soils, PhD Thesis, Wayne State University, Detroit, MI.
- Achampong, F., Anum, R.A., Boadu, F., Agbeko, P.K., (2013). Post Construction Failure Analysis of Road Pavements in Ghana , *International Institute of Science, Technology and Education, Civil and Environmental journal,*
- Achampong, F., Anum, R.A., Boadu, F., Obada, J., (2013). Contamination of groundwater around garbage dump. *International journal of scientific and engineering research, vol 4, issue 8,* 2274-2290 pp.
- American Association of State Highway and Transportation Officials (2005), Freezing and Thawing test of Compacted Soil-Cement Mixtures, AASHTO designation T 136-97.
- Gidigasu, M.D. (1976), laterite, soil engineering, *development in geotechnical engineering,* vol.9, 420-477 pp.
- Arulanandan, K and Tunbridge , A.D., (1969). The performance of soil road test in Ghana, *spess, sess, Laterite Soils. Proc, int.conf. Soil Mech. Found. Eng., 7th, Mexico,* 2:181-190.
- ASTM D4318-00, Standards Test Methods for Liquid, Plastic and Plasticity Index of Soils.
- ASTM, 1958. Wetting and drying tests of compacted soil-cement mixtures. ASTM Designation: D559-57. *ASTM standards, Part 4,* 1176-1181.
- Holts, Roberts D., Kovaks, William D. (1981), introduction to geotechnical engineering, Englewood Cliffs, NJ.

- Nanda, R.L. and Krishnamachari, R.,(1958). Study of soft aggregates from different parts of India with a view to their use in road construction, II. Laterite. *Central Road Res. Inst.,Inbia*, 32 pp
- Remilon, A., (1955). Stabilization of laterite soils. *Highw.Res.Board,Bull.*, 108:96-101.