

Soil Stabilization Experimentation with Natura l Pozzolana for Cost Effective Road Construction Projects in Tanzania

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Abstract
Subgrade plays an important role in safe and cost-effective pavement construction, given that the materials are suitable but there is a requirement for improvement of both the plasticity and the bearing capacity of local existing soils especially in Dar es Salaam. Laterite soil is a residual soil that has a tendency of being soft when excluded from air and rapid hardening when exposed in air with high resistance to water and air penetration. As a result of wetting and drying process, vertical movements take place in the soil mass that leads to failure of pavement in the form of settlement, cracking and unevenness. Also, the scarcity of the utilization of crushed rock (CRR) and crushed stone (CRS) as base courses material for road pavement construction constitute a problem in some location within Tanzania due to the far location of quarry site and the overall transportation and material costs. Laterite soil is one of the local materials available in some areas, but this type of soil has low strength for road base construction since it exhibits certain unique properties of thermal and mechanical instabilities that make them different from other road construction materials. This often results to their tests results not conforming to conventional specifications requirements and the materials being rejected for use due to much poorer gradings than the local residual granitic gravels such as crushed rock CRR, despite performing very well when used in roads. Statistically, Tanzania reportedly imports about 40,000 tons of fly ash on annual average in the construction sectors. Soil stabilization will go a long way to reduce costs of these importation. The objective of this research is to determine the laterite soil properties after stabilization and the research question is how can we use the natural pozollana to stabilize soil as a solution to the problems created by these soils in construction?
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1. Introduction

In order to do construction in regions of extensive occurrence of sands and laterites, we need to upgrade the soil properties in these areas to make sure they fall within the specified requirements. Improvement factors like bearing capacity and plasticity of weak clay soils is always one of the most important issues in construction of civil engineering projects. The long-term performance of any construction project depends on the soundness of the underlying soil. Soil stabilization aims to improve both load bearing capacity characteristics and workability while at the same time increasing stability and permeability (Netterberg and Pinard, 2013). There are several additives, which are utilized for ground modification such as cement, lime and mineral additives such as fly ash, silica fume, natural pozzolana and rice husk ash. These stabilizers have been used under various contexts. The choice of selection depends on several economic, practical and environmental parameters. Soil stabilization especially with natural pozzolana is a cost-effective method applied among the others due to its reactiveness and uniqueness of locally available pozzolana (Mbakisya,2014). Generally, a natural material with active silica which is an additive for cement is called Pozzolan. The properties of pozzolan are mentioned in ASTM C618 as "a silica or silica alumina material which is not capable of being cemented itself, but can synthesized with Calcium Hydroxide in the presence of water and common heat with powder condition that produces complexes which have properties of being cemented". The use of pozzolans either naturally or synthesized is not only to decrease the cost of cement production (because there is no need for any processing and any other cost to be produced as cement clinker), but also increases the durability of concrete in corrosive environments. In addition, other properties of concrete such as rate of strength gaining, heat of hydration and permeability will be affected positively (Tuncer, 2003). However, the use of natural and synthetic pozzolanic materials with cement not only decreases the cost of cement production but also because of their physical and chemical properties form remarkably an appropriate base to the reform of the properties of concrete.

Since early twentieth century, the mixed cements especially with natural pozzolans were used to decrease the heat of hydration in massive concrete. Pozzolana includes consumer incentives to improve quality (decrease permeability, decrease vulnerability because of synthesize with Calcium Hydroxide resultant of cement hydration and decrease of cement heating), increase of cement producing volume not only without decrease its quality but also with increase of it, reduce energy consumption and therefore helping to preserve the environment and reduce air pollution (Al-chaar and Alkadi, 2016). During mixing of natural Pozzolan in the presence of water the pozzolanic reaction takes place, which is "Calcium Hydroxide + Silica + Water →Calcium-Silicate-Hydrates" (C-S-H) This C-S-H, provides the hydraulic binding properties of the material (COWI, 2004). Pugu is one of the areas in Dar Es Salaam that have this type of soil condition which when its mechanical properties will be improved can be used as sub-base and base course construction material instead of CRR or CRS in road pavement works especially in low volume traffic road. Pozzolana soil in all circumstances is noted by (De Vita, Angrisani and Clemente, 2008) apart from typical features of pyroclastic soils, does not have negligible cohesive in unsaturated conditions. Hence the need for treatment.

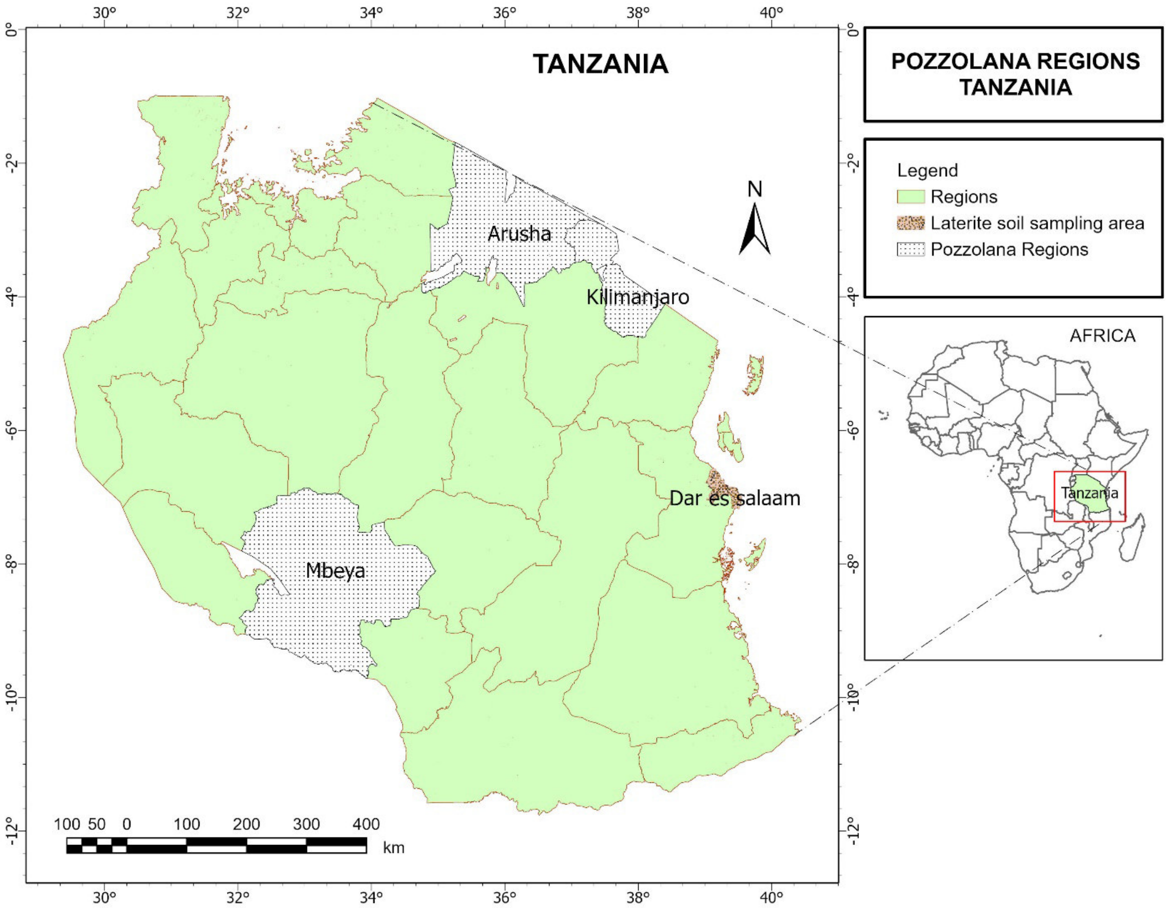
2.0 STUDY AREA

The lateritic soil samples to be used will be taken from Gholani quarry at Kigogo Sokoni area Pugu in Dar es Salaam. The natural pozzolana to be used will be Tembo Pozzi from Mbeya Cement Company. **Pugu** is a Tanzanian town close to Kisarawe about 20 km south-west of Dar es Salaam. It is formally an administrative ward of the Illala district in the Dar es Salaam Region. At the 2002 census, the ward had a total population of 14,652. Pugu is located in a hilly region called the Pugu Hills. The local population is mostly from the Zaramo ethnic group, with a smaller percentage of Makonde people. The village has a large agriculture cattle market, a school, and a mission. A historical cemetery commemorates the German missionaries that were killed here in the 19th century. With a population of over six million people, Dar es Salaam is the largest city in East Africa and the seventh-largest in Africa. Located on the Swahili coast, Dar es Salaam is an important economic centre and is one of the fastest-growing cities in the world. The town was founded by Majid bin Said, the first Sultan of Zanzibar, in 1865 or 1866. It was the main administrative and commercial center of German East Africa, Tanganyika, and Tanzania. The decision was made in 1974 to move the capital to Dodoma and was officially completed in 1996.

3.0 Materials and Methods

This study was fundamentally based on quantitative methodological approach which involved preparations of numerous test samples for computation of volumetric parameters for the mechanical properties of both unstabilized and stabilized samples. Both primary and secondary sources of data were used to achieve the objectives of the study. With regard to the Primary Sources, this involved collections of numerous parameters of engineering properties of prepared samples from the laboratory. Primary data were also collected through laboratory experiments based on CML tests like Sieve analysis, Proctor test, California Bearing Ratio (CBR), unconfined compressive strength and Atterberg limits for both unstabilized sample and stabilized samples. Secondary sources from the following were the methods employed for successful completion of the research; a) Literature Review: This involved extensive surveying of numerous literature that consists of basic information obtained from variety of sources such as articles, journals and previous research papers also this will include the information obtain through field observations and other narrations from experts related to the study.

Materials of laterite soil were obtained from Gholani quarry Pugu area at Ilala municipal where by the lateritic soil samples were packaged in sand bags and transported to the laboratory for testing. During the collection of soil sample for testing, the top soil which were containing vegetable matters and living organism were first removed. Three types of pozzolans which are found in three regions in Tanzania mainland namely Arusha, Mbeya and Kilimanjaro were evaluated in consideration of their chemical composition. Test were carried out on these pozzolans so as to identify the one with better pozzolanic properties, and the pozzolan from Mbeya was found to be superior than the others due to high percentage (silica + aluminium + iron oxide). Stabilizing sample of natural pozzolan was requested and transported directly from Mbeya cement company limited laboratory in Songwe, Mbeya. See below the map showing the regions where Pozzalana are found in Tanzania.



3.3.1 Sampling techniques: Quatering and Riffling techniques were used in obtaining a small representative quantity of even distributed soil particles by dividing large quantity of sample using a riffle box, which divided materials into two equal parts. Then, one of the obtained parts is poured again into the riffle box, until the minimum requirement of quantity of mass to be sieved is met, as described in pavement and materials design manual by the ministry of works.

3.3.2 Sieve analysis Particle size Distribution -Wet Sieving was conducted according to central materials laboratory (CML). The sample for sieve test were air dried and required grams were measured and soaked in water for two hours and washed over 0.063 mm sieve. The retained soil was oven dried after which it was placed on an already prepared stack of sieve with different aperture sizes arranged in a way that every upper sieve had a larger opening than the sieve below. The test sieves were agitated so that soil samples roll over the test sieves and mass of retained soil in each sieve was determined.

3.3.3 Compaction test: Compaction tests aimed at establishing the relationship between compacted dry density and soil moisture content to compaction parameters-optimum moisture content and maximum dry density were carried out. Standard proctor compaction test was performed on the investigated soil in accordance to CML. Lateritic soil was compacted at varying moisture content and then dry densities at respective moisture contents was determined. Compaction curve was then plotted from moisture content and maximum dry density was established. The compaction was achieved by free falling of the 4.5 kg rammer through 300mm in five layers where each layer receiving 27 blows.

3.3.4 Atterberg limit test Atterberg limit was conducted in accordance to central material laboratory (CML Test). The test was done in laboratory by cone penetrometer method. Where air-dry sample passing the 425 µm sieve No 36 was mixed with distilled water and used to determine the consistency limits of the soil. Liquid limit was determined using the Cone Penetrometer Method CML where an air-dry soil sample passing the 425 µm sieve was mixed with water and the soil paste filled in the metal cup and the surface of the soil paste and then released for a period of 5 seconds and the penetration recorded. This test was repeated over for four different moisture contents. The moisture content corresponding to a cone penetration of 20 mm was taken as the Liquid limit.

3.3.5 California Bearing Ratio Test (CBR), was conducted on neat soil. The dry weight required for filling the mould was calculated based upon the maximum dry density (MDD) and corresponding optimum moisture content which will be achieved from standard proctor test. The static method of compacting soil specimen in the

CBR mould will be used. The correct mass of the wet soil will be placed in the mould in five layers and each layer gently compacted with the spacer disc. A filter paper will be placed on top of the soil followed by a 5cm displacer disc. The mould will be compacted by pressing it in between the planets of the compression testing machine until the top of the spacer disc came flush with the top of the mould. The load will be held for 30 seconds then released. The neat soil will be tested after soaking in water for four days. The CBR value will be measured by an empirical test device and is simply the resistance to a penetration of 2.5mm of standards cylindrical plunger of 50mm diameter, expressed as percentage of the known resistance of the plunger to 2.5mm in penetration and at 5.0mm penetration.

4.0 Review of Existing Literatures

Laterite Soil is rock type soil rich in aluminum and iron oxide formed in wet and hot tropical areas by the process known as Tropical weathering (Laterization). Tropical weathering (Laterization) is an intensive and long-lasting weathering of the underlying parent rock at which wide variety in thickness, grade and ore mineralogy of a resulting soil are produced (Netterberg and Pinard, 2013). Laterite soil is a rusty-red soil in color with poor fertility and high clay content which possess greater amount of iron and aluminum oxide. The average index properties of lateric soil, i.e., liquid limit, plastic index, gradation, compaction and CBR varies for different type of laterite soil. In addition, lateritic soils possess a greater amount of iron and aluminum oxides which affect the physical characters of the deposits where they occur. In general, the physical and engineering properties for African countries' laterite soil including Ghana, Senegal, Niger, Gambia, Sudan, Liberia, Gabon, Sierra Leone, Burundi, Ivory Coast, Mali, Uganda, Kenya also Tanzania and the rest of African countries are reported by (Todor and Morin, 2002) to be;

i) Liquid limit (LL) 35 – 69 %
ii) Plastic limit (PL) 19 – 39 %
iii) Plasticity index (PI) 16 – 30 %
iv) Maximum Dry Density (MDD) 1.80 – 2.16 g/cc
v) Optimum Moisture Content (OMC) 10.4 – 21.0 %
vi) Unsoaked California Bearing ratio (CBR) 25 – 100 %
vii) SWELL (%) 0.00- 6.80.

4.1 Material type used for base course layers

Base course layers' materials are indicated by means of code as CRR or CRS for materials made by crushing and screening of hard rocks, G80 or G60 for natural gravel materials, and C2, C1 or CM for stabilized or modified material (Ministry of works,2000), at which refer to materials with certain defined properties as described below:

4.1.1 Crushed Rock (CRR) or Crushed Stone (CRS)

These are the commonly and widely used base course materials in Tanzania, at which they are made by crushing and screening different types of hard rock. In order for these material type to be used as base course layers, they should meet the respective material standard. And the crushed materials falling below the class CRR and CRS should be classified to G80 or lower. Many natural materials (including laterite soil) can be stabilized to make them suitable for road pavements, but this is preferred only when the cost of stabilizing the material is less costly than importing material which can certify the requirement without stabilization (Ministry of works, 2000). Take into account that, the modified or stabilized materials for road pavement layers are classified due to their normal unconfined compression strength (UCS) as: - i) C2 - (Stabilized materials with minimum UCS value of 2 MPa) ii) C1 - (Stabilized materials with minimum UCS value of 1 MPa) iii) CM - (Modified materials with UCS minimum value of 0.5 MPa). The materials that comply as C1 and C2, will certify the requirements for base course pavement materials. The materials classified as C2, C1 and CM for pavements construction, their properties before and after stabilization should comply with the requirements.

4.1.2 Soil stabilization: is the process of improving the physical and engineering properties of a soil to obtain some predetermined target (Ojo, et al., 2016). The purpose of soil stabilization is to enhance the strength of unsuitable material for use as part of road structure in which increased strength is then taken into account in the pavement design process. The process may include the blending of soils to achieve a required gradation or the mixing of commercially available additives that may alter gradation, texture or plasticity or act as a binder for cementation of the soil. In addition, soil stabilization is any treatment applied to a soil to improve its strength and reduce its vulnerability to water. Soil stabilization is important as it improves the engineering properties of a soil, thus making it more stable. Soil properties such as strength, compressibility, workability, swelling potential and volume change tendencies may be altered by various soil stabilization methods (Henry and Chidozie, 2015). There has been argument in the literature about why soil stabilization should be carried out. Reasons for stabilizing soils includes: i) Reduction of plasticity or the swelling characteristics of clays due to moisture change. ii) Reduce permeability iii) Improve soil gradation i.e. particle size distribution iv) Improve the bearing capacity hence increase durability and strength v) In wet weather, stabilization may provide a working platform of construction operations. Choice of soil stabilization method according to (Hensley and Berryman, 2007) includes: i) Soil type: This primarily refers to the particle size distribution and chemical composition. Compaction is not recommended for the grained soils as they are easily powdered and could be blown off. Treatment of some soils that has a lot of sulfates with calcium base stabilizers such as lime and cement can cause extreme swelling of soil. ii) Moisture content: In very dry soils, dust may be formed when the soil is compacted while high moisture content could cause soil particles segregation hence loss of soil stability which may result the soil to become plastic. iii) Site conditions: Physical conditions such as space have to be considered. Stationery continuous method, which requires space where a central unit is to be installed, will not be applicable where there is space limitation. iv) Cost: The method of stabilization chosen must be cheaper than other available techniques. Soil stabilization techniques may be grouped under four main categories; i) Improvement of soil property of the existing soil without using any admixture. For example; Compaction and drainage which improve the inherent shear strength of soil. ii) Improvements of soil property with the help of admixtures such as cement, lime, fly ash, Desirable properties of stabilized materials iii) Strength: The ability to resist shear stresses developed as a result of traffic loading. iv) Resistance to moisture: Ability to resist the absorption of water, thus maintaining shear strength and modulus, and decreasing volumetric swell. The general procedures in soil stabilization are i) Scarification ii) Pulverization iii) Proportioning of materials iv) Mixing v) Add water if any vi) Compacting and vii) Finishing.

4.1.3 Types of soil stabilization: Mechanical stabilization This is the process of altering soil properties by changing the gradation through mixing with other soils, densifying the soil using compaction efforts, or undercutting the exiting soils and replacing them with granular materials. Mechanical stabilization consists of compacting the soil to give effect on its resistance, compressibility, permeability and porosity. The soil is mechanically treated so that maximum air can be eliminated and this contributes to an increase in its density. With mechanical stabilization, the particle size distribution constituting of the material is not affected. But its structure is changed because the particles are redistributed. Mechanical stabilization is widely used in road construction and requires a prior analysis of the soil to determine the optimum water content for better soil compressibility. This type of stabilization is mostly done during compaction, pre-loading and mixing (Henry and Chidozie, 2015). A common remedial procedure for wet and soft soil is to cover it with granular material or to partially remove and replace the wet sub grade with granular material to a predetermined depth below the grade lines. The aim of this compaction of granular layer is to distribute the wheel loads over a wider area and serves as a working platform. Other types of stabilizations include: **Chemical stabilization:** which consists of adding other materials to the soil or chemicals that alter its properties, either by a physic-chemical reaction between particles and the added materials or by creating a matrix that binds or coats the particles. The transformation of soil index properties by adding chemicals such as cement, fly ash, lime or combination of these often the physical and chemical properties of soil including the cementation of the soil particles (Henry and Chidozie, 2015). There are two primary mechanisms by which the chemical alters the soil into a stable sub-grade. i) Increase in particle size by cementation, greater shear strength reduction in the plasticity index and reduced shrink/swell potential. ii) Absorption and chemical biding of moisture that will facilitate compaction. **Drainage stabilization:** This is another type of soil stabilization in which excess water available in pavement structure is removed hence leave the structure stable, Strength and stability of most fine-grained soils will change with moisture content. Improvement of the stability of fine-grained soil requires provision of appropriate drainage system so as to control its water content for inert material that does not undergo volume change due to soaking, the maximum water content (saturation content) can be controlled by applying adequate compaction thereby reducing the voids in between the granular particles (Hensley and Berryman, 2007). But this can be achieved through controlling moisture content either by; i) Providing adequate drainage system such as side drains parallel to the road, miter drains and construction of culverts ii) Raising the road level by filling the embankment. Scholars have also argued on the best method of stabilization, in order to determine the best stabilizers suited for a specific application, it is necessary to have a basic understanding of how each stabilizer works as well as the impact of soil properties. For example, Coating particles, binding particles together, and formation of new compounds are main mechanisms that can occur when using additive. The degree and speed of mechanism depend on the composition of the stabilizer and the material being treated but some stabilizers work independently, while others require water or 15 water plus silica and alumina present in clays to perform such as lime (COWI, 2004). Also, the mineralogy, quantity and particle size of fines in the soil or base can greatly impact the performance of the individual stabilizers. Therefore, most adopted types of chemical stabilizers are; i) Cement used mostly in granular materials ii) Lime used in fine gained soil such as clayey soils iii) Bituminous used in granular soils such as gravels and sand. The general selection of an appropriate stabilizer(s), depends on a number of factors: - i) Soil mineralogy and content like sulphates, organics ii) Soil classification such as gradation and plasticity iii) Goals of treatment iv) Mechanism of additives v) Desired engineering and material properties for example strength, modulus vi) Design life vii) Environmental conditions such as drainage, water table viii) Engineering economics like cost saving against benefits (Hensley and Berryman, 2007). Bitumen stabilization is also noted in some studies as suitable for use in granular soils. Bitumen as a binding agent creates cohesion between soil particles and makes the soil water proof; thus, preventing the loss in strength of the soil due to water penetration. The only problem with bitumen is the difficult in mixing it with soil, thus making it seldom used (Okunuwadje and Osokpor, 2014). Not all materials can be stabilized with cement but the most suitable stabilizing agent depends on the particle size distribution of the soil as determined from sieve analysis and plasticity index (PI) of the soil as determined from the Atterberg limit tests as will be discussed below. The design content of stabilizer expressed as percentage of the dry weight of the soil is determined according to CML tests, and standard specifications for road works, shall not be less than the Initial consumption of Lime (ICL). When mixing, the content of stabilizer should exceed the ICL by 1% point so as to ensure that an irreversible stabilization reaction does not occur.

5.0 Results and Discussions

5.1 Atterberg limits tests.

The soil was stabilized with cement at 4.5%, 5% and 5.5%, then Atterberg limits tests were carried out to determine the Liquid Limit (LL) and Plastic Limit (PL) at all given stabilizer content from which the Plasticity Index (PI) at each stabilizer content were computed. The following data shows the summary results for Atterberg limit tests of the soil sample stabilized at 4.5%, 5% and 5.5% respectively. This range chosen is supported by previous research in Syria where natural pozzolana and lime are added to soil within range of 0%-20% and 0%-8% respectively (Swaidani, Hammound & Meziab, 2016).

The summary results of the soil stabilized with 4.5% of pozzolana.

Table 1: Liquid limit (LL) and plastic limit (PL) at 4.5% results.

Test No.	1	2	3	4	**PL**	**PL**
Moisture content (w) (%)	32.2	36.5	39.5	42.7	25.3	24.0
Cone penetration (mm)	15.5	19.5	22.7	25.4	24.6	

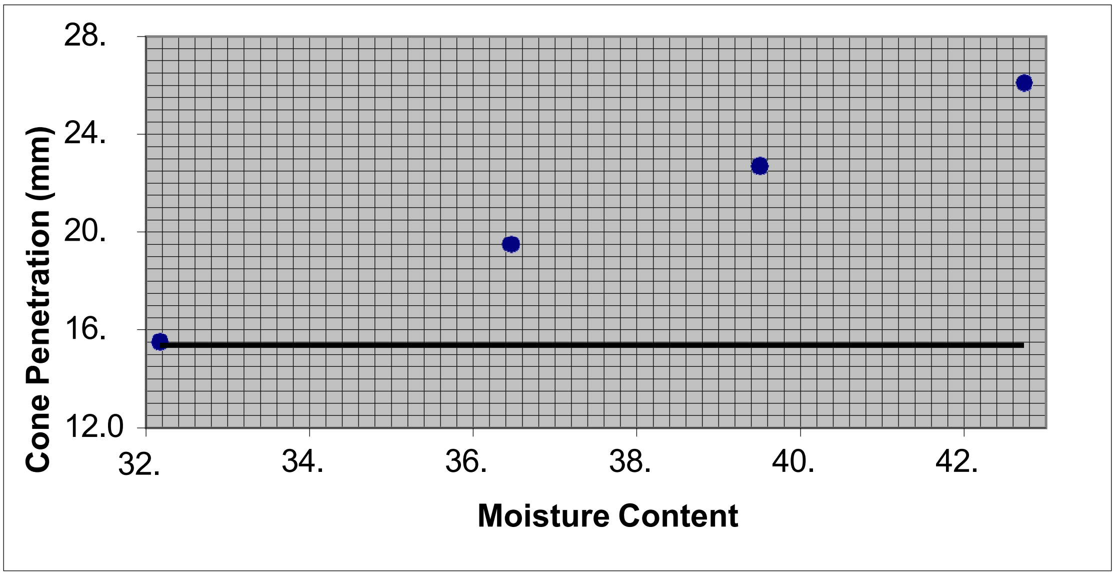


Figure 2: Fall cone Atterberg Limits Results Curve at 4.5%.

Liquid limit (LL)	36.4
Plastic limit (PL)	24.6
L/ Shrinkage (%)	5.1
Plasticity index (PI)	11.8

Source; (Author, 2022)

The summary results of the soil stabilized with 5.0% of pozzolana.

Table 2: Liquid limit (LL) and plastic limit (PL) at 5.0% results.

Test No.	1	2	3	4	**PL**	**PL**
Moisture content (w) (%)	29.6	32.9	35.3	38.4	25.7	25.8
Cone penetration (mm)	15.5	19.2	22.6	24.3	25.7	

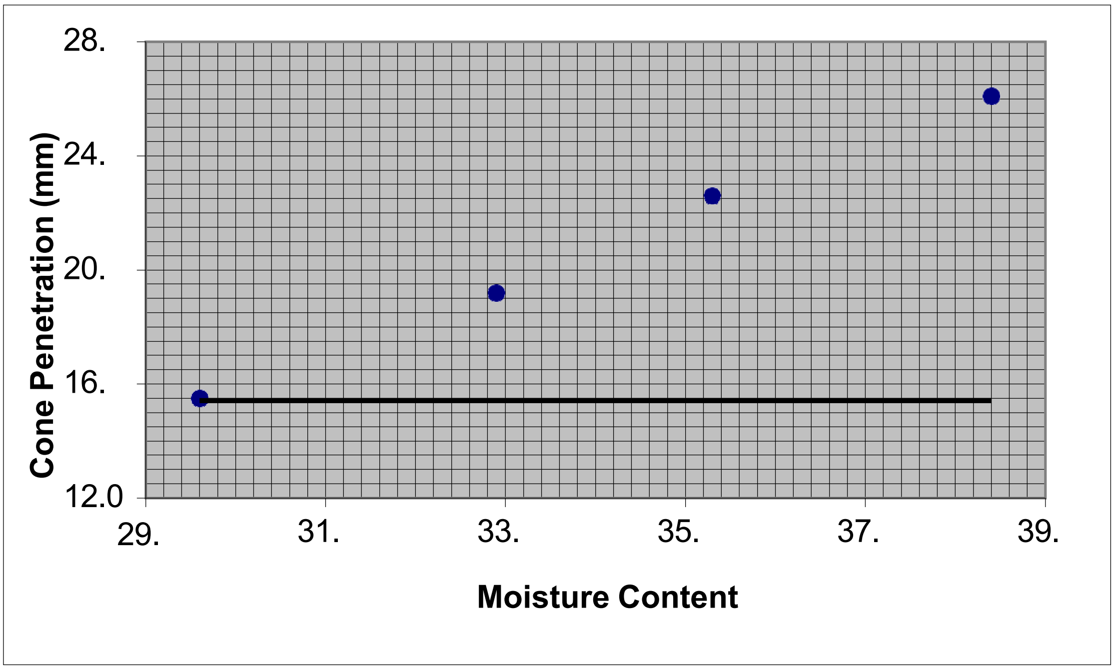


Figure 3: Fall cone Atterberg Limits Results Curve at 5%.

Liquid limit (LL)	33.6
Plastic limit (PL)	25.7
L/ Shrinkage (%)	3.3
Plasticity index (PI)	7.9

Source; (Author, 2022)

The summary results of the soil stabilized with 5.5% of pozzolana.

Table 3.: Liquid limit (LL) and plastic limit (PL) at 5.5% results

Test No.	1	2	3	4	PL	PL
Moisture content (w) (%)	27.8	30.1	32.4	35.3	26.2	26.9
Cone penetration (mm)	16.4	19.3	22.1	24.3	26.5	

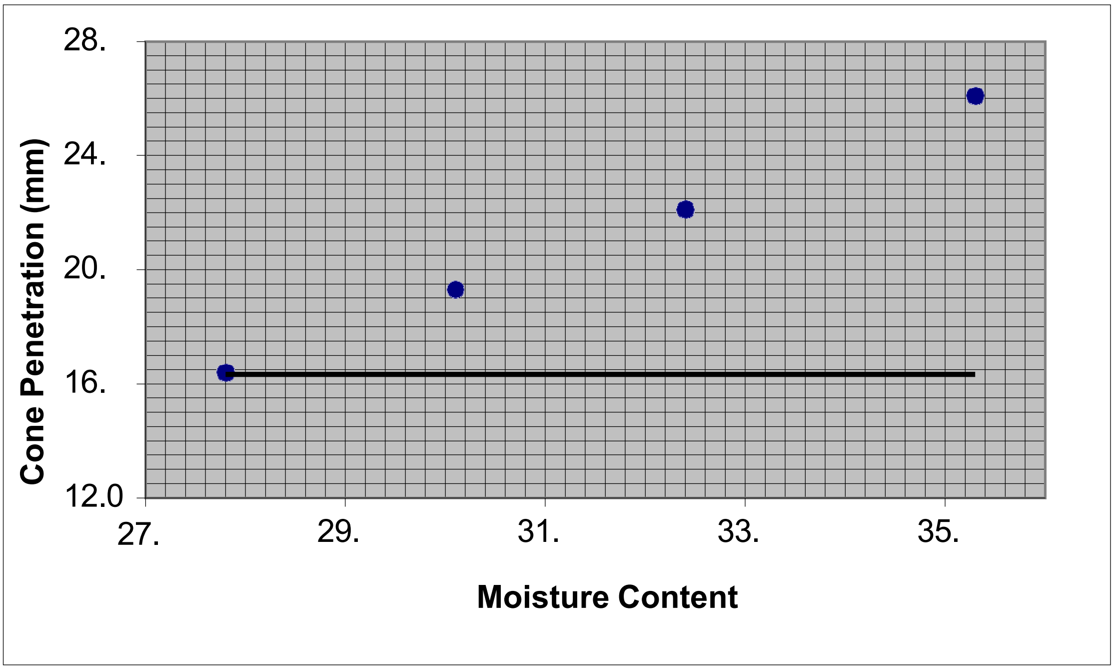


Figure 4.: Fall cone Atterberg Limits Results Curve at 5.5%.

Table 5: Fall Cone Parameters

Liquid limit (LL)	30.6
Plastic limit (PL)	26.5
L/ Shrinkage (%)	2.1
Plasticity index (PI)	4.1

Source; (Author, 2022)

5.1.1 Compaction Test

Compaction test for the sample stabilized at 4.5%, 5% and 5.5% was carried out and the results were summarized and recorded as given below:.

The summary results of the soil stabilized with 4.5% of pozzolana.

Table 6: Summary of Compaction Test after Stabilization at 4.5%

Maximum dry density	1.878 g/cm^3
Optimum moisture content	10.8%
Natural moisture content	5.4%

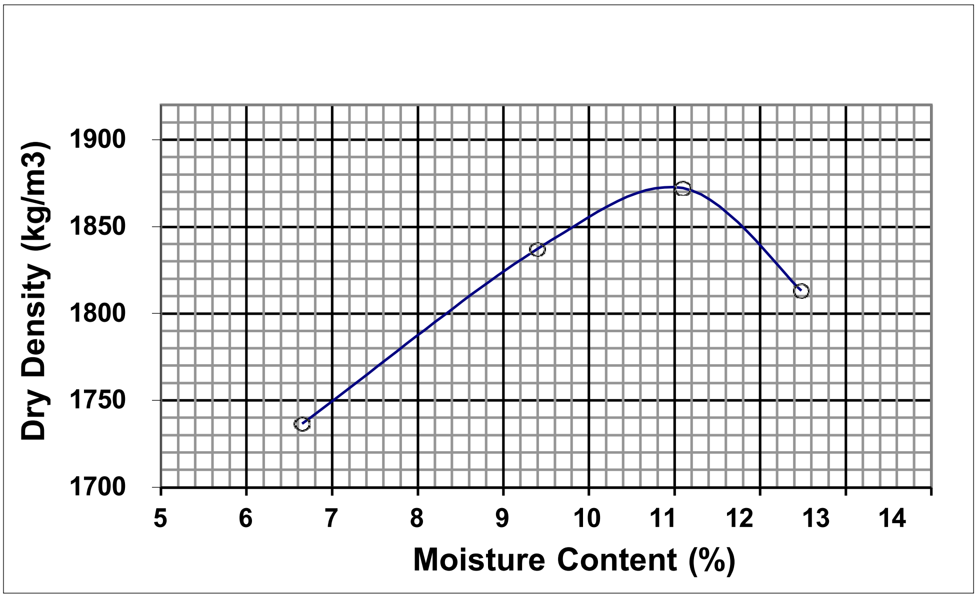


Figure 5: Proctor compaction test results curve for 4.5% of pozzolana
Source; (Author, 2022)
The summary results of the soil stabilized with 5% of pozzolana.
Table 7: Summary of Compaction Test after Stabilization at 5%

Maximum dry density	1.840g/cm^3
Optimum moisture content	11%
Natural moisture content	5.4%

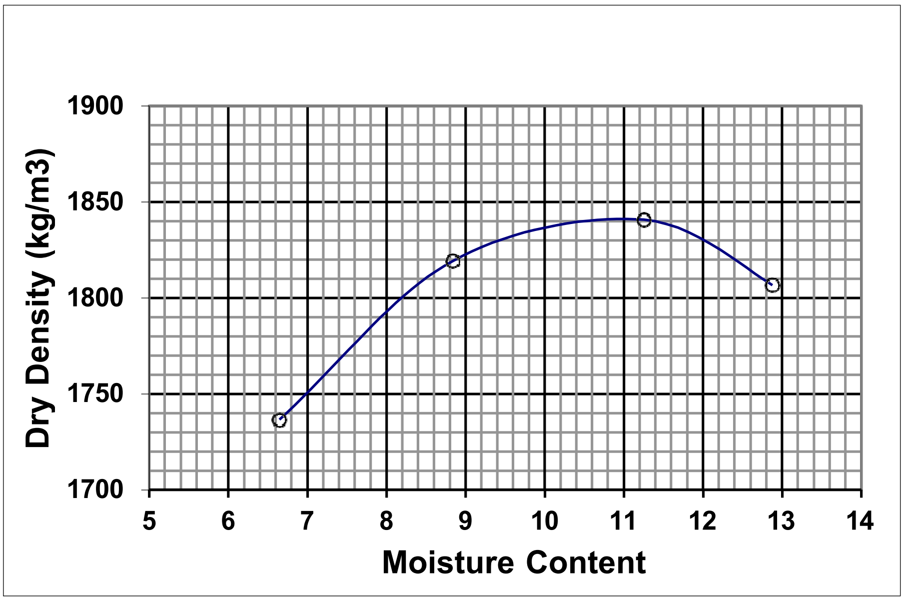


Figure 6: Proctor compaction test results curve for 5% of pozzolana Source; (Author, 2022)
The summary results of the soil stabilized with 5.5% of pozzolana.

Table 8: Summary of Compaction Test after Stabilization at 5.5 %

Maximum dry density	1.809 g/cm^3
Optimum moisture content	11.3%
Natural moisture content	5.4%

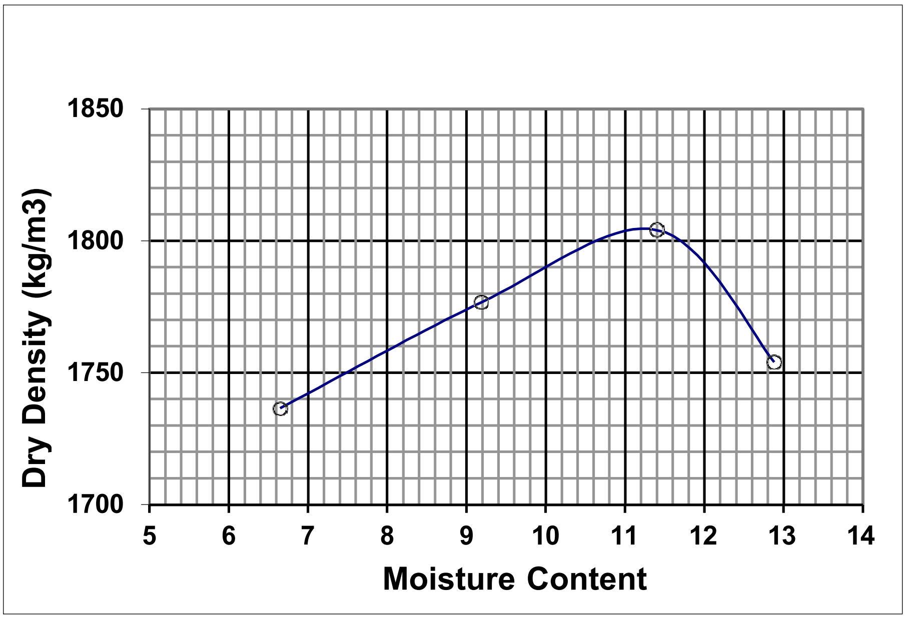


Figure 7: Proctor compaction test results curve for 5.5% of pozzolana Source; (Author, 2022)

5.2 Unconfined Compressive Strength (UCS) Test.

Since the strength of modified / stabilized materials are designed due to their UCS value, then the UCS test were carried out with cement admixture at 4.5%, 5% and 5.5% of pozzolana as the stabilizing agent. While the detailed results for the test at 4.5%, 5% and 5.5% Of pozzolana are shown, here are the recorded test results: -

Table 9: Unconfined Compressive Strength Results at 4.5%, 5% and 5.5% of pozzolana

Pozzolana Content (%)	Ultimate Load Applied (KN)	Individual UCS Value (Mpa)	Average UCS Value (Mpa)
4.5	20	1.1	1.2
	24	1.3	
	22	1.2	
5.0	35	1.9	1.8
	29	1.6	
	33	1.8	
5.5	38	2.1	2.2
	42	2.3	
	38	2.1	

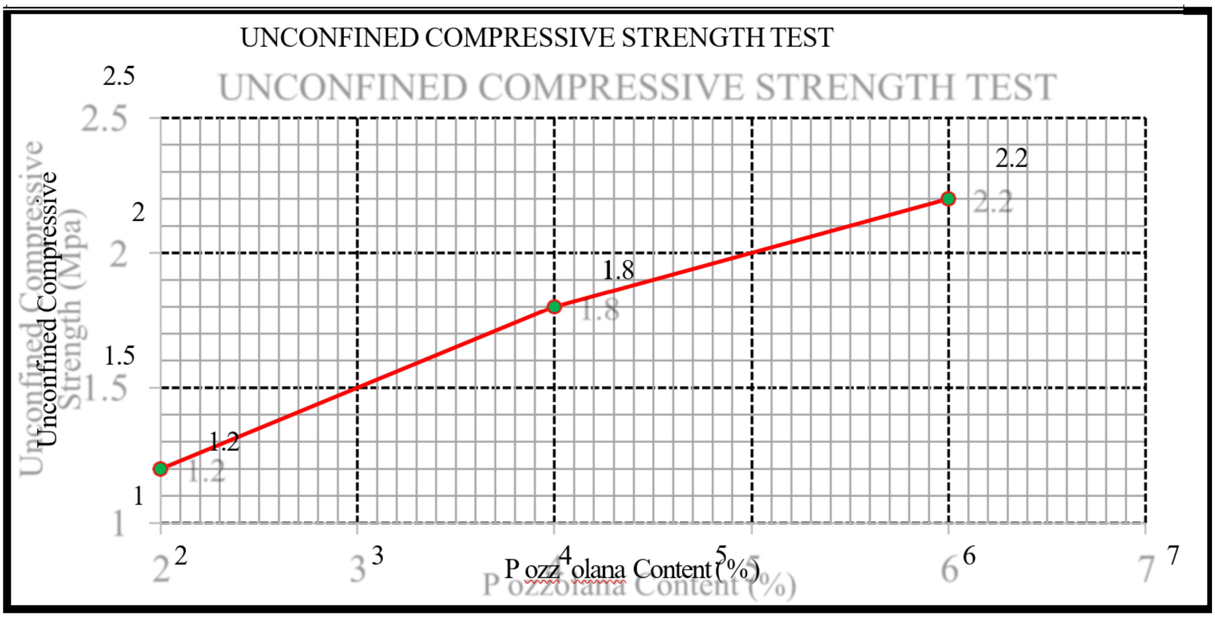


Figure 8: Unconfined Compressive Strength Results Curve at 4.5% - 5.5%.
Source; (Author, 2022)

5.3 Discussions

The information obtained from Atterberg Limits tests after stabilization shows that from 4.5%, 5% and 5.5% content of pozzolana, there was a slight increase in Liquid Limit as compared to that of unstabilized soil while from 4.5%, 5% and 5.5% of pozzolana content the Liquid Limit started to decrease as the percentage (%) of pozzolana increases. The results show that, the plastic Limit was increasing as well as the pozzolana content increase. The overall effect of stabilization with natural pozzolana on Plasticity characteristics is the reduction of plastic index (PI) of the soil which decreased from 10.86%, to 3.87% at 4.5%, 5% and 5.5% of pozzolana respectively. This result is also in agreement with previous studies and result by (Harichane, Ghrici, Kenai & Grine, 2011) which shows that cohesive soils can be successfully stabilized by combing natural pozzalana and lime.

5.4 Conclusions

According to Tanzania Standard Specification for Road Works, the properties of laterite soil before and after stabilization as the results from different tests carried out in this study show that, the soil sample mixed with pozzolana at 4.5% and 5% has certified the requirements as C1 and CM material classes. Although all the materials stabilized at 4.5%, 5% and 5.5% of pozzolana archived the required UCS values as C2, C1 and CM material classes, but 5% and 5.5% of pozzolana the CBR value before stabilization was 15% which is less than the minimum required (30%) for C2 material class, and at 5.5% the material has PI of 10.07% after stabilization which is greater than the maximum required (8%). Therefore, with these reasons the materials should not be used as a C2 material class. Laterite soil was characterized through sieve analysis and Atterberg limits, then by AASHTO soil Classification system, the soil was classified as A-2-6 Silty or clayey gravel and sand. Using 4.5% and 5% of pozzolana will be adequate to stabilize the soil in order to obtain a normal UCS value of at least C1 material class. Natural pozzolana improved the properties of the soil by decreasing PI of the soil and increasing the normal UCS value of the soil. Laterite soil can be used as a base coarse material for roads designed at C1 material class.

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