World Journal of Engineering Research and Technology
WJERT
www.wjert.org SJIF Impact Factor: 4.326

COMPACTED BEHAVIOUR OF CEMENT STABILIZED LATERITIC SOIL AND ITS ECONOMIC BENEFIT OVER SELECTIVE BORROW MATERIAL IN ROAD CONSTRUCTION: A CASE STUDY IN WOLAYITA SODO

Dumessa Gudissa Lemu*[1] and R. K. Verma[2]

[1] (MSc) Department of Civil Engineering, Institute of Technology, Ambo University, Ambo, Ethiopia.

[2] (Ph.D) Department of Civil Engineering, Institute of Technology, Arba Minch University, Arba Minch, Ethiopia.

Article Received on 14/12/2017 Article Revised on 05/01/2018 Article Accepted on 26/01/2018

***Corresponding Author**
Dumessa Gudissa Lemu
(MSc) Department of Civil Engineering, Institute of Technology, Ambo University, Ambo, Ethiopia.

ABSTRACT

This study assessed the effects of cement on the behavior of compacted lateritic soil collected from WolayitaSodo, Southern Ethiopia, to examine the benefits of cement stabilized lateritic over selective borrow material both in the quality and saving cost. The basic index and engineering properties of lateritic soil were determined following the ASTM procedure and classified as A-7-5 and inorganic silt according to the AASHTO classification system and Unified Soil Classification System, respectively. The soil samples were subsequently stabilized with 3%, 5%, 7%, and 9% cement. Results showed that stabilization of the lateritic soils with cement increased the Maximum Dry Density, California Bearing Ratio, and Unconfined Compressive Strength while there was a reduction in Optimum Moisture Content as cement up to7%. The effect of curing time indicated marginal on the compaction characteristics and CBR, whereas it revealed substantial effects in unconfined compressive strength tests results. Therefore, it is concluded that Lateritic soils from WolayitaSodo stabilized with 5% cement proved better quality than the selective borrow material taken from the existing nearby areas and its economic benefits over selective borrow material by 26.95%. Thus, the stabilization of lateritic with cement around

WolayitaSodois effective in the constructions of stable and durable sub-grade and sub-base course layer.

KEYWORDS: Lateritic Soil, Cement Content, stabilization, selective borrow material, Cost.

INTRODUCTION

The cost-effectiveness of any road project depends on up the availability of the natural material that utilized in the construction of pavement layers. One such naturally occurring material is laterite, which locally known as red clay soil – a type of residual soil that occurs extensively in humid tropical and sub-tropical zones of the world, including Ethiopia, central, southern and western Africa (Netterberg, 2014). Ethiopia is a country in the ways of developments, many highway and railway projects are to be constructed in all over the country. Thus, those projects along with many thousand kilometers by their nature; pass through different topography, climate, type of soil and drainage condition. In all the area these projects pass through, it is difficult to get the soil that meets minimum quality requirements. The forces engineers to find other solutions such as stabilization with additives or replacing with the material that has the desired quality. Studies identify that lateritic soil (red clay soil) is found in Western part of Ethiopia such as Assosa, Najo –Mandi, BegiJarso and Southern part around Wolayita Sodo, Dilla, NegelleBorana. In WolayitaSodo, where the present study has been conducted, all forming factors such as rolling slope with good water runoff, distinct rainy season and having warm summer are fulfilled for the formation of lateritic soils. The previous study also identified that the area is dominated by brown, redcolorsoil, which has appreciable amounts of Sesquioxide (Hanna, 2008). As (Netterberg, 2014) Laterites have not been used in the upper layers of pavement (sub-base and base course) for some reasons: - The materials commonly exhibit gaps in the grading curve, High Plasticity Indices (greater than 15) and Lower Soaked CBR Value. Therefore, the use of lateritic soil was limited. As a result, other more expensive options are adopted such as hauling over long distances other natural gravels which meet the standard specifications. The study area, WolayitaSodo, is a junction for five nearby towns such as Arba Minch, Gofa, Hossana, Jimma, and Shashamane. The construction of the road connects Arba Minch, Hossana and Shashamane were completed recently, whereas the roads connect Gofa and Jimma is a gravel road, in the future Ethiopia road authority planned to upgrade to a sealed standard. A document obtained from Ethiopia road authoritySodo district indicates that in the construction of Alaba- Humbo road, the contractor's use selective borrow material nearby the area in the construction of subgrade and sub-base layers of the pavements of the road passes through side town where lateritic soil exists. When road pavement layers constructed, it is difficult to get materials that fulfill all the quality requirements specified by road authority standards. In such cases, to find the solution by using different alternative method either by replacement of the poor material with high-quality materials or stabilization with an appropriate binder such as Portland cement or hydrated lime. Thus, they improve the quality of the material to the required standards by saving cost and time. Using soil improvement techniques rather than using other methods, such as replacing or adding reinforced soil, either regarding performance and ease of work and also from an economic aspect and the speed of work, is thus justifiable. Soil specimens were taken from WolayitaSodo town along the main road that comes from Shashemene to Arba Minch. Before sampling, visual site investigations were made to consider the different soil types and to sample evenly in the town. The three different areas were selected for the data collection: Golla, near the new bus station (in the town) and WolayitaSodo University. For each area, two test pits at a half kilometer distance were selected. Two samples at the depths of 1.5 and 2.5 meters below the ground level were selected from each pit. This study, therefore, intends to take advantage of cement as a stabilizer of lateritic soil used for construction subgrade and subbase layers of road pavement over the uses of gravel borrow material for heavy traffic loaded road (trunk roads) and assess the effects of cement on the compaction characteristics of lateritic soil, strength characteristics and swelling properties.

Statement of the Problem

Studies have been done by Zelalem (2005), Wakuma (2007), Hanna (2008) and Wossen (2009) on the investigation of the index / engineering properties lateritic soil, shear strength parameters of lateritic soil and appropriate laboratory procedure to characterize lateritic soil in different parts of the country, but no emphases have been laid on the behavior of lateritic soil stabilized with cement. The influence of cement on compaction characteristics of lateritic soil such as maximum dry density and optimum moisture content and also strength characteristics including CBR and unconfined compressive strength; and plasticity index of Wolayitasodo soil have not studied yet. Therefore, it was felt essential to study the properties of lateritic soils, its behavior when stabilized with cement. In addition to this, it is of paramount to know the cost benefits of cement stabilized over replacing borrow material. Thus, this study tries to fill all gaps mentioned above.

OBJECTIVE OF THE STUDY

General objective

The main objective of the study is to assess the behavior of compacted lateritic soil stabilized with cement and to evaluate cost-benefit analysis of lateritic soil stabilized with cement over selective borrow material for the construction of subgrade and sub-base course highway around WolayitaSodo town, Ethiopia.

Specific objectives

The specific objectives of the study were to:

- To determine the effect cement content on the plasticity index, the compaction characteristics, the CBR value and unconfined compressive strength of compacted lateritic soil.
- To determine the effects of curing time on the compaction characteristics, CBR value and unconfined compressive strength.
- To compare the cost of cement stabilization and selective borrows material for the study area.

Description of study area

The study area, WolayitaSodo town is located in the Southern Nations, Nationalities and Peoples Regional State (SNNPRS) within latitude N06.87237^{o} - N06.83168^{o} and longitude E037.770969^{o}- E037.75458^{o} at the entrance of the town from Shashemene and exit to Arba Minch respectively. Two trunk roads connect the town with Addis Ababa through Shashemene, 390km from Addis Ababa and through Butajera- Hossana or Butajera-Alabakulito 307 km. This study was made along the main road passing through sodo town. It is the parts of Alaba – Humbo project, measures about 6 km starting from entrance of the soda town from Shashamane (locally called Golla area) up to exit to the Arba Minch (at edges of the wolayitaSodo University). This portion of road was constructed by Keangnam ENT. Ltd and has supervised by Beza Consulting Engineers PLC. The study area was divided into three parts based the soil colors. In each area two test pits were located at distance intervals of 500m. This distance is equal to the maximum intervals already used in sampling to check quality of the existing subgrade quality by Beza consulting engineer's plc. According to (Hanna, 2008), the records from 1992 to 2007 taken from the meteorological station at WolayitaSodo town, the mean annual is 1343 mm. The rainfall season is from May to October and it has two peaks (May and August) without having a distinct dry season between the peaks. The mean annual temperature is 19.9°C and monthly values range between 17.7°C in July and 22.1°C in February and March.

MATERIALS AND RESEARCH METHODOLOGY

Materials

Characterization of the main materials used in this report is found essential to predict the necessary behavior of treated soil. This includes Portland pozzolana cement and soil.

Portland Pozzolana Cement (PPC)

The Portland pozzolana cement used in this research was manufactured by Mugher Cement Factory. The component Portland pozzolana cement listed on the company website was 5% gypsum and pumice (15% - 30%). The chemical and mineralogical compositions of Portland pozzolana cement of the Mugher Cement Factory (Table 2.1) have accepted and adopted as per analysis made by Dinku and Gudissa, 2010 (Journal of the EEA).

Table 2.1: Chemicals and Mineralogical composition of Mugher Portland Pozzolana Cement.

Chemical composition	Percentages (%)
SiO_2	22.15
Fe_2O_3	3.43
Al_2O_3	5.76
CaO	65.05
MgO	1.05
SO_3	1.04
Others	1.52
Mineralogical composition	**Percentages (%)**
C_3S	47.11
C_2S	27.96
C_3A	9.46
C_4AF	10.44

[Source, Journal of EEA. Vol. 27] (Dinku and Gudissa, 2010)

Soil

Soil which was collected from the study area was the main material for the research activities. It was to be stabilized with the Portland pozzolana cement manufactured by Mugher Cement Factory. The soil in the study area mostly consisted of red soil, has been defined as lateritic soil (Hanna, 2008). However, characterization of the soil was necessary for establishing the effect of cement stabilization, and therefore it was done by conducting various tests described in the next sections. The test pits were named and abbreviated for simplification.

Table 2.2: Test pits name and descriptions.

GP1= Golla Area Pit One	NBSP1 = New Bus Station Pit One	WSUP1= Wolayita sodo university pit one
GP2= Golla Area Pit Two	NBSP2 = New Bus Station Pit Two	WSUP2= Wolayita Sodo University Pit Two

Table 2.3: Test pits name and corresponding depth.

GP11= Golla area pit one at depth 1.5m	NBSP11= New Bus Station Pit One at depth 1.5m	WSUP11= WolayitaSodo University pit one at depth 1.5m
GP12= Golla area pit one at depth 2.5m	NBSP12= New Bus Station Pit One at depth 2.5m	WSUP12= WolayitaSodo University pit one at depth 2.5m
GP21= Golla area pit two at depth 1.5m	NBSP21= New Bus Station Pit two at depth 1.5m	WSUP21= WolayitaSodo University pit two at depth 1.5m
GP22=Golla area pit two at depth 2.5m	NBSP22= New Bus Station Pit two at depth 2.5m	WSUP22= WolayitaSodo University pit two at depth 2.5m

Twelve disturbed soil samples were collected from the study area for the accomplishment of this work. The images in the Fig. 2.1 indicate the colors of the soil specimens collected from different pits. It is observed that the soil found in test pits GP1, GP2, WSUP1, and WSUP2 were red, brown, whereas the color of the soil in a test pit no. NBSP1 and NBSP2 were brown dark (Fig. 2.2). The bonding or cementing effects between particles were observed in the test pits WSUP1 and WSUP2 and were marked with a circle (Fig 2.4)

Figure 2.1: the color of soil from GP1 and GP2 test pits.

Figure 2.2: Color of soil from NBSP1 and NBSP1 test pits.

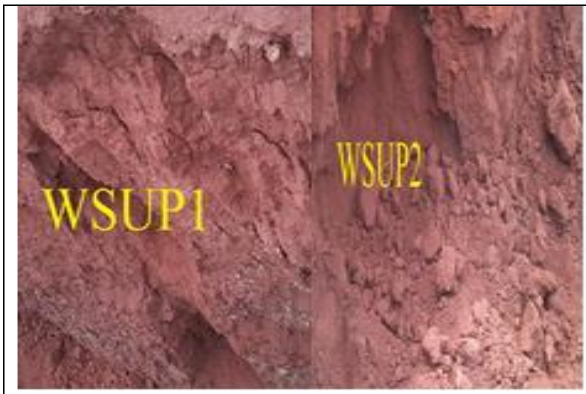
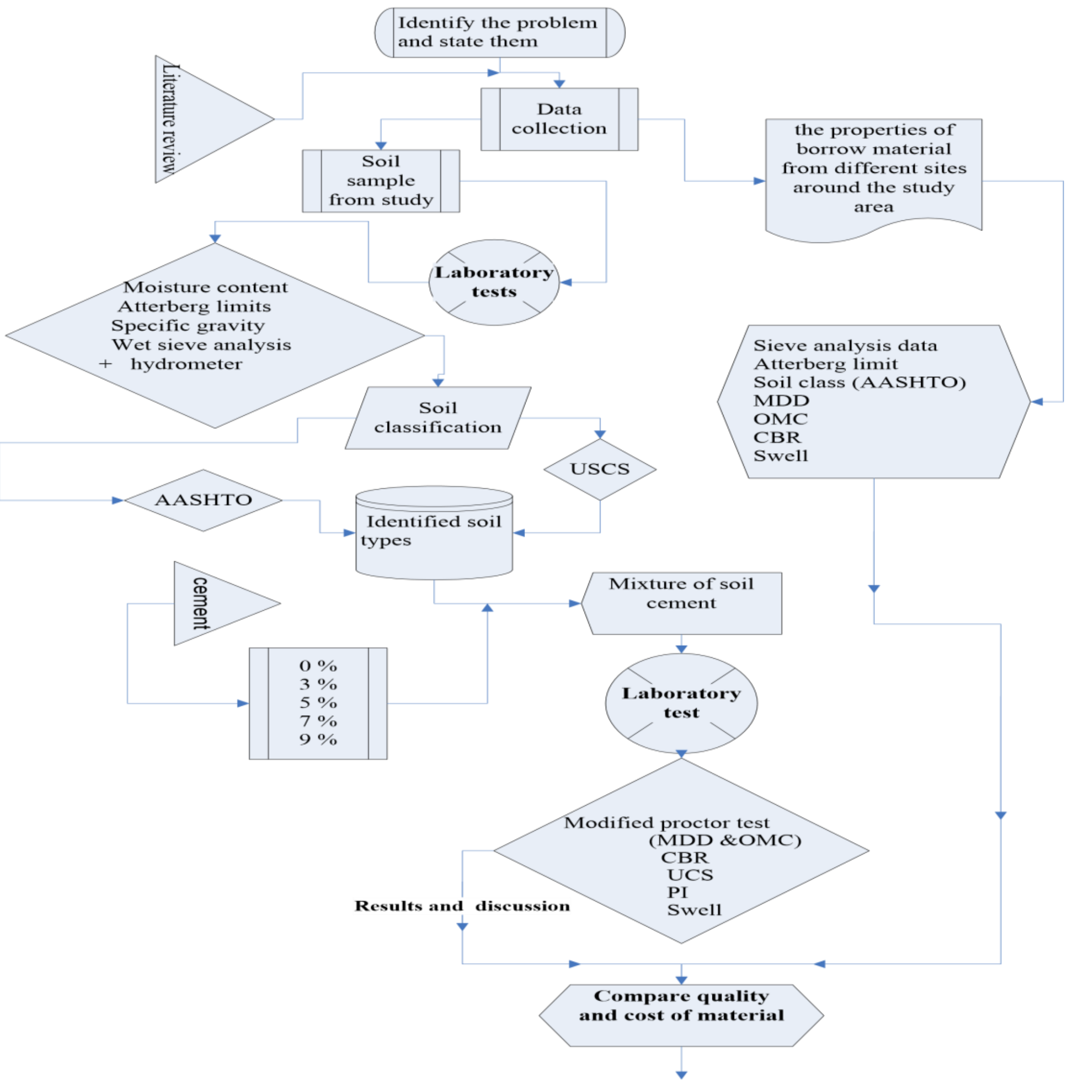


Figure 2.3: Color of soil from different pits of the study area.

Figure 2.4: a typical cemented soil observed during sampling

RESEARCH METHODOLOGY

To achieve the objective of this study, methodology adopted was presented in the flow chart (Fig. 2.5).



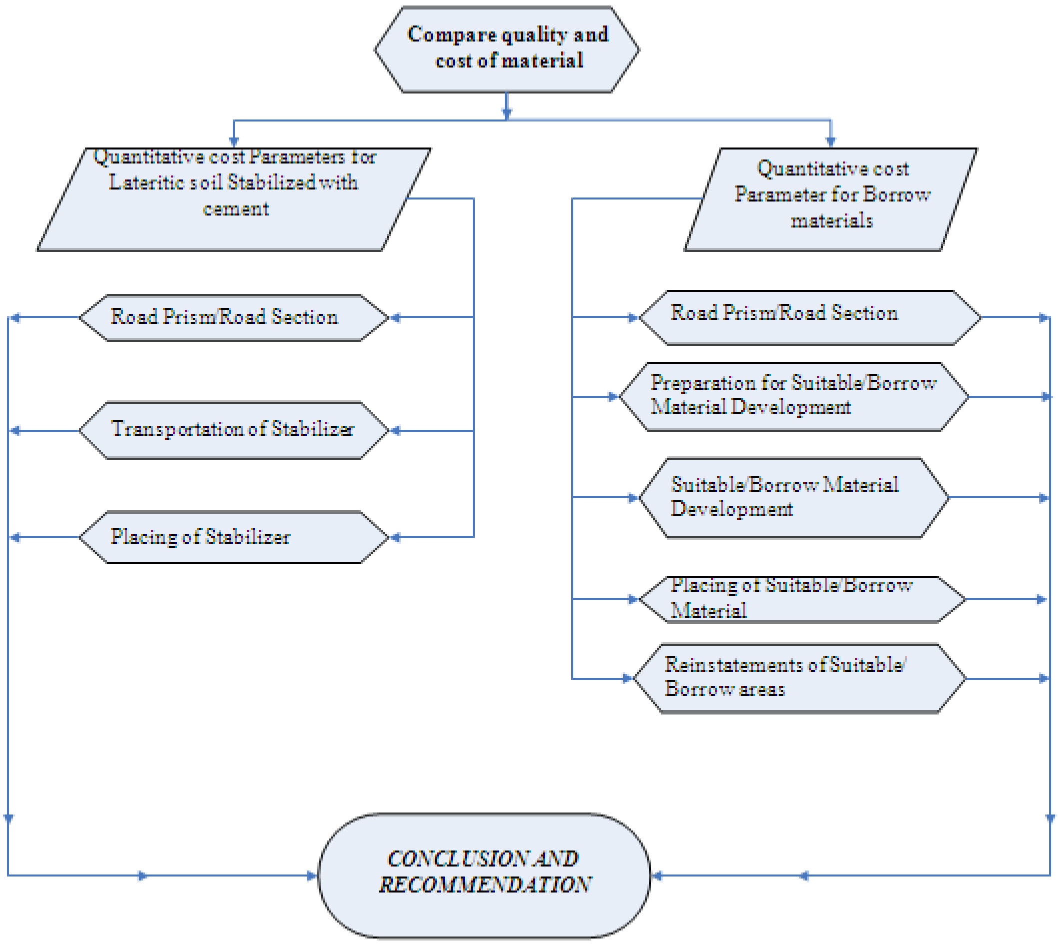


Figure 2.5: Adopted Methodology flow charts.

The laboratory tests for characterizing soil in study area

The following laboratory tests were conducted to identify the soil sample to judge its suitability for the construction of the pavement layers such subgrade, sub-bases according to AASHTO classification. Moisture Content determination (ASTM D 2216-98) Oven-drying methods were used to in all laboratory tests for determining the moisture contents. The various tests which needed the determination of water content included Atterberg limits and modified compaction tests, i.e., Liquid limit, plastic limits and optimum moisture content of soil samples.

Specific gravity determination (ASTM D 854 – 14)

The Specific gravity of soil solids passing sieve No.4 was determined by pycnometer of a capacity of 200 ml. The samples used for this test were air dried. The specific gravity was calculated by

$$G_S = \frac{(W_{PS}-W_P)}{((W_A-W_P)-(W_{PS}-W_P)} \quad \text{Where,} \quad G_S = \text{specific gravity}$$

W_p = mass of empty, clean pycnometer (grams)

W_{PS} = mass of empty pycnometer + mass of dry soil (grams)

W_B = Mass of pycnometer + dry soil + water (grams)

W_A = Mass of pycnometer + water (grams)

Particle Size Distribution (ASTM D 422-63)

Wet sieve analysis was performed on 1000 grams of air-dry soil specimen. The soil specimens consisted of flocculated particles, and therefore these were placed in water for a minimum period of 18 hours for deflocculating. Each sample was then washed on the sieve No. 200 to separate the course from fine fraction until clean water started coming out. Both fractions, i.e., + and – 200 mm sieve contents, were placed in an oven for drying. Sieve analysis was carried out on the coarse fraction. The sieve size used for this test included 9.5mm, 4.75mm, 2.36mm, 1.18mm, 0.6mm, 0.3mm, 0.15mm and 0.075mm. Hydrometer analysis was performed in assessing the quantities of silt and clay in the fine fraction for each soil specimen.

Atterberg Limits (ASTM D 4318-00)

Atterberg limits of lateritic soil under study were determined on air dried, and oven dried samples treating them as tropical soils. Samples collected from the study area were spread in a thin layer in open air for a considerable period, but not less than two days to dry. Casagrande liquid limit apparatus was used for the determination of liquid limit on soil samples passing sieve No.10. However, the specimen mixed with a suitable quantity of water was kept for 16 hours to mature and then used for liquid determination. A plastic limit was also determined on samples passing No.10 sieve and well matured. A limited quantity of well-matured soil specimen was used to roll into threads of 3 mm diameter. The plasticity index was then computed for each soil based on the values obtained from the liquid and plastic limit. The liquid limit and plasticity index was utilized to classify each soil.

Soil Classification (ASTM D 2487-06 and ASTM D3282-09)

For the soil classification of soil, AASHTO and USCS were adopted because AASTO is widely used in highway engineering and USCS is equally widely is used for general engineering purposes. Both the classification systems are based on the particle-size distribution and Atterberg limits. Both systems divide the soils into two major categories, coarse grained and fine grained, as separated by the No. 200 sieve. According to the AASHTO system, the soil is considered fine-grained when more than 35% passes through the

No. 200 sieve. According to the USCS, soil is considered fine-grained when more than 50% passes through the No. 200 sieve. Both the systems have developed their charts for the demarcation of soil in various zones which have been used in this study.

Comparative study of original soil and treated soil with cement

Sample preparation

Lateritic soil available in the study area was not competent for the construction of good quality of pavement layers and therefore traditionally, it was being replaced by another soil of better engineering properties. It was therefore thought to study the soil as it was and with Portland pozzolana cement treatment. Air dried lateritic soil were sieved through the sieve No.4 (4.75mm) to remove courser particles, then mixed with different cement contents 3%, 5%, 7% and 9 % by dry weight percentages.

The procedures followed in all the preparation of mixture as follows

Suitable quantities of air dry lateritic soils were measured for conducting of each of the tests i.e. modified proctor test, CBR, UCS tests. Specified cement amount was uniformly spread on the dry soil sample and each mix was thoroughly mixed by hand till a uniform mixture of color appeared. Soil samples proposed for Modified Proctor test were mixed with a suitable quantity of water based on the dry weight of the sample taking 8%, 16%, 24%, 32%, and 40% as percentages of water to be added so as to find the amount of optimum water content which could be corresponding to the maximum dry density. The wet samples so mixed with cement were placed in airtight plastic bags for curing period of 2 hours on the first day, then 7, 14 and 28 days at room temperature. The moisture contents were checked daily or as required and the mixed soil cement agitated to prevent flocculation of the clay particles. Cement mixed lateritic soil was compacted at modifying proctor test densities as per ASTM D1557 – 12 after curing periods of 2 hours, 7, 14 and 28 days to study the effect of curing period on the maximum dry density and optimum moisture content. Similar procedure for the preparation of soil-cement specimens were adopted for other tests too i.e., CBR and UCS tests. These tests were, however conducted on optimum moisture content and dry density was confirmed after each test.

Laboratory tests on untreated and cement treated lateritic soil

The procedure adopted for conducting the compaction test, CBR and UCS tests on soil and treated-lateritic soil are discussed in the following sub-sections. The untreated and cement treated lateritic soil was compacted by the same energy as was used while compacting the soil specimen in the Modified Proctor test to achieve maximum dry density and optimum moisture content to study the relative effects of percentages of Portland pozzolana cement on the lateritic soil. Similar studies were made in case of CBR and UCS tests, effects of curing period are also studied.

Compaction proctor test (ASTM D1557 – 12)

Soil samples of each untreated and treated soil at different percentage of cement were subjected to modified Proctor compaction tests to determine the maximum dry density and optimum moisture content. For thus, air-dried soil sample passing through sieve No. 4 were mixed with cement, as described in section 3.4.1. All Modified Proctor Compaction tests were performed by the standard (ASTM 1557). The soil at selected molding water content was compacted in five layers into a mold of 150 mm diameter, with each layer compacted by 56 blows of a 44.48-N rammer dropping from a height of 457.2 mm, subjecting the soil to a total compactive effort of about 2700 KN-m/m^3. The resulting dry unit weight was determined. The procedure is repeated for a sufficient number of molding water contents to establish a relationship between the dry unit weight and the molding water content in the soil. Fig. 2.6 shows one such typical soil sample obtained while conducting modified Proctor tests

Figure 2.6: Typical compacted soil sample.

Unconfined compression strength test (ASTM D2166M – 13)

Remolded specimens were prepared in the cylindrical molds of 38 mm diameter and 88mm height at the optimum moisture content. Dry density so obtained was within a minimum variation of achievement in modified Proctor tests. It is emphasized that accuracy was maintained in almost all the tests.

Each specimen so prepared was tested in unconfined compression testing machine using a strain rate of approximately 1.27 percent per minute. Typical cylindrical soil specimens and testing machine are shown in Fig. 2.7 (a) and (b). A data acquisition system was used to record the applied load and deformation. Corrections to the cross-sectional area were applied before calculating the compressive stress on the specimen.

Each specimen was loaded until a sample was failed. Figures 2.7 (c) and 2.7 (d) shows the typical failed soil sample and their failure patterns.

Figure 2.7: Samples prepared for UCS, and typical failure patterns.

California bearing ratio test (ASTM D1883 - 07)

The untreated and cement treated lateritic soil were compacted into a CBR molded in five equal layers, applying 56 blows of a 44.48-N rammer dropped from a height of 457.2 mm, subjecting the soil to a total compactive effort of about 2700 KN-m/m^3, then soaked four days. Figure 2.8, shows a typical sample of soaking in the water bath. A collar was added to the top of the specimen, and a perforated base plate was attached to the bottom to allow the ingress of water. The water level was kept just below the top of the collar. After this, the instrument of a soaking tank was set up. The initial reading was taken immediately after the placement of the mold in the water bath, and the final reading was recorded over four days of soaking. The soil and mold were taken out of the water and drained for 15minutes.The soil and mold were mounted on the CBR machine and tested as per ASTM D1883-07.

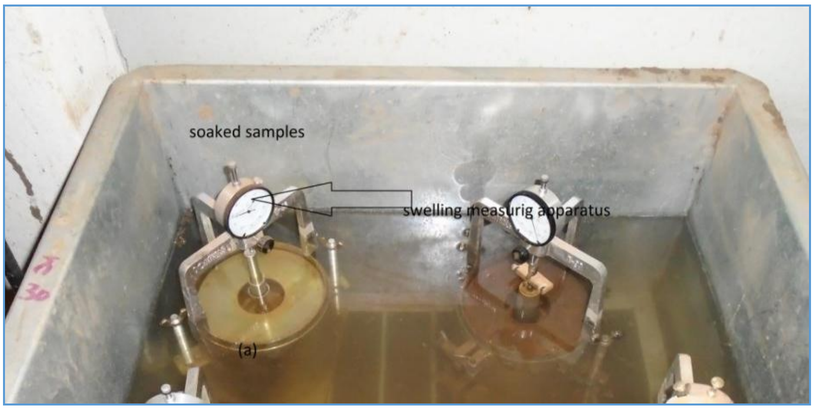


Figure 2.8: Typical samples under soaking before the CBR test.

RESULTS AND DISCUSSION

Validity of the Test Results

Before going to characterize the soil used in this study, the validity of the laboratory test results was verified. In every case, a minimum of three tests was conducted to check the variation between them, and then the average value was taken.

Specific gravity

The specific gravity values obtained from pycnometer test vary from 2.65 to 2.79 (table 3.1). The higher value of specific gravity of some soil specimens indicated that the soil in study area consisted of heavy material. These findings, to a great extent, was in agreement with the findings of (Hanna, 2008) who reported the specific gravity of Wolayitasodo soils varying from 2.61 to 2.97. Hanna on the basis of her studies reported that the soil under study was lateritic soils and therefore it could be inferred that the specific gravity could be higher due to the iron contents of the soil.

Table 3.1: Average specific gravity values of different pit tests.

Test pits	**GP1**	**GP2**	**NBSP1**	**NBSP2**	**WSUP1**	**WSUP2**
Average specific gravity	2.79	2.72	2.65	2.69	2.74	2.76

Particle size analysis

The data obtained from sieve and hydrometer tests for all the samples were plotted on the semi-log graphs as given in Fig 3.1. Contents of sand, silt and clay was determined for each sample (Table 3.2) according to the sizes prescribed in AASHTO, USCS and lateritic soil classifications as follows:

- According to USCS as Gravel (75mm - 4.75mm), Sand (4.75mm - 0.075mm), Silt (0.075mm - 0.002mm) and Clay < 0.002mm
- According to AASHO as Gravel (> 2mm), Sand (2mm - 0.05mm), Silt (0.05mm - 0.002mm), and Clay < 0.002mm.
- According Lateritic classification (Lyon, 1971), as clay (< 0.002mm), Lateritic silts (0.002mm- 0.06mm), Lateritic sand (0.06mm- 2mm), Lateritic gravel (2mm-60mm and coarser > 60mm. This study indicates that the percentage passing 200 (0.075mm) sieve varied from 63.2% - 87.05% for different soil specimens. From these results, it can be inferred that soil in the entire study area consisted of fine-grained soil with fine fractions more than 50% passing 200 (0. 075mm) sieve.

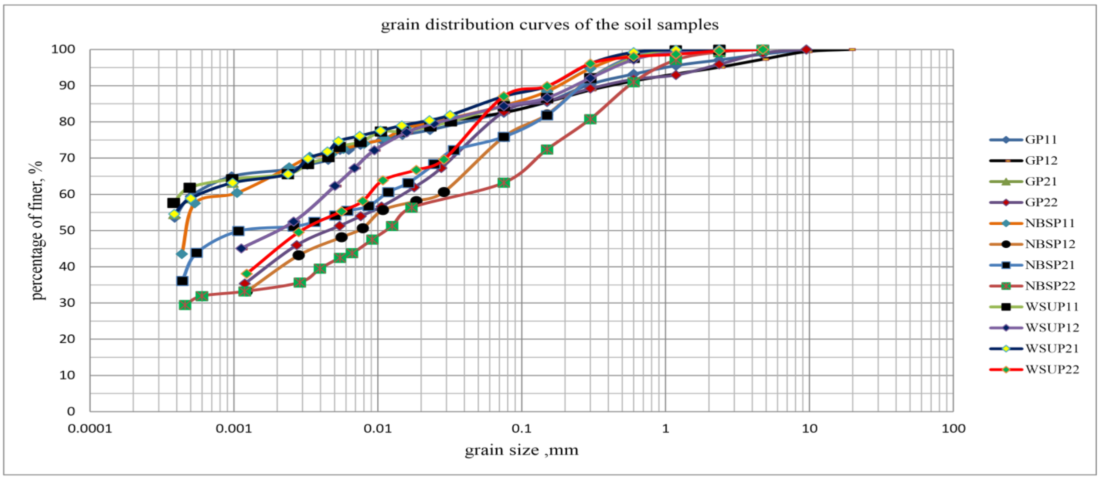


Figure 3.1: Grain Size distribution curve of the samples.

Table 3.2: Percentage amount of the gravel, sand, silt, and clay each sample by different classification systems.

Test Pits	Classification according to	The percentage amount of Particle Sizes			% Clay
		% gravel	% Sand	% silt	
GP11	Lateritic	3.37	15.46	14.80	66.37
	AASHTO	3.37	16.37	13.89	66.37
	USCS	1.30	16.15	15.75	66.37
GP12	Lateritic	5.47	12.88	32.88	48.76
	AASHTO	5.47	13.84	32.29	48.76
	USCS	2.70	14.53	33.79	48.76
GP21	Lateritic	4.28	15.65	36.62	43.45
	AASHTO	4.28	17.45	34.82	43.45
	USCS	0.60	16.63	39.92	43.45
GP22	Lateritic	5.01	17.18	37.13	40.68
	AASHTO	5.01	20.47	33.84	40.68
	USCS	1.00	16.23	42.09	40.68
NBSP11	Lateritic	0.03	16.67	15.85	67.45
	AASHTO	0.03	17.46	15.06	67.45
	USCS	0.00	15.5	17.05	67.45
NBSP12	Lateritic	0.17	28.93	32.70	38.19
	AASHTO	0.17	32.24	29.40	38.19
	USCS	0.00	24.15	37.66	38.19
NBSP21	Lateritic	0.28	25.20	24.03	50.49
	AASHTO	0.28	26.09	23.14	50.49
	USCS	0.00	24.15	25.36	50.49
NBSP22	Lateritic	1.34	37.24	26.97	34.45
	AASHTO	1.34	38.42	25.79	34.45
	USCS	0.00	36.81	28.74	34.45
WSUP11	Lateritic	0.08	17.04	17.30	65.58
	AASHTO	0.08	18.03	16.31	65.58
	USCS	0.00	15.65	18.77	65.58
WSUP12	Lateritic	0.48	16.61	34.15	48.76
	AASHTO	0.48	17.57	33.19	48.76
	USCS	0.00	15.65	35.59	48.76
WSUP21	Lateritic	0.03	14.72	19.65	65.60
	AASHTO	0.03	15.91	18.46	65.60
	USCS	0.00	12.95	21.45	65.60
WSUP22	Lateritic	0.74	17.90	37.58	43.78
	AASHTO	0.74	21.70	33.78	43.78
	USCS	0.00	12.95	43.27	43.78

Atterberg Limits and Plasticity Charts

Atterberg limits tests were done in an air-dried and oven- dried specimens with the concepts to study the effect of temperature on Atterberg's limits of soils under study. The test results are summarized in table 3.3. The data regarding the liquid limit indicate the variation of LL ranges from 56 to 67 % and those of plasticity index varied from 22 to 29 % for air-dried specimens. The corresponding values for oven-dried specimens were found to be in the range from 51- 59 % and 19- 25 % respectively. These data further indicate that LL of soil specimens was smaller than those obtained from air-dried specimens. However, the differences in the values of liquid limit of the oven- and air-dried specimens were less than 4%. It can be inferred that the Atterberg limit tests can be conducted in either condition as per convenience.

Table 3.3: Atterberg's limit test results of different pits under oven and air dried condition.

Air-dried Soil Specimens			Oven-dried Soil Specimens	
Test Pits	**LL (%)**	**PI (%)**	**LL (%)**	**PI (%)**
GP11	62	26	55	19
GP12	58	23	54	22
GP21	56	22	52	20
GP22	60	24	57	22
NBSP11	66	25	59	21
NBSP12	56	25	51	20
NBSP21	57	25	52	22
NBSP22	56	26	51	24
WSUP11	67	29	58	25
WSUP12	56	24	52	24
WSUP21	64	28	59	23
WSUP22	56	28	51	23

Figures 4.3 and 4.4 show that the Casagrande classification charts of the soils samples collected from the study area for both air-dried and oven- dried specimens. Data concerning to LL and PI were plotted on Casagrande plasticity chart. All specimens are located below the Aline which indicated that the soil in the study area consisted of silt. However, the particle size 33, analysis indicated the soil specimens were dominated by clay contents (Table 4.4). X-ray study by Hanna (2008) reported that the Wolayita sodo soil consisted of Kaolinite. Chart produced by Morin and Todor (1976), Fig. 3.2, indicates that Kaolinite though it is clay, but occupies its place under A-line. The same is found true in the soil under study. The soil under study was therefore classified according to USCS as MH (table 4.4). Also, as the specifications of AASHTO, the soil could be designated as a group A-7 with subgroup A-7-5. Group index is another measure of a quality of soil in AASHTO classification. It is described

by the following equation

GI= (F- 35) [0.2+0.005 (LL - 40)] + 0.01 (F-15) (PI-10)

Where F is the percent passing No.200 sieve. Other notations are usual. According to group index, the suitability of the subgrade is judged by its value. Higher the value of group index, lower will be the quality of the soil as subgrade material. The values of group indices are presented in Table 4.4. From the data presented, it is found that group indices in the soil specimens varied from 19 to 28. Any value equal to 20 or more indicates that the soil subgrade is related to poor quality. By these data, the soil in study area consisting of lateritic soil can be placed in the category of 'fair to poor quality.' This might be the reason that lateritic soil in the study area was replaced by selective borrows material to provide stable subgrade and sub-base materials.

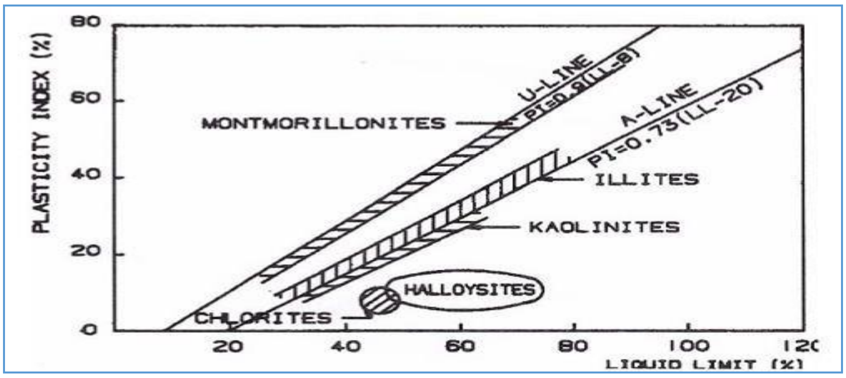


Figure 3.2: Location of common clay minerals on Casagrande plasticity chart (Morin and Todor, 1976).

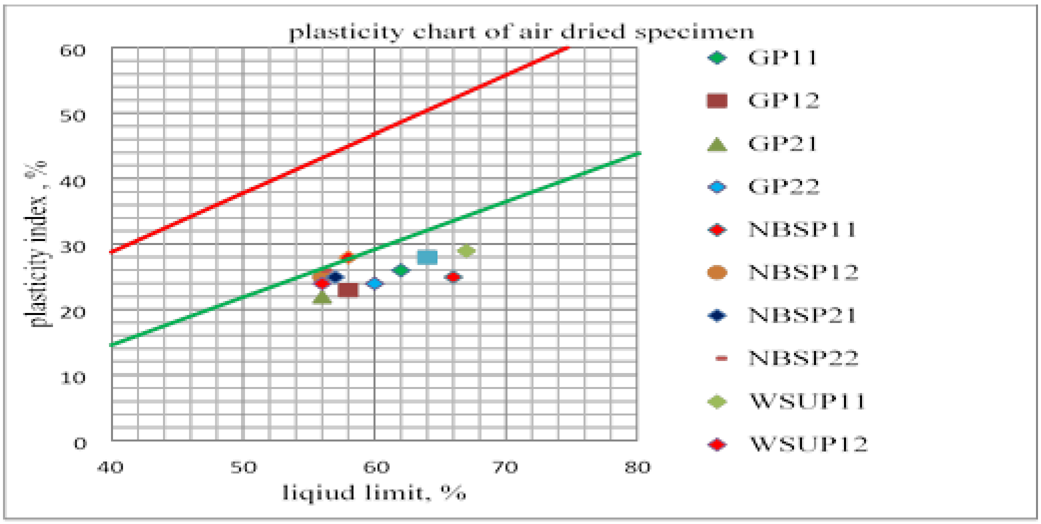


Figure 3.3: Plasticity charts of oven dried soil samples

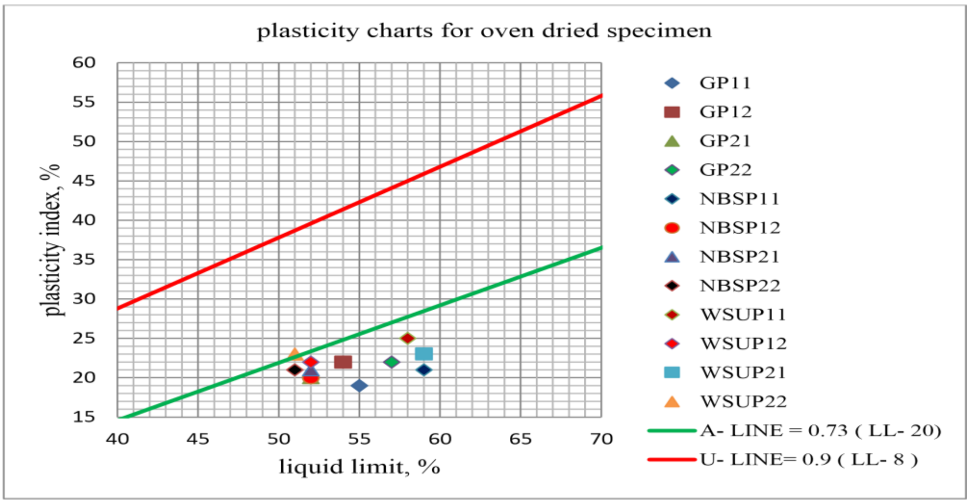


Figure 3.4: Plasticity charts for air-dried soil samples.

Effects of Cement on the Compacted Behavior of Lateritic Soil

To evaluate the effects of cement, on the compacted behavior of lateritic soil from the study area, modified Proctor test, CBR and UCS laboratory tests were performed on soil specimens, and cement treated mixes. Atterberg limit tests were also conducted in the similar conditions to study the behavior of cement stabilization on the plastic nature of the soil. However, as the soil in the entire study area was found to be same, i.e., MH as per USCS, the variation in various characteristics of soil treated mixes concerning location of pits was not considered. The study made concerning various tests is presented in the following sub-sections.

Effects Cement on the Atterberg's Limits

Data related to the Atterberg Limits, obtained from untreated soil and cement-treated soil mixes are presented in Table 3.3, Fig. 3.4 and 3.5. It was observed from these data that liquid limit of the cement stabilized lateritic soil slightly decreases with cement content, whereas the plastic limit increases gradually with the cement content. The addition of 3%, 5%, 7% and 9% cement to lateritic soil decreased the liquid limit by 45%, 43 %, 41% and 40 % respectively. The corresponding values of plastic limits obtained were 29% to 32%, 34%, 35% and 35%. Reduction in the plasticity index was observed from 28% for a soil to 12%, 4 % and non-plastic for cement mixes. This change of Atterberg limit is due to the cation exchange reaction and flocculation–aggregation for the presence of more amount of cement, which reduces the amount of clay fraction in the soils that control the plasticity index of soil (Afolagboye L. O &Talabi, 2014). The data of Atterberg limit tests on cement-treated soils, if plotted on Casagrande plasticity chart, fall on the left side of the vertical line indicating LL=50%. It is stated that the soil after cement treatment converted into the Non-Plastic material. These results are in agreement with the results reported by Oyediran (2011) on the stabilization of lateritic by cement.

Table 3.4: Typical Atterberg's limits test results of untreated and treated with different cement contents.

	Soil specimen 1		
Cement content, %	**Liquid limit**	**Plastic limit**	**Plasticity index**
0	56	32	24
3	45	38	7
5	42	39	3
7	41	40	1
9	40	40	0
	soil specimen 2		
cement content,%	**liquid limit**	**plastic limit**	**plasticity index**
0	57	33	24
3	45	37	8
5	43	39	4
7	41	40	0
9	40	40	0
	soil specimen 3		
cement content, %	**liquid limit**	**plastic limit**	**plasticity index**
0	58	32	26
3	48	37	11
5	45	40	5
7	44	42	2
9	41	41	0

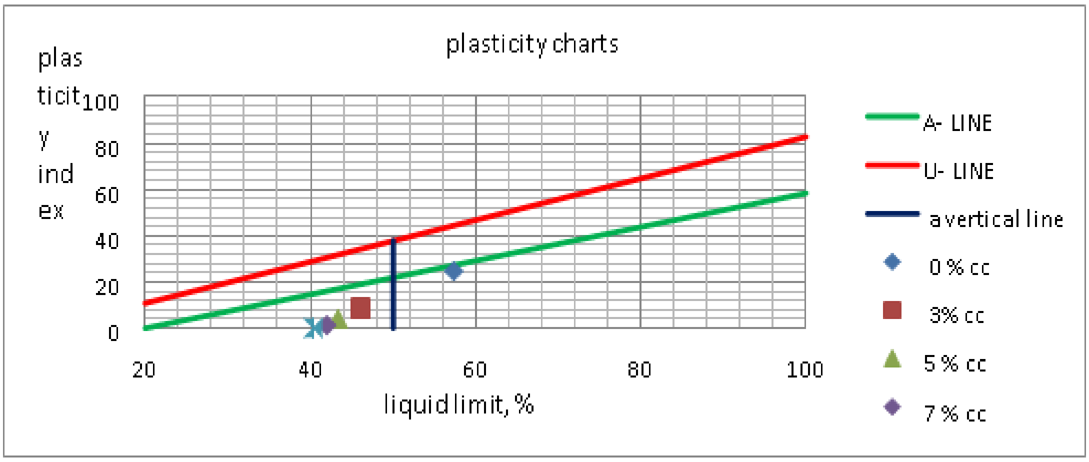


Figure 3.5: Typical Variation of LL and PL with cement content.

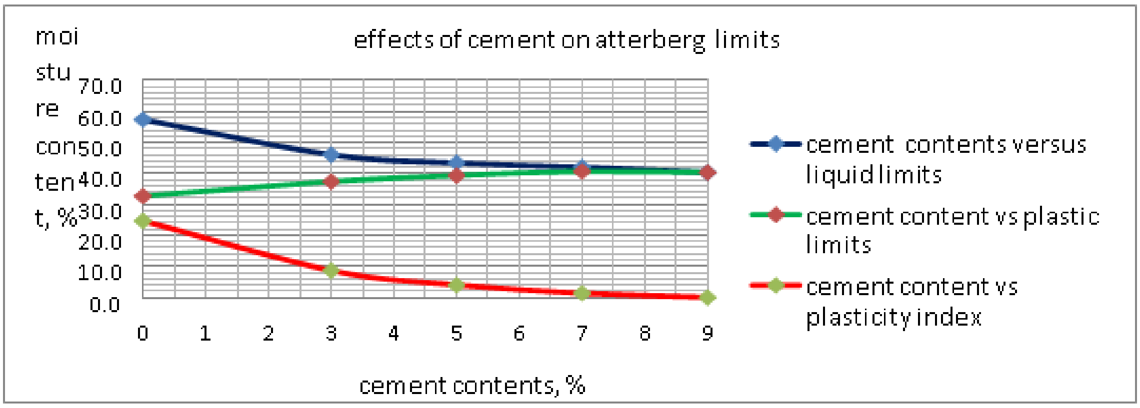


Figure 3.6: Typical effect of cement on the location, soil sample within the Plasticity charts.

Effect of Cement on Compaction Characteristics

The effect of cement on soil was studied through the Modified Proctor tests. The variation in results related to dry density and water content for different curing period 2hr, 7, 14 and 28 days are presented in Fig. 3.7, 3.8 and 3.9, respectively to describe the relation between moisture contents and dry density. As shown in the Fig. 3.7, for the samples curing for 2hrs, an increase in the maximum dry density by 1.95% to 2.55%, when cement content increased from 0 to 5%. As shown in Fig. 3.10 the pattern of increases in MDD is up to a certain point with the increase in cement content. Therefore, it was observed that MDD increased slightly by 0.6% when cement content increased from 5% to 7%. The value of MDD decreased by 0.5% as cement content was 9% of those samples tested on the first day. Almost similar patterns in the variation of MDD was observed when the samples were tested at curing periods of 7, 14 and 28 days. However, percentage variation was different. The values of optimum moisture content were found in decreasing order by 20% as cement content increased from 0% to 9 % (Fig. 3.11). The overall effects of cement on the Maximum Dry Density was a 6 % increase as cement content increased from 0% (untreated) to treat by 7 % of cement content, then it decreased by a very low margin. This is in agreement with the results reported by(F.H.M. Portelinha, 2012)‘‘Lateritic soil-cement mixtures showed higher values of maximum dry unit weight than the untreated soil" and (Oyediran, 2011), also reported that as cement content increases MDD increases up to a certain point then decreases, whereas the OMC value is vice versa. The reduction in maximum dry density is a result of flocculation and agglomeration of fine-grained soil particles which occupies a larger space leading to a corresponding drop in maximum dry density. It is also the result of the initial coating of soils of cement to form a larger aggregate, which consequently occupies larger spaces.The MDD and OMC for the samples cured up to 28 days are shown in table 3.5. It is observed that the curing effects were marginal on the compaction characteristics of lateritic soil with cement and the patterns of change with parameters are shown in figures 3.12 and 3.13 for 2hrs, 7, 14 and 28 curing period. The curves of moisture- density relation follow the same patterns for the cement content at different curing period. Changes were observed in the shapes of the curves for the samples cured for 28 days; they are sharps (bell-shaped) than the others.

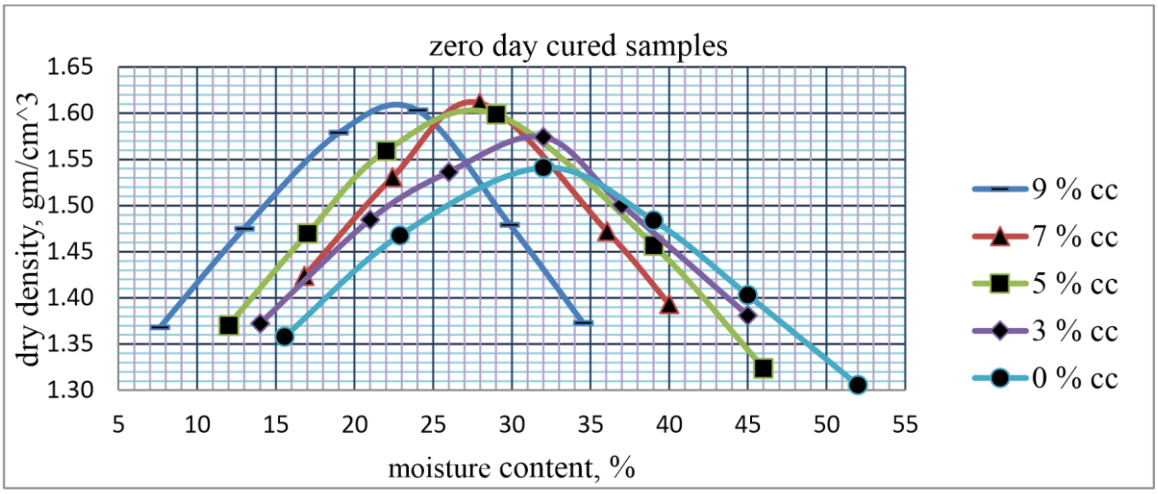


Figure 3.7: Moisture – density curves of untreated and cement treated by different percentages of lateritic soil cured for 2hrs.

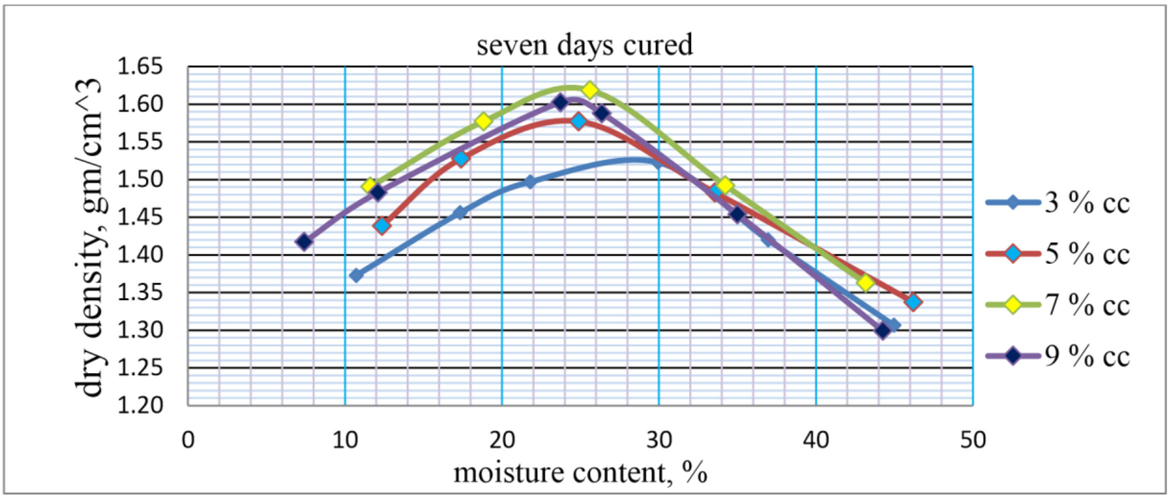


Figure 3.8: Moisture – density curves of cement treated the lateritic soil with seven-day curing.

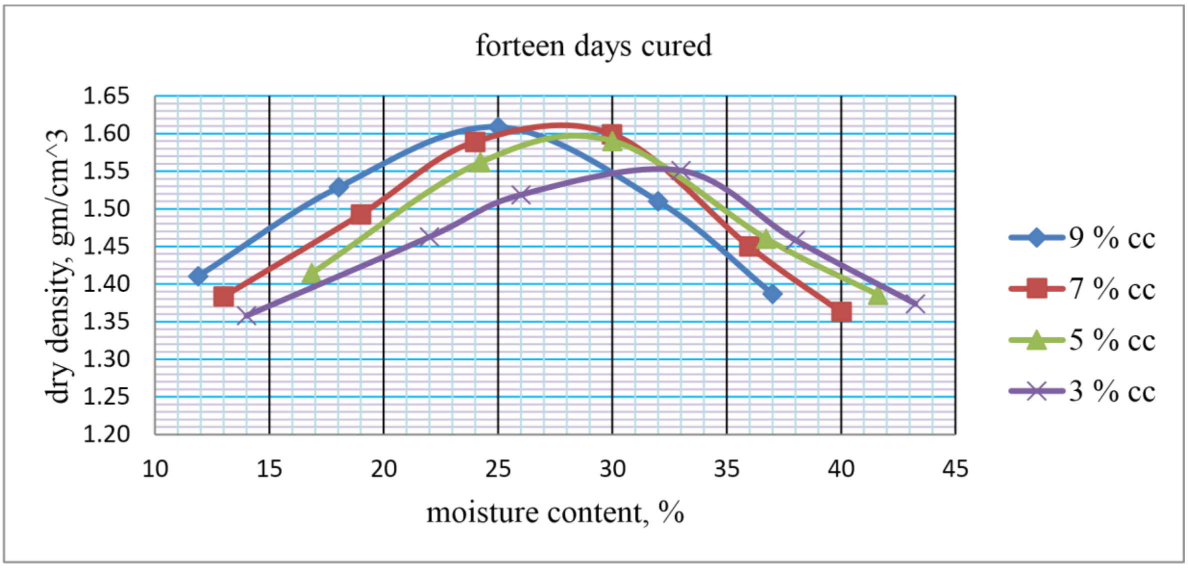


Figure 3.9: Moisture- density curves of cement treated lateritic soil cured for 14 days.

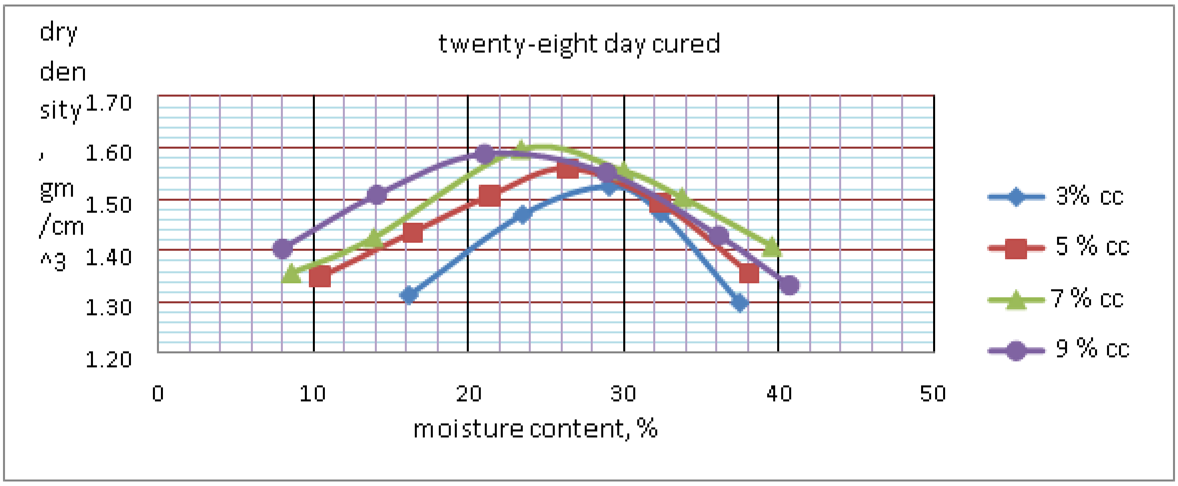


Figure 3.10: Moisture- density curves cement treated lateritic soil cured for 28 days.

Table 3.5: typical MDD and OMC for different curing periods.

Curing for 2hrs			Cured for 7 days		Cured for 14 days		Cured for 28 days	
CC	**MDD**	**OMC**	**MDD**	**OMC**	**MDD**	**OMC**	**MDD**	**OMC**
0	1.545	32	1.545	32	1.545	32	1.545	32
3	1.58	32	1.535	31	1.565	31	1.535	29
5	1.605	27.5	1.58	27	1.6	26	1.565	25
7	1.615	25	1.625	24	1.615	24	1.605	22
9	1.608	24	1.61	23	1.61	22	1.595	22

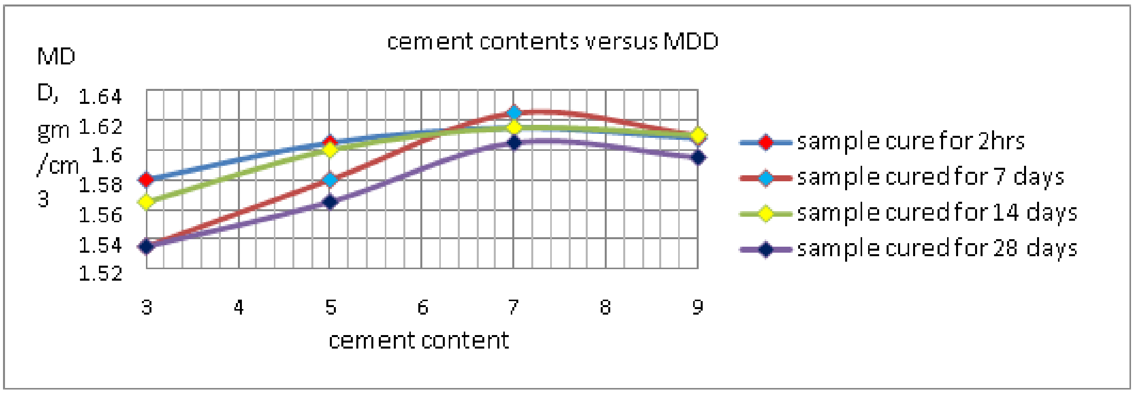


Figure 3.11: Typical increments patterns of MMD with cement content at different curing period.

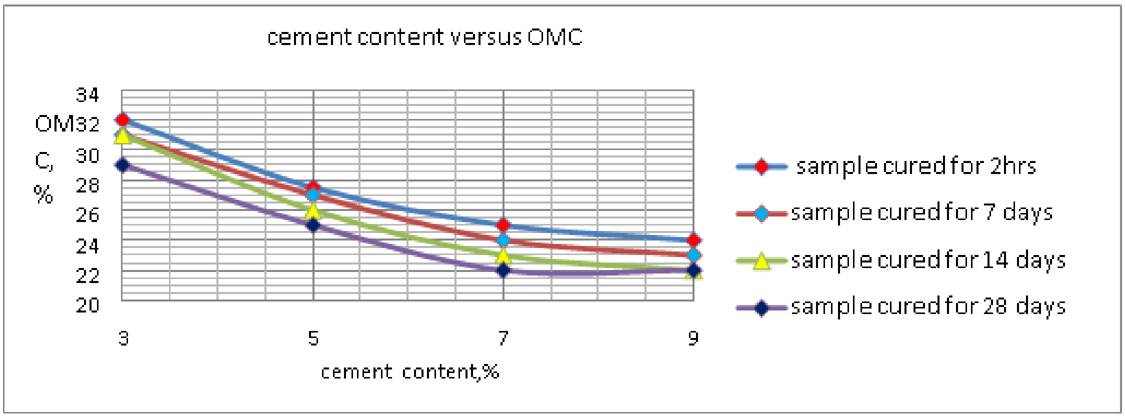


Figure 3.12: Typical decrement patterns of OMC with cement content at different curing period.

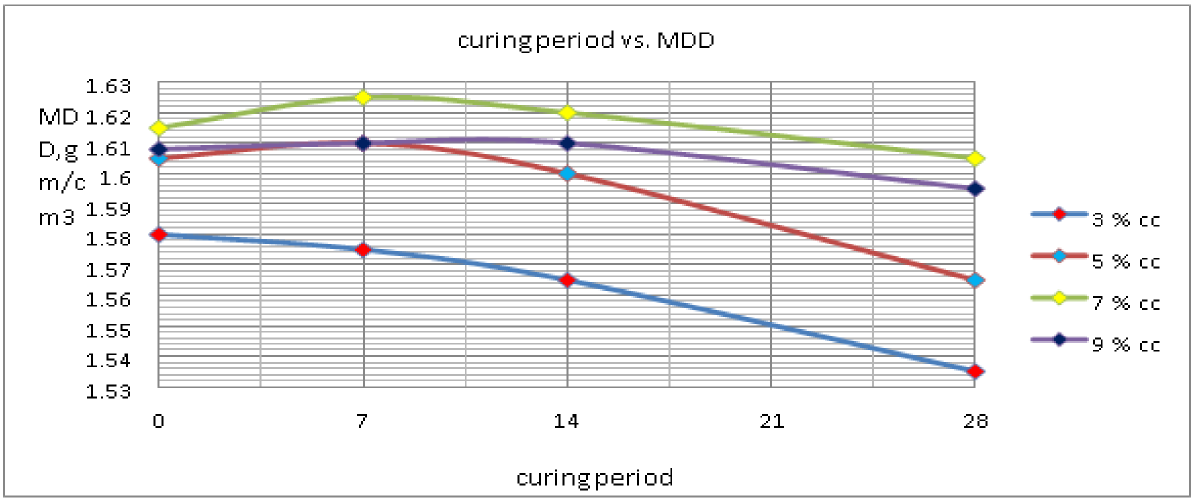


Figure 3.13: Typical change patterns in MDD with curing period

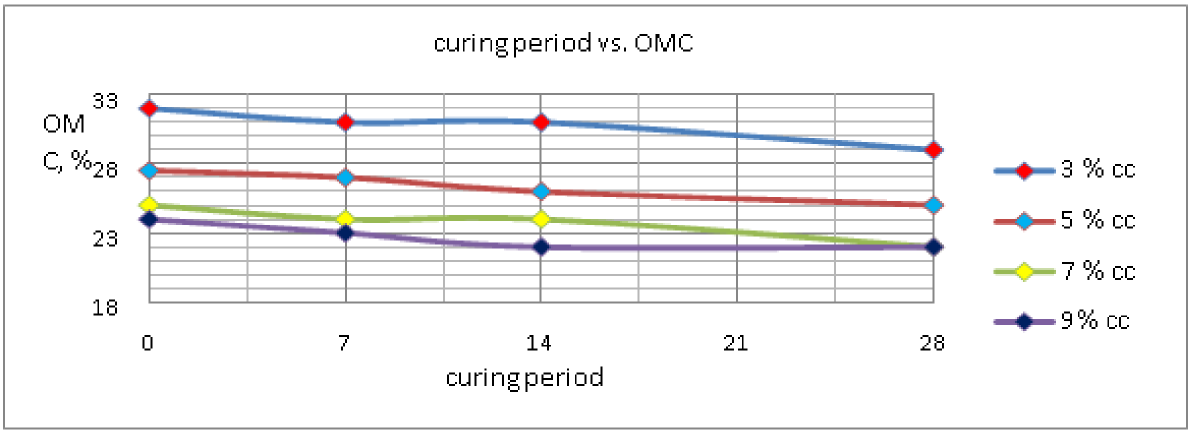


Figure 3.14: Typical change patterns of OMC with curing period.

Effects of Cement on CBR value

The CBR value of untreated soil collected from Wolayita sodo are compacted at optimum water as determined by modified proctor test. The maximum density so achieved was determined and found to be almost equal to that obtained by Modified Proctor test. The penetrations versus load data were generated during the load application through a plunger to the specimen which was given in Fig. 3.14 to 3.18. CBR values were calculated corresponding to 2.54 mm penetration and are presented in table 3.6. The values of CBR for untreated soil varied in the range of 3.4 % to 4 %. It indicated that the soil had very low values of CBR and therefore it was not suitable for the highway pavements.

This was another reason for its replacement by another good soil. The CBR values of cement treated soil samples as given in Table 3.6 indicated an increase in its value from 3.4% for the untreated soil to 71.6% when the soil was treated with 9 % of cement. CBR values constantly increased with the increase in cement contents (Fig. 3.19). Whatsoever, the effect of curing on CBR values of treated soils was found insignificant (Fig 3.20). These data indicated the effectiveness of cement stabilization for lateritic soil found in Wolayitasodo.

However, for economic considerations, it was thought proper to select 5% of cement for stabilization of this soil. The CBR value corresponding to this cement content was achieved at 46.3%, which was considered to be sufficient for designing pavement for this road.

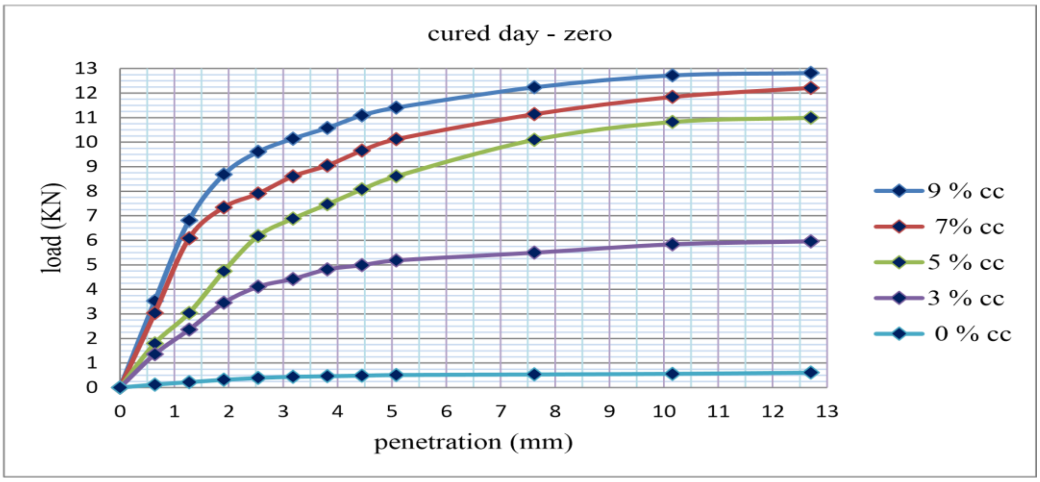


Figure 3.15: Penetration vs. load curves of untreated and treated specimen cured two 2 hours.

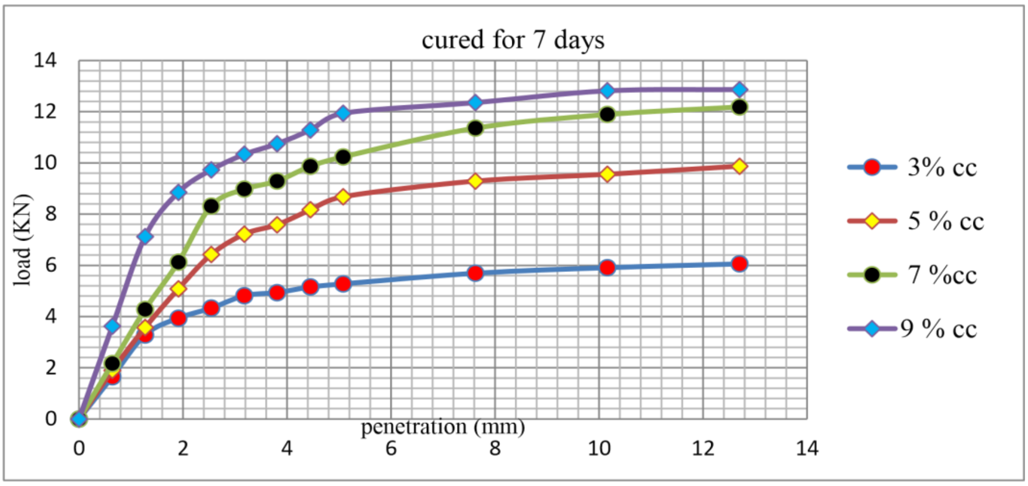


Figure 3.16: Penetration vs. load curves of CBR test specimen cured for 7 days.

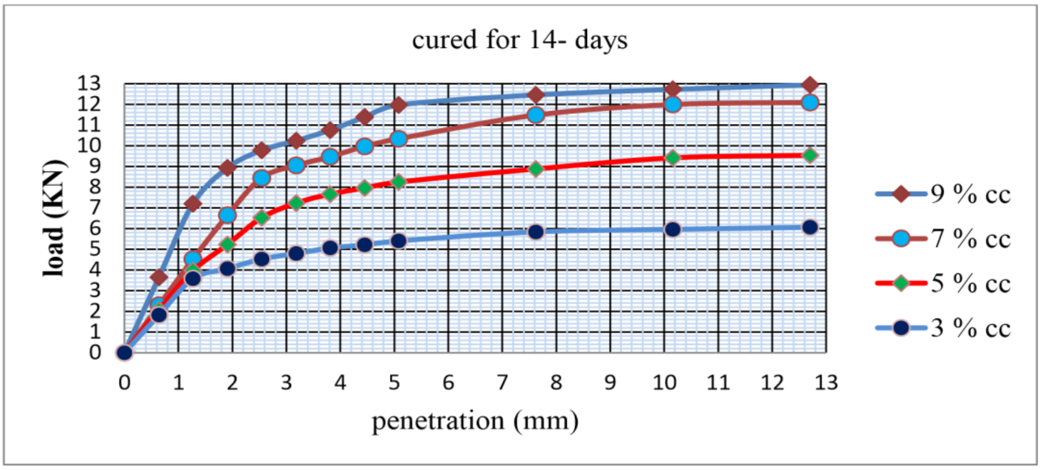


Figure 3.17: Penetration vs. load curves of CBR test specimen cured for 14 days.

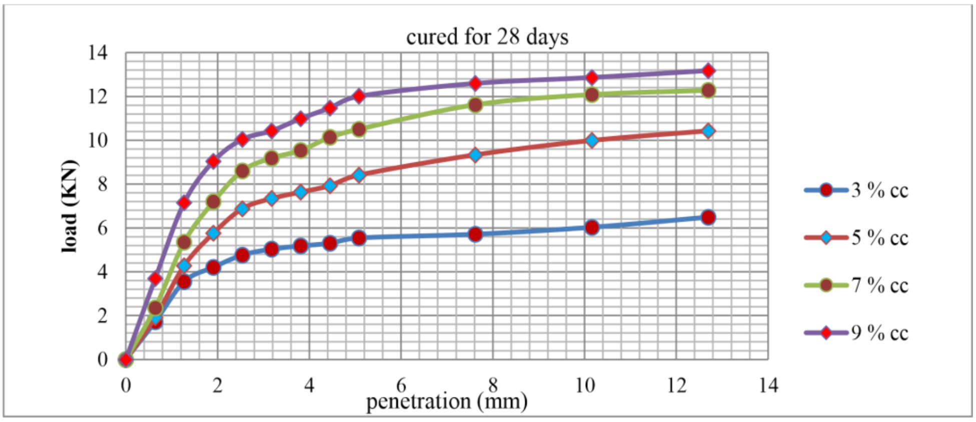


Figure 3.18: Penetration vs. load curves of CBR test specimen cured for 14 days.

Table 3.6: A typical CBR value on the first days.

Sample type	MDD gm/cm^3	OMC (%)	CBR at 2.54mm	CBR at 5.08 mm	Swell (%)
Untreated (0 % cc)	1.48	32	3.4	3.4	1.11
Treated with 3% cc	1.56	30	30.6	26	0.86
Treated with 5% cc	1.61	25	46.3	43	0.52
Treated with 7% cc	1.62	23	59	50.5	0.21
Treated with 9% cc	1.61	23	71.6	57	0.06

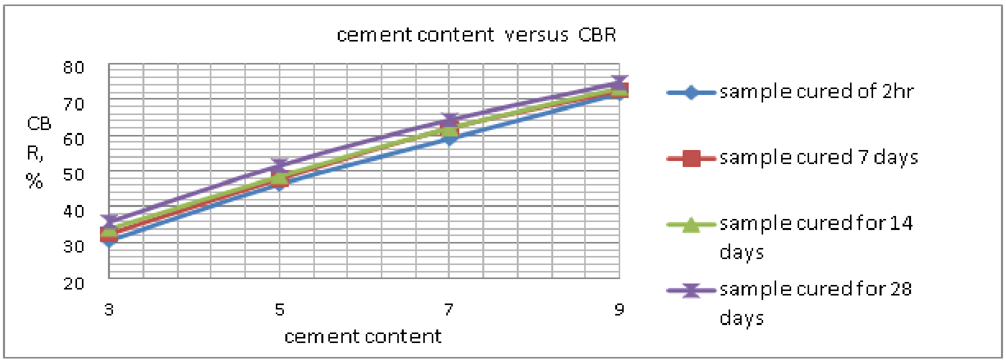


Figure 3.19: A typical increment of CBR value with cement at different current period.

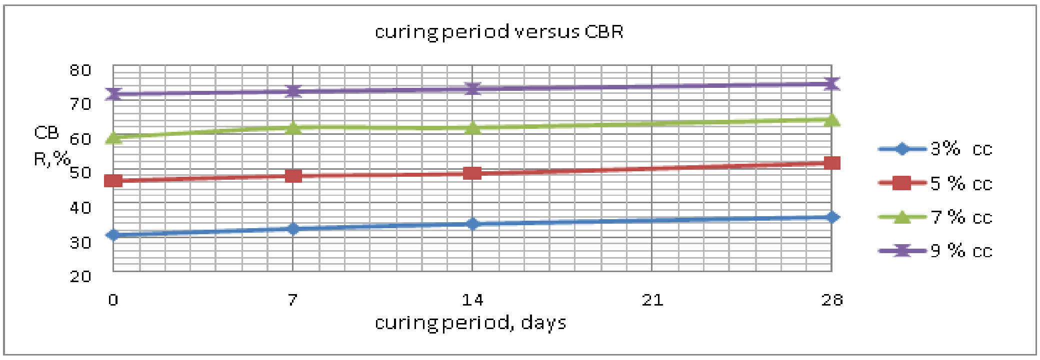


Figure 3.20: A typical pattern of CBR value with a curing period at different cement content.

The effect of swelling was studied for untreated soil and cemented treated soil mixes. It was found that the swell was not significant for the soil itself (0.8%) as indicated in Fig.4.21. Whatsoever, cement treatment reduced the swell to 0.2 to zero percent if it was treated by 3% and 9% of cement respectively.

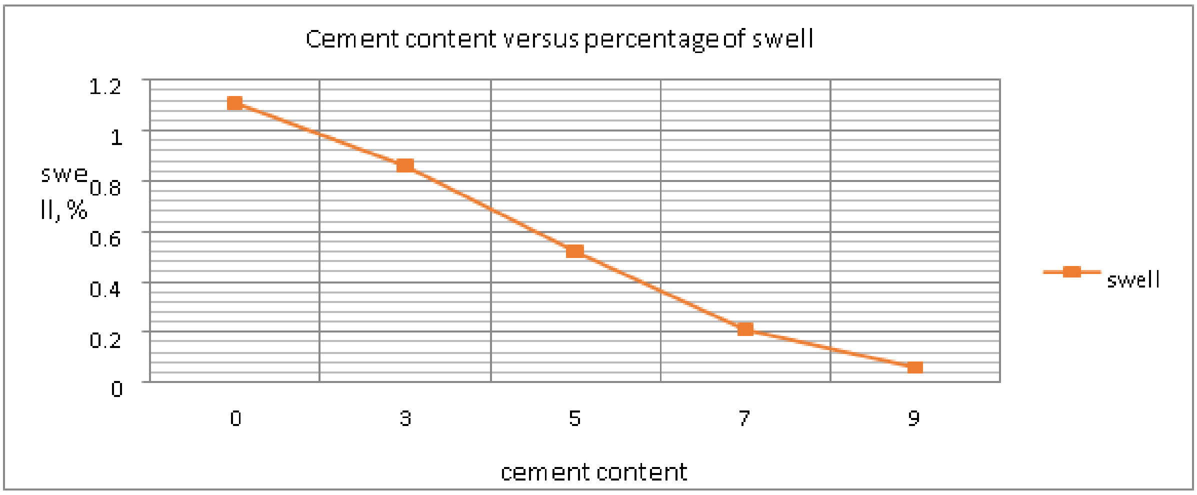


Figure 3.21: a typical patterns decrement of swell percentage with cement.

Effects of Cement Unconfined Compressive Strength

The data generated for unconfined compression tests are presented in the form of graphs in Fig. 3.22, 3.23, 3.24 and 3.25. The figures illustrate the stress, strain behavior of original lateritic soil and cement treated lateritic soil under vertical load. Untreated compacted lateritic soil specimens had unconfined compressive strength 103.98kpa, whereas those for treated with cement by 3%, 5%, 7% and 9% were 176.64kpa, 280.52kpa, 372.06kpa, and 811.77kpa respectively for the sample cured for two hours only. The values indicated an increasing trend in UCS of treated specimens. The rate of increment in unconfined compressive strength is low as cement content increased from zero to 3% and it is increased to the maximum rate of increment up to120% as cement increased from 7% to 9% in the first days mixing.

The trends of changes in UCS with various percentages of cement content of the lateritic soil are presented in Fig. 3.26 for the sample cured at 2hour, 7 days, 14 days and 28 days. This results in agglomeration in large size particles and caused the increase in compressive strength.

The effect of curing period was observed on unconfined compressive strength and is presented in Fig. 3.22. It was observed that UCS increased with curing period within the same cement contents of the lateritic soil. The minimum increment observed in lateritic soil sample treated with 3% cement content was from 176.64 kPa to 310.32kpa, whereas the maximum increment was in the lateritic soil sample treated with 9 % cement content from 811.77 kPa to 1045.22 kPa. Thus, the rates of increment in UCS variables with cement contents.

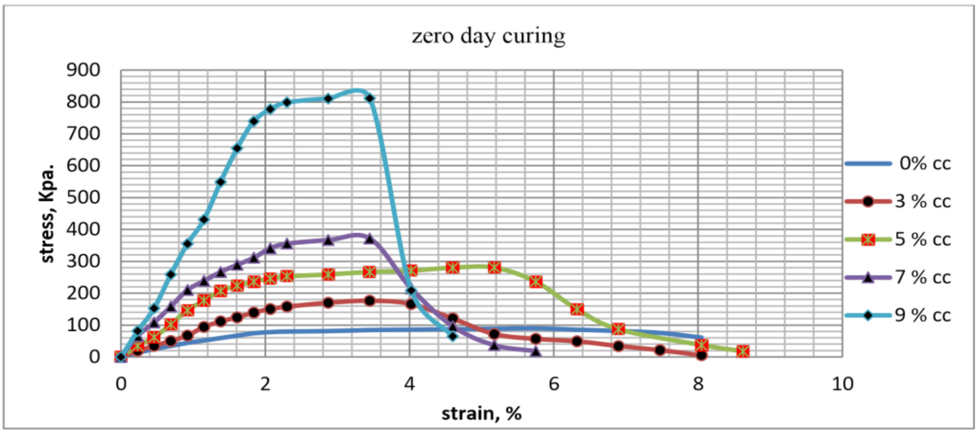


Figure 3.22: Stress-strain graphs from UCS tests cured for 0 days.

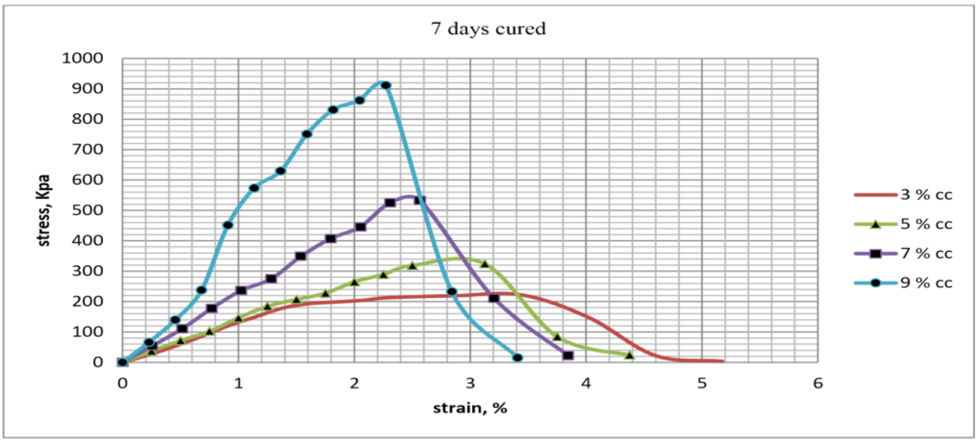


Figure 3.23: Stress-strain graphs from UCS tests cured for 7 days.

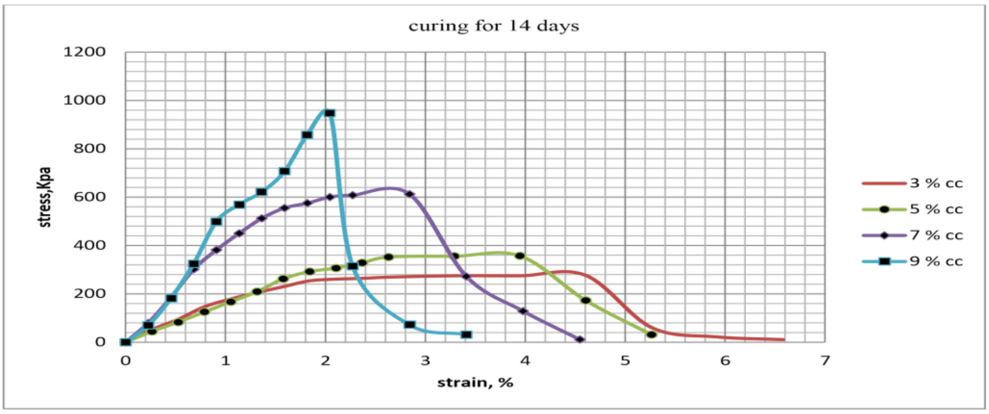


Figure 3.24: Stress-strain graphs from UCS tests cured for 14 days.

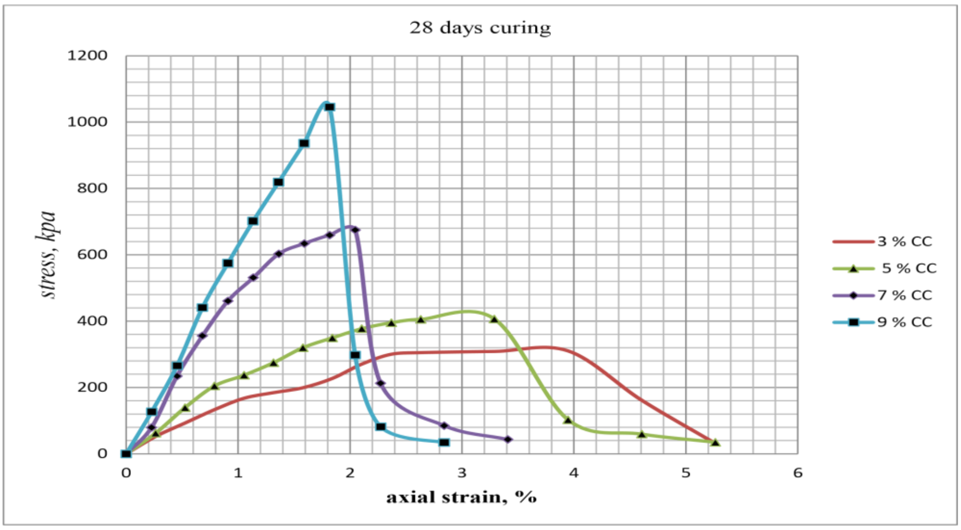


Figure 3.25: Stress-strain graphs from UCS tests cured for 28 days.

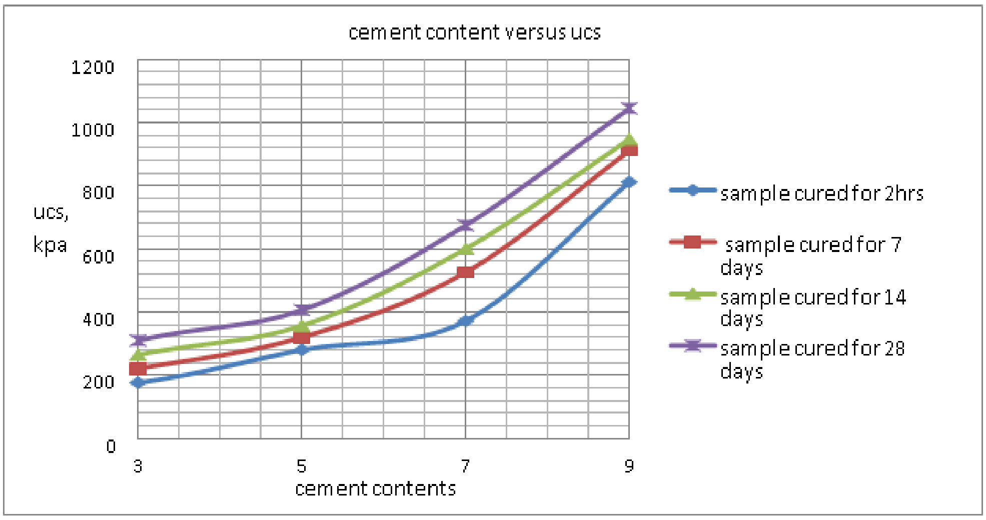


Figure 3.26: Unconfined compressive strength of soil samples for the different curing period.

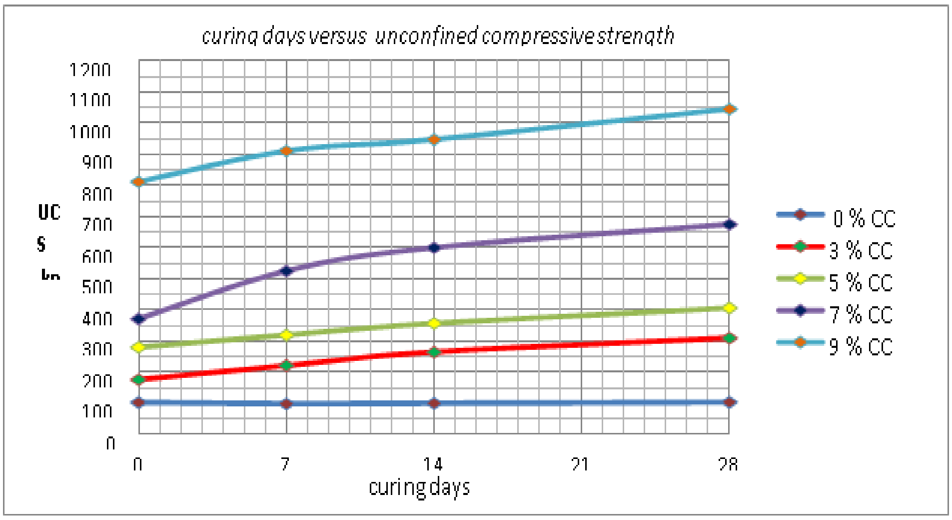


Figure 3.27: Variation of UCS with curing period.

Cost comparisons of the lateritic soil stabilization and Selective borrow material

Cost analysis of stabilizing cement

The quality of existing lateritic soil in the study area was examined using the procedures discussed in previous chapters through laboratory test results. By test data, presented in this thesis the suitability of this soil for highway construction was under question. Therefore, the decision to stabilize the soil with 5% cement was considered to be appropriate to meet the requirements of the ERA specifications for good to excellent subgrade material.The minimum CBR value needed for such situation is 30%.

Table 4.1: Properties of cement stabilized lateritic soil by different cement contents.

Cement content	LL	PL	PI	MDD gm/cm3	OMC (%)	CBR (%)	Swell (%)
0 %	57	33	25	1.48	32	3.4	1.11
3 %	46	37	9	1.56	30	30.6	0.86
5 %	43	39	4	1.61	25	46.3	0.52
7 %	42	41	1	1.62	23	59	0.21
9 %	40	40	0	1.61	23	71.6	0.06

Cost analysis of replacing selective borrow material

As Beza consultants engineers reported in the progress report no. 23 different borrow material site was existing around Wolayita sodo town located between chainage of 64+300 and 76+400 from starting point of this project chainage 00+00 at the Bridge of Bilate River near Alabakulito town. The properties of selective borrow material from different places near the study are presented in table 4.2. From those different borrow sites the one located on the chainage 68+650 LHS, 1.5km better than others in quality, it has CBR 30% and plasticity index of 6.

This point distance from the center of the study area (72+500) is 5.35km. Cost for replacing the soils with borrows material was done for the average of this distance from the centres do town.

Table 4.2: Properties of selective borrow material nearby the study area (source, ERA sodo district office).

Station	LL	PL	PI	MDD	OMC (%)	CBR (%)	Swell (%)	AASHTO classification
1[1]	42	31	11	1.47	24	21	0.6	A-7-5
2[b]	38	28	10	1.465	25	20	0.82	A-2-4
3[c]	37	28	9	1.57	21.5	18	0.08	A-4
4[d]	34	28	6	1.6	20.6	30	0.87	A-2-4
5[e]	35	25	10	1.493	20	20	0.32	A-4
6[f]	39	26	13	1.499	19	23	0.11	A-2-6

Table 4.3: Quantitative cost for cement stabilization of lateritic soil for per km of road

Quantitative cost analysis cement stabilization					
No.	**Activity**	**Unit**	**Unit price**	**Unit**	**Unit price**
	I. Road Prism/Road Section				
1	Clearing and Grubbing within Road Prism	Birr/m^2	4.74	Birr/km	37,900.26
2	II. Transportation of Stabilizer				
	Purchase Cost of Stabilizer from mugher Cement Factory	Birr/qtl	265.00		
		Birr/m^3	3,388.55		
	for 1m^3 of lateritic soil, 0.095m^{3}of cement required	Birr/m^3	338.00		
	purchase Cost of Stabilizer of cement	Birr/m^2	169.00	Birr/km	1, 352,000.00
3	Transport Cost of Stabilizer from mugher cement factory	Birr/qtl	120.00		
		Birr/m^3	1,807.23		
	For 1m^3 of lateritic soil, 0.095m^{3}of cement required	Birr/m^3	171.69		
	Purchase Cost of Stabilizer(cement)	Birr/m^2	85.85	Birr/km	686,800.00
	III. Placing of Stabilizer				
4	Hauling of Stabilizer	Birr/m^2	48.05	Birr/km	147,845.30
5	Mixing of Stabilizer	Birr/m^2	71.94	Birr/km	575,517.38
6	Placing of Stabilizer	Birr/m^2	54.19	Birr/km	433,545.90
	Total Quantitative Cost		**433.77**		**3,233,608.84**

Table 4.4: Quantitative cost for replacing selectively borrow material.

Quantitative cost analysis gravel replacement			
No.	**Activity**	**Unit price (*birr/m*^{2})**	**Unit price (*birr/ km*)**
	I. Road Prism/Road Section		
1	Clearing and Grubbing within Road Prism	4.74	397,900.26
2	Under Cut Excavation	49.51	396,098.50
3	Disposal of Under Cut Excavation	126.23	388,412.61
4	Reinstating of Undercut Disposal Site	58.02	464,141.53
	II. Preparation for Suitable/Borrow Material Development		
5	Clearing and Grubbing for Borrow Production	4.74	397,900.26
5.1	Excavation of Overburden	49.51	396,098.50
	III. Suitable/Borrow Material Development		
6	Borrow Production	14.64	292,705.88
7	Transportation of Borrow material	75.54	302,163.19
	IV. Placing of Suitable/Borrow Material		
8	Road bed preparation & Placing of Borrow Material	33.82	450,982.81
	V. Reinstatement of Suitable/Borrow areas		
9	Reinstating of Overburden Excavated material	77.33	618,666.90
	Total quantitative cost	**494.08**	**4,105,070.44**

4.3 Comparison of quantitative cost- benefits cement stabilization and replacing selective borrow material

The comparisons of the cost benefits were made from tables 4.3 and 4.4. As shown in the tables, the total quantitative cost of cement stabilization was estimated as 3,233,608.84 Birr/km against the cost of 4,105,070.44 Birr / km for replacing selective borrow material from a 5km distance. The saving in cost for cement stabilization thus estimated came out to be 26.95%.

CONCLUSION AND RECOMMENDATION

Conclusion

Based on the laboratory test results in this study, effects of the cement on the lateritic soil samples of WolayitaSodo area, the following conclusions can be drawn:

The lateritic soil used in this study was dominated by fine-grained soil with 63.5%87.5% passing sieve no. 200 (0.075mm). Its plasticity index is above 19 % for air and oven dried condition. It was classified as the A-7-5 group with group index above 20 based on the AASHTO soil classification system and MH by USCS soil classification system. All specimens from Wolayita sodo are located below the A-line which indicated that the soil in the study area consisted of silt. The addition of cement to this soil was decreasing the liquid limit and increases plastic limits. This causes the reduction of plasticity index, which improves the workability of the soil. The cement has changed the compaction characteristics of lateritic soil collected from the study area. As the cement content increases, the MDD, CBR, and UCS increase, while there was a reduction in the OMC. The effects of the Curing period were marginal on the compaction characteristics and CBR value, while it has a substantial effect in UCS.

Stabilization of lateritic soils with 5 % of cement content in the study area was effective both in quality and cost.

Recommendation

To achieve uniform compaction, it is recommended to use automatic compactors in determining the compaction parameters, CBR and UCS the soil. The Pavement performance is closely related to the stiffness of the underlying base and subgrade materials. Tests to measure the stiffness of untreated lateritic soil and cement treated lateritic soils, such as resilient modulus tests, should be considered in the future researches. More so, as this study follows the procedures using quantitative only cost parameters for the cost-benefit analysis, it is suggested to evaluate the benefits accurately the qualitative cost of replacing and stabilizing, which needs more investigation in collaboration with all stakeholders to establish a sound indicator that could help in making a decision in using either replace by selective material or stabilizing locally available with additives.

REFERENCES

1. Afolagboye L. O &Talabi, A. O. Effect of curing time on the unconfined compressive strength of lateritic soil stabilized with tyre ash. *Impact: International Journal of Research in Applied Natural and Social Sciences (IMPACT: IJRANSS)*, 2014; 190-199.
2. Amu, O. a. Characteristics of bamboo leaf ash stabilization on the lateritic soil in highway construction. *Int. J. Eng. Technology*, 2010.
3. Amu, O. O. Geotechnical properties of lateritic soil stabilized with sugarcane straw ash. *American journal of scientific and industrial research*, 2011; 323-331.
4. Beeghly, J. H. *Recent experiences with lime-fly ash stabilization Of Pavement Subgrade Soils, Base, and Recycled Asphalt.* Lexington,: the University of Kentucky, Center for Applied Energy Research, 2003.
5. Bello, A. Influence of Compaction Delay on CBR and UCS of Cement Stabilized Lateritic Soil. *The Pacific Journal of Science and Technology*, 2011; 87-98.
6. Charman, J. H. *Laterite in road pavements.* London: London Construction Industry Research and Information Association Special Publication, 1988.
7. Dinku and Gudissa, W. a. The use of limestone powder as an alternative cement replacement material: an experimental study. *Journal of eea*, 2010; *27*.
8. F.H. Beinroth, H. E. Properties, classification, and management of oxisols. *International Journal of Scientific & Engineering Research*, 2014; *5(6): 631*-632-636.
9. F.H.M. Portelinha, D. L. Modification of a Lateritic Soil with Lime and Cement; An Economical Alternative for Flexible Pavement Layers, 2012; 51-63.
10. Gidigasu, M. Laterite Soil Engineering. *Elsevier Scientific Publishing Co.*, 1976.
11. Hanna, T. S*tudy of index properties and shear strength parameters of laterite soil in southern part of Ethiopia the case of Wolayita sodo.* Addis Ababa, 2008.
12. Huat, B. B., Sew, G. S., & Ali, F. H. *Tropical Residual Soils Engineering.* London: Taylor & Francis Routledge, 2004.
13. Jiregna, D. *Detail Investigation on Index Properties of Lateritic Soils - The Case of Nedjo-Mendi-Assosa.* Addis A baba: Addis Ababa university faculty of technology, 2008.

14. Lyon, A. *Laterite and lateritic soils and other problem soils of Africa.* Baltimore, Maryland, u. s. a.: agency for international development aid/csd-2164, 1971.
15. Mu'azu, M. A. Influence of Compactive Effort on Bagasse Ash with Cement Treated Lateritic Soil. *Leonardo Electronic Journal of Practices and Technologies*, 2007.
16. Netterberg, D. F. *Review of Specifications for the Use of Laterite in Road Pavements.* South Africa Council for Scientific & Industrial Research, 2014.
17. Onyelowe, K. C. Cement Stabilized Akwuete Lateritic Soil and the Use of Bagasse Ash as Admixture. *International Journal of Science and Engineering Investigations*, 2012; 16-20.
18. Osinubi K. J. Lime modification of black cotton soil, 1995.
19. Oyediran, I. A. Effect of Increasing Cement Content on Strength and Compaction Parameters of some Lateritic Soils of Southwestern Nigeria. *EGJE*, 2011; *16*: 1501-1514.
20. Raychaudhuri, S. The occurrence, distribution, classification, and management of laterite and lateritic soils. *Journee Georges Aubert*, 1980.
21. SaravutJaritngam, W. O. Development of Strength Model of Lateritic Soil-Cement. *ENGINEERING JOURNAL*, 2013; 70- 77.
22. Stewart, S. a. *Engineering Report for Alemgen- Hossana – Sodo road design project.* Addis Ababa, Ethiopia, 1998.
23. Suksiritawonkul, A. *Stabilization of dredged sludge as construction materials.* Graduate school, Kasetsart University, 2007.
24. Townsed, F. Geotechnical characteristics of residual soils. *Proceeding of American Society of Civil Engineers*, 1985; 111: 77-93.
25. Wakuma, F. *Investigating the Index Properties of Residual Tropical Soils of Western Ethiopia (The Case of Asossa).* Addis Ababa Addis Ababa University Faculty of Technology, 2007.
26. Wesley, L. D. *Fundamentals of soil mechanics for sedimentary and residual soils.* Hoboken, New Jersey: John Wiley & Sons, Inc., 2009.
27. Wossen, M. *The investigation into the appropriate laboratory testing procedures for the determination of the index properties of the Lateritic Soils of Western Ethiopia.* Addis Ababa: Addis Ababa university faculty of technology, 2009.
28. Zelalem, A. *Basic Engineering Properties of Lateritic Soils Found in Nejo – Mendi Road Construction Area, Wollega.* Addis Ababa: Msc.thesis Addis Ababa University, 2005.