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Stabilization of Laterite Soil with Pozzolan-Calcium hydroxide Binders for Construction of Low Volume Roads in Mbeya Tanzania

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Abstract

The study stabilized Laterite soils by using Natural pozzolan – Calcium hydroxide binders for the aim of improving its strength. Characterization and stabilization process of Laterite soil under laboratory conditions were conducted. The Laterite soils used for this study were classified as clayey soils with a plasticity index of 33%, a maximum dry density of 1525 kg/m^3 and a California bearing ratio of 6.7%. Natural pozzolan – Calcium hydroxide binders (PoCH) at proportions of 70%:30% (70Po30CH) and 50%:50% (50Po50CH) were used as binders to Laterite soils. The binders were replaced to Laterite soils at dosages of 5%, 10%, 15%, 20%, 25%, and 30% by weight. The stabilized Laterite specimens were cured for 7, 28 and 48 days. The results indicated that the addition of Natural pozzolan – Calcium hydroxide binders to the Laterite soils reduced the plasticity indices from 33% to 13.7% at 30% of 70Po30CH and from 33% to 10.8% at 30% of 50Po50CH binders.The unconfined compressive strength (UCS) values of Laterite soils mixed with 20% of 70Po30CH and 50Po50CH and cured for 28 days were 1.4 MPa and 1.2 MPa respectively. The study revealed that the strength of Laterite soils can be improved through stabilization with 70Po30CH and 50Po50CH binders at dosage of 10% to 25% for the construction of improved subgrade and subbase layers of low-volume roads in Mbeya Tanzania.

Keywords: Low-volume roads; stabilization; Pozzolan; UCS; CBR; Laterite soils; Calcium hydroxide; MDD.

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1. Introduction

Laterite soils are described as tropical soils that are produced by advanced weathering accompanied by relative enrichment in iron and aluminum sesquioxides due to the decomposition of primary minerals and the removal of bases and silica [1]. Laterite soil is capable of hardening upon exposure to wetting and drying, and its dominant color is reddish because of the presence of a high amount of iron, which, in some studies, is known as red soils Reference [1, 2].

Laterite soils have different unique characteristics: they are cohesive and cohesion-less soils comprising fine clay, silt, sand and gravel [3]. Some Laterite soils can expand and shrink under wet and dry conditions, whereas others do not exhibit expansion and shrinkage properties [1, 3]. In this context, Laterite soils have a wide range of engineering properties, which include strength properties and binding and particle gradation properties for the construction of road pavements [1, 2, 3].

The irregularities in characteristics of Laterite soil makes it necessary to determine its engineering properties for the construction of road pavement layers [3]. For example, well-graded Laterite gravel soils perform satisfactorily as unbound road foundations. However, some Laterite gravel soils exhibit gap graded with variable fine and sand fractions and coarse particles of variable strength, which may breakdown, limiting their usefulness as pavement materials on roads with heavy traffic [6].

Previous studies on Laterite soils as materials for road construction have suggested that the performance of road pavements constructed using Laterite soils depends upon number of factors, such as the type of Laterite soils, blending and stabilization techniques, design and construction techniques of the pavement layers and weather conditions [7, 8]. The behavior of Laterite soils in pavement structures depends mainly on their iron and aluminum oxide (sesquioxide) contents, particle size characteristics, the nature and strength of the gravel-sized particles, the degree of compaction, and traffic and weather conditions [9].

The selection of an appropriate method to improve Laterite soils for use in road construction is important for pavement engineers. The extensive use of Laterite soils for road construction projects is sometimes limited because of unsatisfactory engineering properties. Some Laterite soils consist of high-plasticity clay, which may cause cracks and damage of pavements and other structural construction projects when dry [10].

Improvement of engineering properties of Laterite soils through blending processes and stabilization with cement, lime artificial and natural pozzolans are being used worldwide. Soil stabilization is the process of improving the engineering properties of soil, such as shear strength, bearing capacity and plasticity index, through controlled compaction and the addition of stabilizers. Several studies conducted to improve the engineering properties of Laterite soils through stabilization processes have been found to be suitable for the construction of subgrades and subbase layers of pavement structures [13, 14, 15].

For this study, the engineering properties of Laterite soils from Busale area in the Kyela district were investigated under laboratory conditions. The Atterberg limits, particle gradations, compaction parameters, California bearing ratios (CBRs) and unconfined compressive strengths (UCSs) of Laterite soil were investigated.

2. Investigation Procedure and Approach

2.1. Investigation procedure

The investigation in this study involved the identification of source materials and classifications based on the AASHTO classification system. Samples of the Laterite soils from Busale area in Kyela District in the Mbeya region were taken to the laboratory for investigation. Natural pozzolan–Calcium hydroxide binders were used as stabilization agent to improve engineering properties of Laterite soils for construction of low-volume roads in Mbeya region. Table 1 shows physical characteristics of Laterite soils according to the AASHTO classification system.

Table 1: Classification of Busale Laterite soil (AASHTO)

Materials	Physical properties	AASHTO Classification	% Fines	% Sand	% Gravel
Laterite soil	Reddish soil	A-7-5 clayey soil	52	17	31

Natural pozzolan were sourced from Rungwe district and industrial calcium hydroxide from local suppliers in Mbeya Region. The natural pozzolan were air dried and grinded into powder form by using disc grinder machine while calcium hydroxide were obtained in powder form. Chemical and physical properties of Natural pozzolan and Calcium hydroxide were also determined. The chemical compositions of the materials were determined by using XRF equipment conducted at Government Chemistry Laboratory located in Mbeya City. Table 2 shows the chemical compositions of natural pozzolan and calcium hydroxide used for this study.

Table 2: Chemical Composition of Natural Pozzolan and Calcium hydroxide

Binder materials	Percentage chemical compositions											
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	P_2O_5	CO_2	LOI	Total
Pozzolan	57.1	19.3	7.1	0.7	0.4	0.1	1.6	3.8	-	-	8.1	98.8
Calcium hydroxide	2.5	1.5	1.0	83.3	0.5	0.5	0.4	-	-	5.0	7.8	100

The physical properties of Natural pozzolan powder and Calcium hydroxide powder were determined by using Blaine air percolation apparatus, following the procedure described by Chengula, and his colleagues, (2018) [22]. The properties determined are specific densities, specific surface areas, mean particle sizes, d10 and d90.

Table 3 shows physical properties of powdered Natural pozzalan and Calcium hydroxide. The chemical composition, mean particle size, specific surface area and density of Natural pozzolan-calcium hydroxide mixtures affect the pozzolanic reactions of stabilized materials [4]

Table 3: Particle size data, specific densities and surface areas of Natural pozzolan and Calcium hydroxide

Binder Materials	**d10 (µm)**	**Mean particle size (µm)**	**d90 (µm)**	**Specific density (g/cm^3)**	**Specific surface area (cm^2/g)**
Calcium hydroxide	0.982	1.468	21.467	2.080	6213.37
Natural pozzolan	1.024	1.754	22.138	2.288	6950.23

2.2. Investigation Approach

The laboratory tests conducted to Laterite soils include particle size analysis, Atterberg limits (liquid limits, plastic limits and linear shrinkage limits), compaction tests and California bearing ratio (CBR) tests. Sieve size analysis was conducted to determine the particle size distribution. The percentages passing were used to group the soil particles into gravel, sand and fines. The Atterberg limit test results, which include liquid limits, plastic limits and plasticity indices together with percentages passing sieve sizes, are used to classify soils according to the AASHTO classification system. The plasticity index is also used as an indicator of the binding properties of materials, and the linear shrinkage limit is used as an indicator of the shrinkage and swelling potential of materials in a changing weather condition [16, 17].

Laterite soils were mixed with Natural pozzolan – Calcium hydroxide binders at different proportions to investigate the influence of Natural pozzolan – Calcium hydroxide binders on the engineering properties of Laterite soils. The tests conducted on stabilized Laterite soil samples include compaction tests and unconfined compressive strength (UCS) tests. Two binders of Natural pozzolana – Calcium hydroxide which are 70% Natural pozzolan 30% Calcium hydroxide (70Po30CH) and 50% Natural pozzolan 50% Calcium hydroxide (50Po50CH), were used as stabilization agents. Table 4 shows the proportions of Laterite soils and Natural pozzolan - Calcium hydroxide mixtures for both binder type and dosage.

Table 4: Percentage compositions of the Laterite, Pozzolan and Calcium hydroxide materials

Materials	**Pozzolana-calcium hydroxide binders**													
	70Po30CH							**50Po50CH**						
%(Pozolan-calcium hydroxide)	0	5	10	15	20	25	30	0	5	10	15	20	25	30
% Laterite soil	100	95	90	85	80	75	70	100	95	90	85	80	75	70
% Pozzolana	0	3.5	7	10.5	14	17.5	21	0	2.5	5	7.5	10	12.5	15
%Calcium hydroxide	0	1.5	3	4.5	6	7.5	9	0	2.5	5	7.5	10	12.5	15

Compaction tests were conducted to determine the maximum dry density (MDD) and optimum moisture content (OMC) of the lateritic materials, which are useful parameters when California bearing ratio (CBR) tests are conducted. For this study, the CBR values at 95% MDD and UCS are considered the measures of the strength of the materials used for the construction of road pavements [16, 12]. The UCS specimens were cured under moist conditions for 7 days, 28 days and 48 days in three replicate for each binder type and dosage. The cured specimens were crushed to obtain unconfined compressive strengths by using universal crushing machine. The Atterberg limits, compaction tests and UCS tests were conducted following the procedures stipulated in MoW 2000 [18].

3. Results and Discussion

3.1. Analysis of the test results of the Laterite soils

The analysis of the laboratory-tested Laterite soil samples was based on the plasticity properties, particle gradation and strength properties as requirement for improved subgrades and subbase layers of unbound low-volume roads (LVRs). The properties include the plasticity index (PI), grading modulus (GM), particle size distribution, and California bearing ratio (CBR). For soil to be used as improved subgrades and subbase layers of LVRs, the PI should be less than 18%, the GM should range between 1.6 and 2.6, and the soaked CBR at 95% MDD should be greater than 15% [12]. To obtain the engineering properties of Laterite soils for the construction of improved subgrade and subbase layers of LVRs, characterization of soils was conducted.

3.1.1.Characterization of Laterite soils

Atterberg limit tests were conducted to Laterite soil materials to determine the plasticity index and linear shrinkage limits. Table 5 presents the results of the Atterberg limit tests for Laterite materials. The results indicates that Laterite soil has plasticity index of 33%, which is above the recommended limit of 18% suitable for construction of improved subgrade and subbase layers of LVRs [12]. According to the AASHTO classification system, the Laterite soil falls under the clayey soil type and in the A-7 group, which are rated as fair to poor materials for road construction. The materials needs the addition of none plastic soils or stabilization to improve their engineering properties. Materials with high PI values have high soaking rates, especially during rainfall seasons, which results in reduced strength of unbound bases and surfacing layers [19].

Table 5: Atterberg limit data for the Laterite soils

Materials	**Liquid limit (LL) (%)**	**Plastic limit (PL) (%)**	**Plasticity index (PI) (%)**	**Linear shrinkage limit (SL) %**
Laterite soil	65	32	33	14

To reduce higher PI values and improve strength of Busale Laterite soils, stabilization with Natural pozzolan – Calcium hydroxide binders was performed. For this study, Natural pozzolan – Calcium hydroxide binders were considered as stabilization agent because when mixed with water they chemically react to form cementitious compounds similar to industrial cements [4]. The particle size analysis for the Laterite soil samples was conducted to determine the particle size gradation. The percentage passing for individual sieve sizes together with Atterberg limits are also used to classify the materials (refer to Table 1) based on the AASHTO classification system. Figure 1 shows the particle size distribution curve of the Laterite soils used for this study. Compaction and California bearing ratio tests were conducted for Laterite soil material to determine its strength in terms of CBR values at 95% MDD [18].

Figure 1: Particle size distribution curves of Laterite soil

3.1.2.Compaction and California bearing ratio of Laterite soils

The compaction tests of Laterite soils were conducted via the modified BS heavy proctor test to determine the maximum dry density (MDD) and optimum moisture content (OMC), as stipulated in MoW 2000 [18]. The results for the maximum dry density and optimum moisture content were 1525 kg/m^3 and 22.5%, respectively. Figure 2 shows the compaction curve of the Laterite soils. Three-point California bearing ratio tests were conducted using modified BS heavy density to determine the CBR values at 95% MDD [18]. The mixing and compaction processes of the sample materials were performed at the optimum moisture content, and the samples were soaked in water for 96 hours and penetrated to determine the resistance to shearing forces at each plunger penetration depth. The average CBR values are calculated from the forces obtained at 2.5 mm and 5.0 mm plunger penetration depths Reference [18].

For the three-point CBR tests of the Laterite sample soils, three different compaction methods and layer thicknesses of the same material were used. The materials in the first mould were compacted via a 4.5 kg pistol weight, 62 blows for 5 layers, the materials in the second mould were compacted via a 4.5 kg pistol weight, 30 blows for 5 layers, and the materials in the third mould were compacted via a 2.5 kg pistol weight, 62 blows for 3 layers. A three-point CBR test was conducted to determine the variation in material strength with the degree of compaction, as described in MoW 2000 [18]. Figure 3 shows the three-point CBR values of the Laterite soils. The CBR at the 95% MDD of the Busale Laterite soil was determined to be 6.7%. The engineering parameters of the Busale Laterite soils indicates that they did not satisfy requirements to be used for construction of improved subgrade and subase layers of LVRs in Mbeya region. The investigation revealed that Busale Laterite soils lacks course grain particles, have high plasticity index above the limiting value and low CBR values below recommended value.

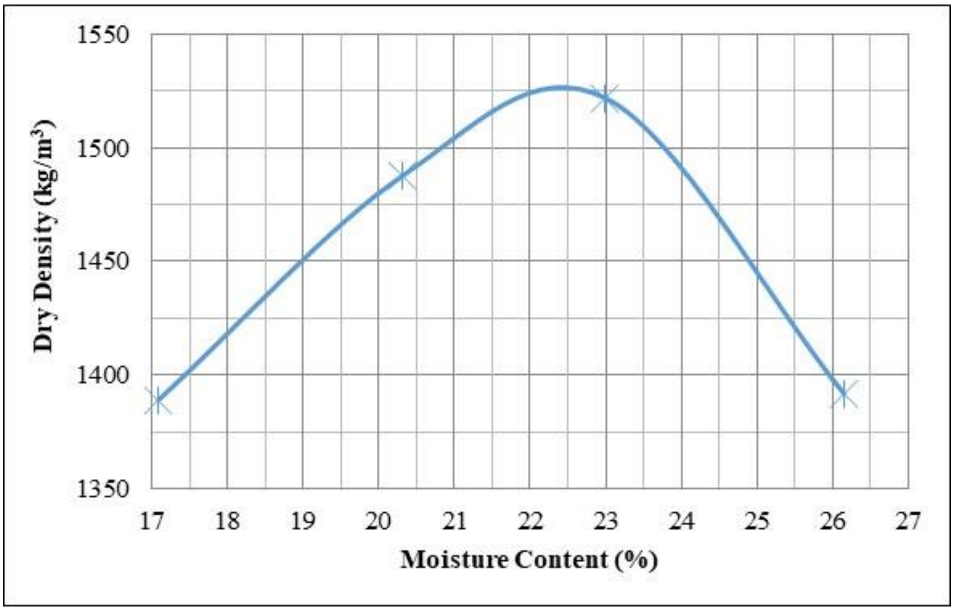

Figure 2: Compaction curve of the Laterite soil

Since Laterite soils are abundantly available in many places of Tanzania as natural subgrade soils including in Mbeya region [23]. Therefore it is important to investigate their engineering properties and make necessary improvement in order the Laterite soils to suit for construction of LVRs in Tanzania.

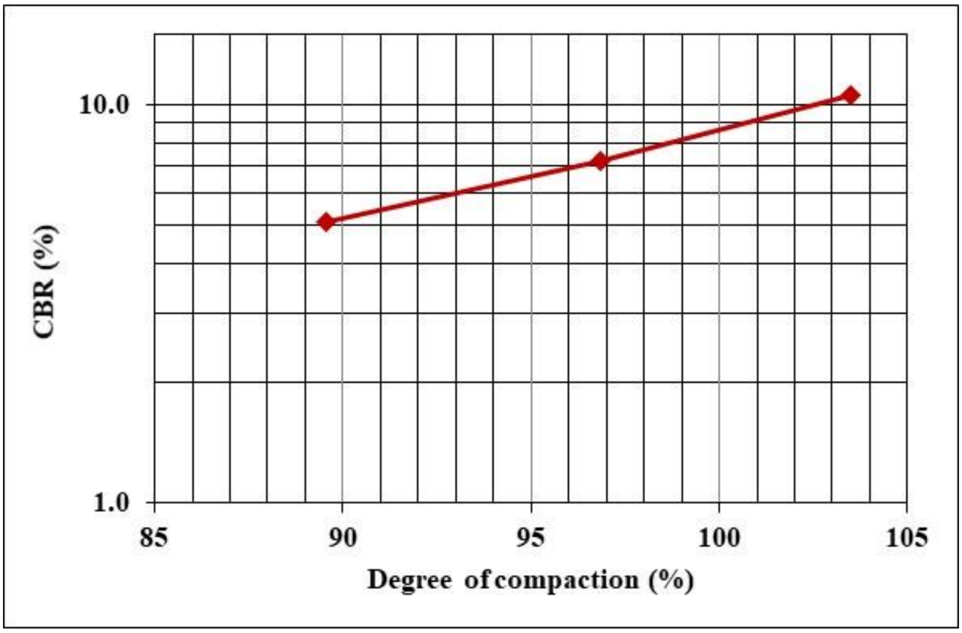

Figure 3: Three-point CBR values of Busale Laterite soil

For this study the improvement of engineering properties of Laterite soils was conducted by stabilizing with the mixtures of Natural pozzolan and Calcium hydroxide binders as stabilizing agent. The increased costs of road projects and increased vehicle operating costs are generally influenced by premature and frequent pavement defects caused by the use of poor materials for pavement construction [17].

3.2. Stabilization of Laterite soils

Stabilization processes were conducted to improve engineering properties of Laterite soil for use as subgrade and subbase layer materials for the construction of low-volume roads in Mbeya. The stabilizer materials used for this study were the mixtures of Natural pozzolan and Calcium hydroxide. Atterberg limit tests, compaction tests and unconfined compressive tests (UCS) on stabilized Laterite soils were conducted.

3.2.1.Atterberg limit tests for stabilized Laterite soils

Two types of Natural pozzolan-Calcium hydroxide binders were used as stabilization agents. Natural pozzolan were mixed with calcium hydroxide at a proportion of 70%Natural pozzolan - 30%Calcium hydroxide (70Po30CH) and 50% Natural pozzolan - 50% Calcium hydroxide (50Po50CH). The mixtures of Natural pozzolan and Calcium hydroxide were then grinded with a disc grinder machine to achieve consistency and uniformity of the mixtures. For each type of stabilization agent, Laterite soil samples were mixed with Natural pozzolan – Calcium hydroxide binders at proportions of 5%, 10%, 15%, 20%, 25% and 30% by weight (refer to Table 4).

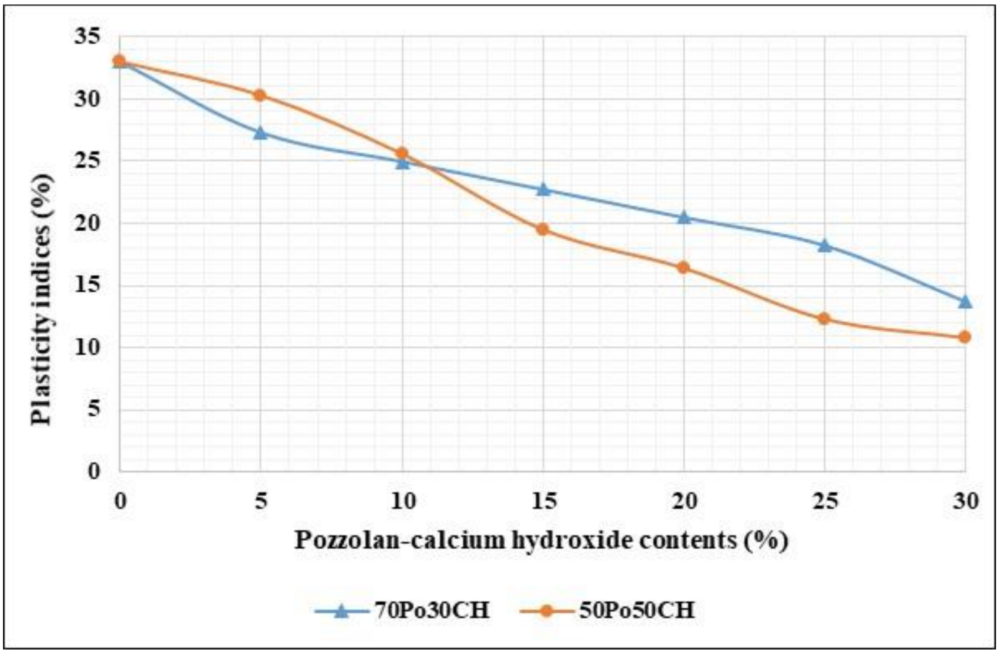

Figure 4: Plasticity index results for the stabilized Laterite soil sample

Atterberg limit tests were conducted on the stabilized Laterite soils for each dosage of Natural pozzolan – Calcium hydroxide binders. Figure 4 shows the variation in the plasticity indices (PI) of the stabilized Laterite soil samples. The results indicate that the PI decreases linearly with increasing dosage of both types of Natural pozzolan-Calcium hydroxide binders. This is because Natural pozzolan and Calcium hydroxide are none plastic materials.The plasticity index decreased from 33% to 13.7% with the replacement of 30% of 70Po30CH binder and from 33% to 10.8% with the replacement of 30% of 50Po50CH binder. To achieve proper mixing and compaction of stabilized fine-grained soils, the plasticity index (PI) should be less than 20%, which ultimately results in high strength [21].

3.2.2.Compaction test of stabilized Laterite soils

Compaction tests of stabilized Laterite soil were conducted in order to determine maximum dry densities (MDD) and optimum moisture contents (OMC) at each binder dosage and type. Figure 5 shows variation of MDD of stabilized Laterite soils with binder type and dosage. The MDD of stabilized Laterite soil samples increased with increasing dosage of Natural pozzolan – Calcium hydroxide up to 20% for both binder types and then dropped as dosage increased from 20% to 30%.

Therefore, change in MDD of the mixtures of Laterite soils and Natural pozzolan – Calcium hydroxide binders occurred due to the differences in particles sizes and densities of Lateritic soils, Natural pozzolan and Calcium hydroxide. The situation results into changes of packing densities, interlocking properties and friction resistance of the mixtures [4]. The maximum dry densities of 1587kg/m^3 for 50Po50CH and 1557kg/m^3 for 70Po30CH binders were determine at 20% of both binders. The increase in MDD indicates improvement of soil properties with the limit of maximum dosage of Natural pozzolan – Calcium hydroxide required for stabilization of the soil.

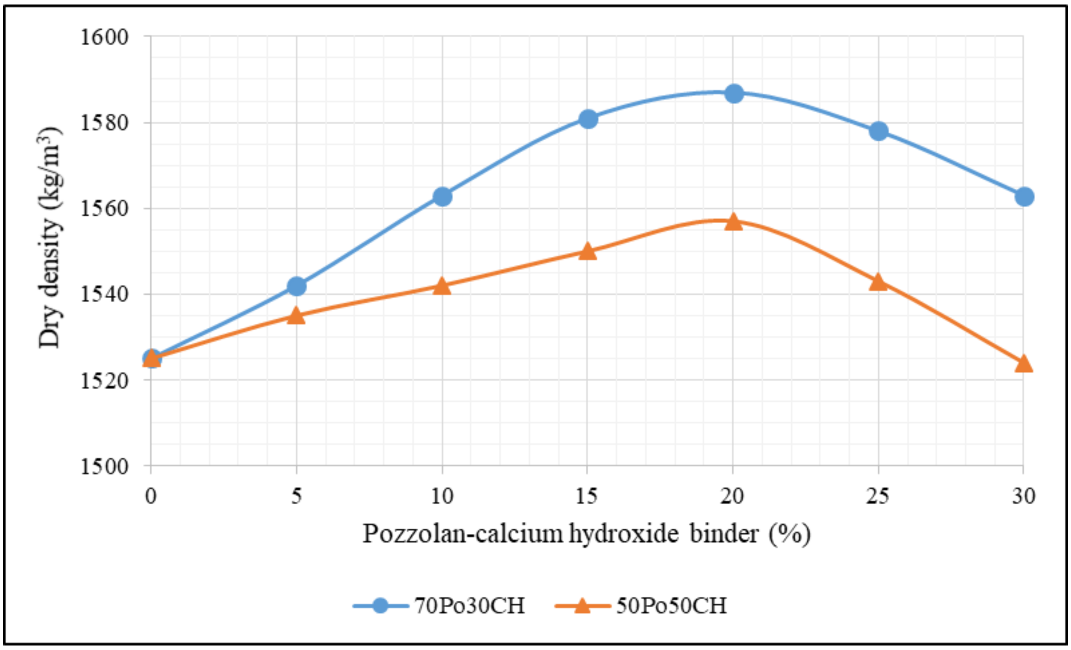

Figure 5: Graphs of MDD for stabilized Laterite soil with 70Po30CH and 50Po50CH binders

3.2.3.Unconfined compressive strength (UCS)

The results of unconfined compressive strength (UCS) tests indicated that compressive strength of cured cylindrical specimens increased with increasing dosage of Natural pozzolan – Calcium hydroxide up to 20% for both binder types and dropped as binder dosage increased from 20% to 30% similar trend with compaction results of stabilized Laterite soil samples. However the compressive strengths of cured stabilized Laterite specimens increased with increased curing period from 7 days to 48 days.

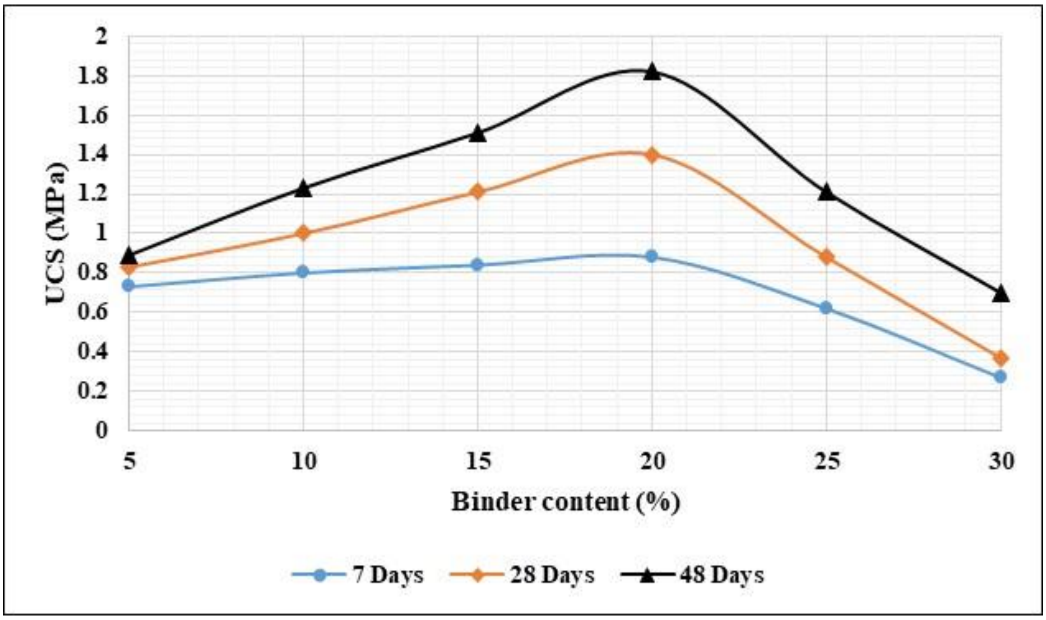

Figure 6: Graphs of variation of UCS for 70Po30CH binder

Figure 6 and 7 shows variation of compressive strength of stabilized Laterite soil samples with increased dosage of Natural pozzolan – Calcium hydroxide and curing period for 70Po30CH and 50Po50CH binders. The maximum compressive strengths for all curing period occurred at 20% of Natural pozzolan – Calcium hydroxide dosage. This is because, maximum densification of sample materials for this study occurs at 20% of Natural pozzolan – Calcium hydroxide dosage. The increased strengths with increased curing period is because of development of cementitious compounds from Natural pozzolanic reactions of Natural pozzolan - Calcium hydroxide binders Reference [4,5]. It has been indicated that higher UCS values of stabilized Laterite soils samples for this study were for 70Po30CH binder compared to 50Po50CH binder for all curing periods. The behaviour is similar to other studies [4, 5] which indicated that optimum chemical combination of silica and aluminum from Natural pozzolan and Calcium from Calcium hydroxide to form calcium silicate hydrates (CSH) and calcium aluminate hydrates (CAH) occurs at proportional around to 70% Natural pozzolan and 30% Calcium hydroxide.

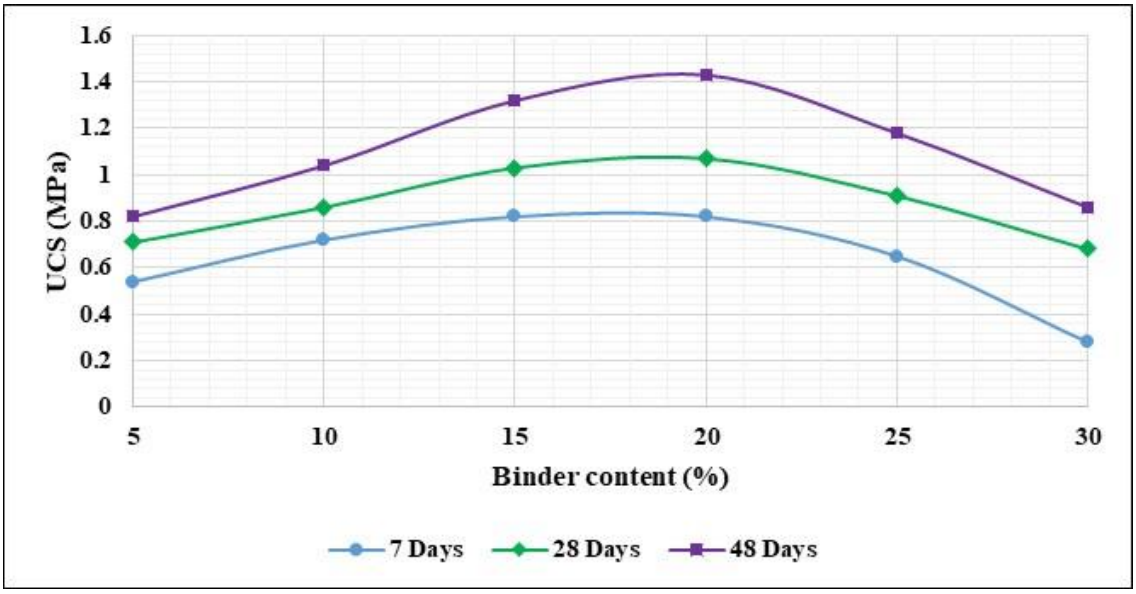

Figure 7: Graphs of variation of UCS for 50P50CH binder

The UCS values of cured specimens stabilized Laterite soils with Natural pozzolan – Calcium hydroxide binders indicated that they are suitable to be used for construction of improved subgrade and subbase layers of road pavement [20]. The CM materials of strength greater than 0.5MPa and less than 1MPa and C1 materials of compressive strength greater than 1MPa and less than 2MPa [20] were achieved at binder dosage of 10% to 25% for curing periods from 7day to 48 days for both binder type. Therefore, the materials were stabilized to reduce the plasticity index and improve their strength so that they can be used as improved subgrade and subbase layers of LVRs.

4. Conclusion and Recommendation

This study investigated strength improvement of Laterite soils stabilized with Natural pozzolan - Calcium hydroxide binders. Atterberg limits, compaction and CBR tests were conducted on Laterite soils and the results showed that Laterite soils from Busale area is clayey with high plasticity and low CBR values.

The test results obtained from Laterite soil are PI value is 33%, MDD is 1525kg/m^3 and CBR value of 6.7%. The Laterite soils were stabilized with mixtures of Natural pozzolan - Calcium hydroxide binders. Two type of binders were used to stabilize Laterite soils which are 70% Natural pozzolan - 30% Calcium hydroxide (70Po30CH) and 50% Natural pozzolan – 50% Calcium hydroxide (50Po50P). The Natural pozzolan - Calcium hydroxide binders were replaced to Laterite soils at proportional interval of 5% by weight from 5% to 30%. The replacement of Natural pozzolan – Calcium hydroxide binders to Laterite soils exhibited a significant effect on both cohesion enhancement and strength development due to pozzolanic reaction.

The UCS results of stabilized Laterite soils at 20% replacement of 70Po30CH and 50Po50CH binders cured for 48 days are 1.92MPa and 1.53MPa respectively. The test results of UCS indicated that Busale Laterite soil can be stabilized with Natural pozzolan - Calcium hydroxide binders at 10% to 25% to obtain CM and C1 materials for construction of improved subgrade and subbase layers of LVRs.

From this study it is recommended that marginal materials like Laterite soils can be improved or modified their engineering properties through stabilization process with Natural pozzolan – Calcium hydroxide binders for construction of low volume roads.

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Appendices

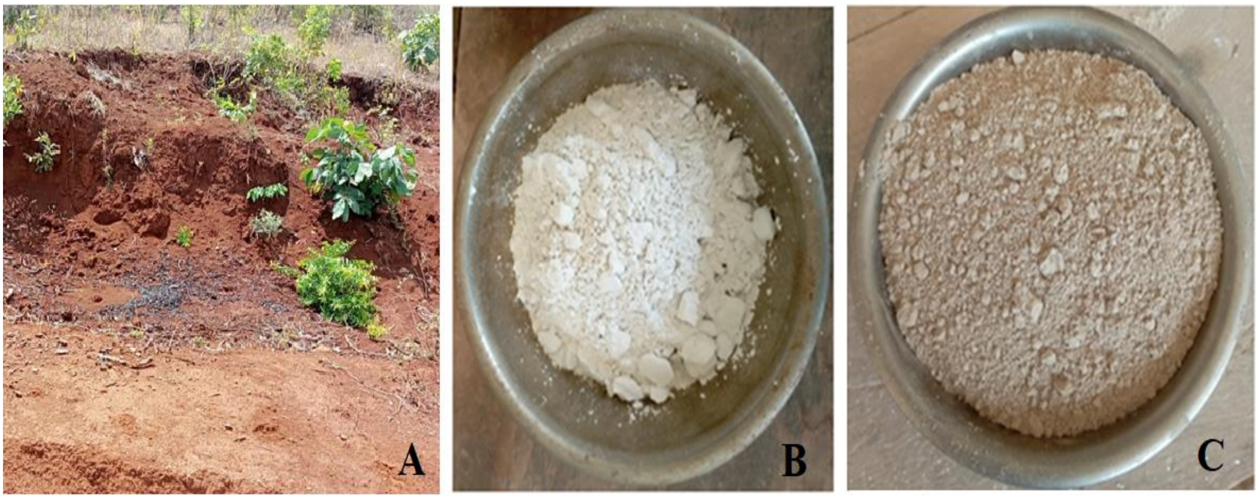

Figure 1A: Photos of materials used for the study: A – Laterite soil, B – Calcium hydroxide powder, C – Natural pozzolan powder

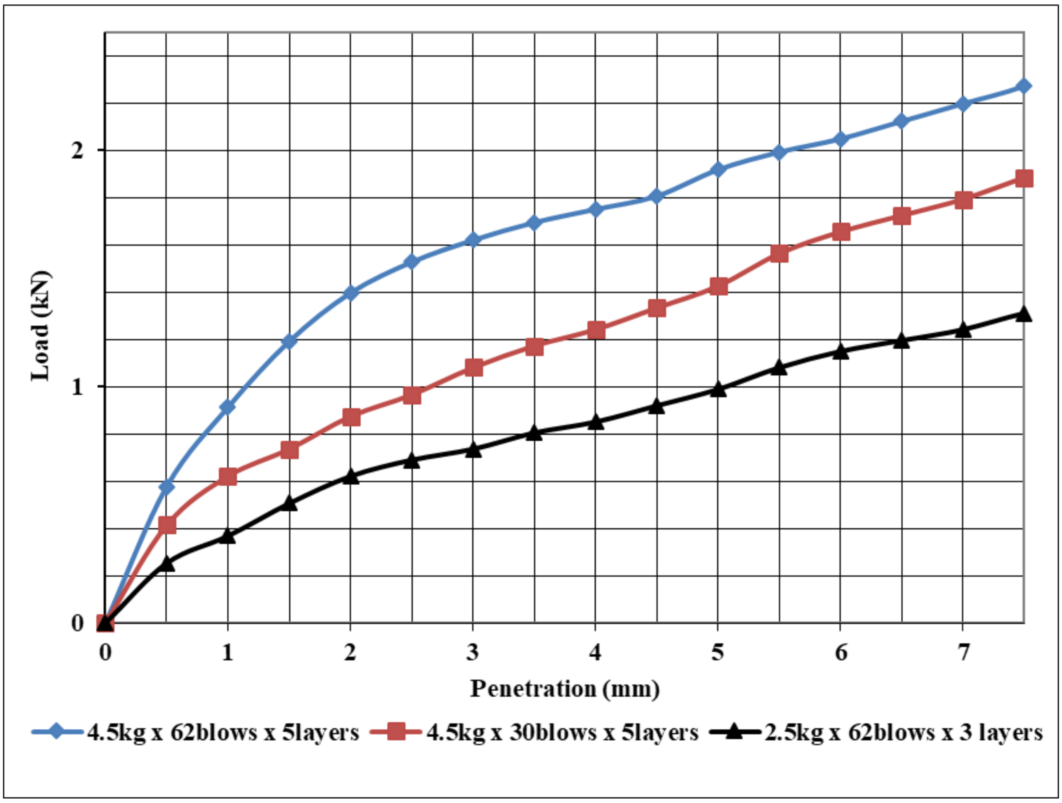

Figure 2A: Penetration resistance of Laterite soils

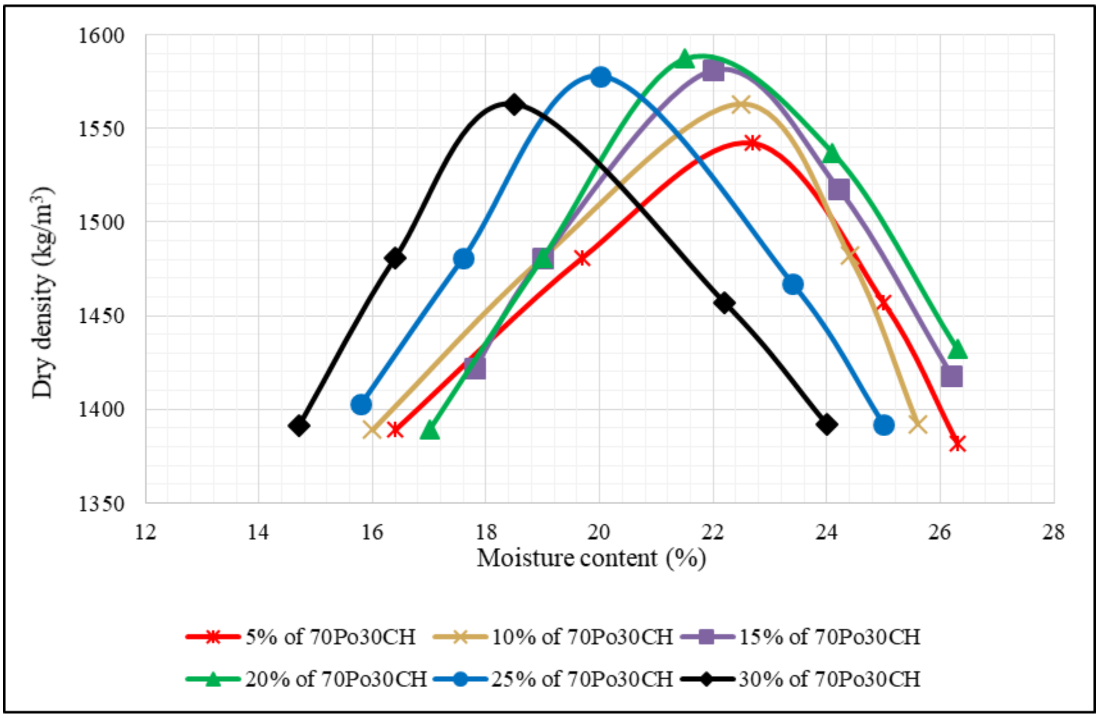

Figure 3A: Compaction curves of the Laterite soils stabilized with the 70Po30CH binder

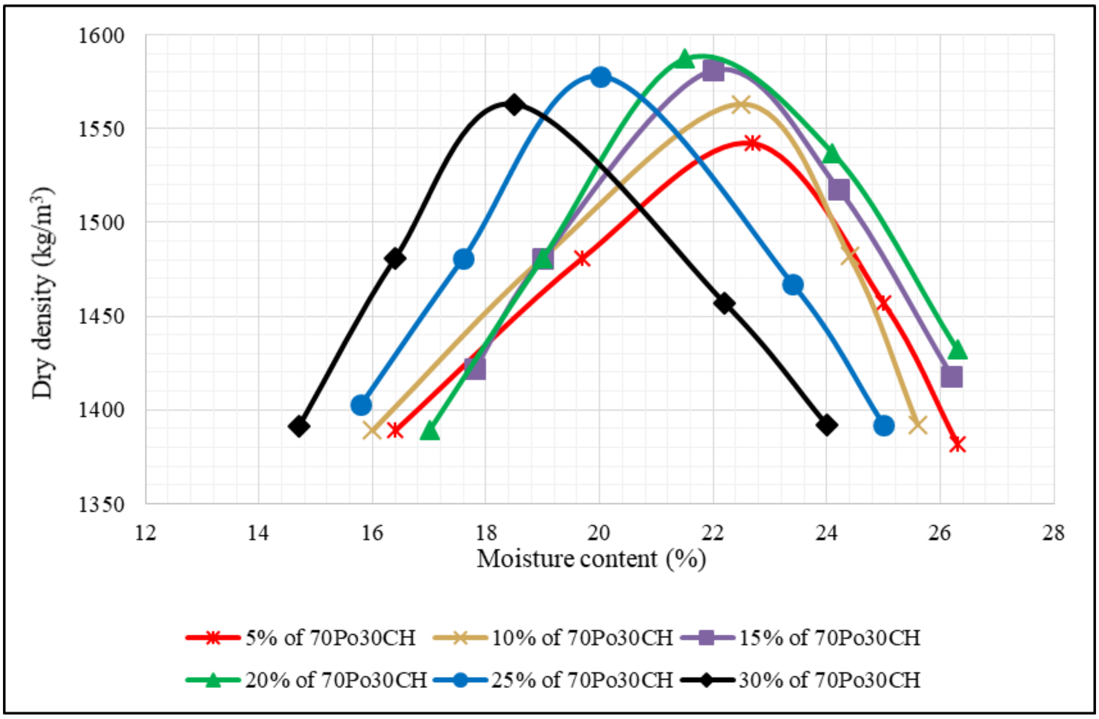

Figure 3B: Compaction curves of Laterite soils stabilized with the 50P50CH binder