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Stabilization of Lateritic Soil for Unpaved Roads Using Molasses in Butere-mumias District, Kenya

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Abstract:
This research examined the mechanism of Stabilization of Lateritic Soil with Cane Molasses. The main objective of the study was to establish whether or not sugar cane molasses can be used as a stabilizing agent on the wearing course on unpaved roads. Other objectives were; to carry out strength assessment of neat lateritic soil and lateritic soil mixed with cane molasses as reflected by California Bearing Ratio [CBR] and to determine the optimum mix ratio of molasses to lateritic gravel required for stabilization. Cane molasses was selected for this purpose because it contained some elements/compounds which are known to react with lateritic soil and change characteristics of the soil. Quantities of molasses in the ratios of 1%, 2%, 3% and 4% were mixed with pre-determined ratios of soil samples and tests done on mixed samples. From the sample chosen along the Bukura-Shibuli road, the tests carried out included Particle Size Distribution, Atterberg Limits, Proctor Compaction, Unconfined Compressive Strength (UCS) and California Bearing Ratio (CBR). It was established that 2% cane molasses by weight of dry soil was the optimum for effective stabilization of lateritic soil. The conclusion was that the increase in CBR values for lateritic soil mixed with cane molasses above those of neat lateritic soil was an indication that cane molasses caused the increase in soil strength. Therefore, Industrial wastes like molasses have significant potential and should be used in place of conventional material for gravel wearing course constructions and should be projected for future construction.

Keywords: *wearing course, lateritic gravel stabilization, molasses, Unconfined Compressive Strength, CBR value.*

1. Introduction

Many parts of the Sugar Cane growing zone within Butere-Mumias District in Kakamega County of Kenya are mostly rural and the roads used for transportation of cane from farms and for access are mostly unpaved roads. However, these roads deteriorate too fast due to the poor methods of stabilization of the gravel wearing course. The lateritic gravel when in use as wearing course is intermixed with sand and little proportions of clay with stones sized roughly between 5 and 15mm. Most gravel is found in quarries which are dug at approximate depth of 1000 – 2500mm where large concentrations of gravel are obtained. However, the gravel used has diminished with time as more has been excavated from the gravel pits for the purpose of maintenance of surface courses on unpaved roads. Trailers while transporting cane exert a lot of pressure on the unpaved roads due to increased loads.

Jan (2012) published a patent and records that the wearing course for gravel roads should have a hard and even surface and yet be elastic in order to withstand traffic and weather, in order not to generate dust and to manage the ground frost in the winter. He further records that the wearing course should comprise additives of starch, kaolin, lime, cement, vegetable substances, minerals or chlorides.

Various methods have been used to stabilize gravel for wearing course surfaces. Lim *et al.* (2014) carried out research on Stabilization Techniques of Rural roads. They attempted to bring together Soil Road Stabilization technologies for the extremes of dry and wet conditions. The methods notably mentioned for stabilizing gravel wearing course surface included:

- Chlorides: They include Calcium Chloride in liquid form, Magnesium Chloride in liquid form and Sodium Chloride (Road Salt). They facilitate compaction and promote soil stabilization. These products are very effective if used. They are also simple to use but can be expensive.
- Resins (Lignosulfonates): These are products available as stabilizers. The basic composition is lignin sulfonate which is a by-product of pulp milling industry. The products work best when incorporated into the surface gravel. Lignosulfonates also draw moisture from the air to keep the road surface moist. However, these products are not readily available within Butere-Mumias region.

- Electrolyte emulsions: They contain chemicals that affect the electro- chemical bonding characteristics of soils and replace water molecules within the soil structure. The treated soil loses its affinity for water. When applied at low rates to the surface of the unbound road surface, electrolyte emulsions perform well for dust suppression.

According to a bulletin on trade notes published by the Institute of Economic Affairs whose publisher is Trade Information Programme Issue No. 8 of August, 2005: sugar production in Kenya was at 450, 000 tons of sugar per annum. For every tone of sugar produced we obtain a ⅓ of a ton of molasses.

Of the 450, 000 tons of sugar produced annually in Kenya, Mumias Sugar Company produces 270, 000 tons of sugar meaning that out of the 270,000 tons of sugar, Mumias Sugar Company produces 90,000 tons of molasses annually.

The National guide for Sustainable Municipal Infrastructure - Canada (2005), notes that the control or minimizing of dust from unpaved roads in rural and urban areas can be done by using dust suppressants. It also informs that inhaling fine dust particles can be a health hazard to road users and residents.

This research determined the suitability of using molasses to stabilize Lateritic Soil for unpaved roads in the Butere-Mumias District, without making use of Chlorides, Resins or Electrolyte emulsions mentioned above.

2. Materials and Methods

2.1. Materials

- Lateritic gravel soil: The lateritic soils were encountered in an already hardened state. The soils obtained comprised of a wide variety of red, brown, and yellow fine grained residual gravels and cemented soils. They were characterized by the presence of iron and aluminum oxides or hydroxides, which gave the colors of the soils (Olugbenga, 2011). The lateritic soils identified came in a variety of material combination i.e. clays, sands and gravels. When the laterites were exposed to air or dried out by lowering the ground water table irreversible hardening occurred producing a material suitable for use as a road stone.
- Molasses: Analysis of molasses according to Shirsavkar et al. (2010) revealed that its major component was sucrose which is literally sugar. Sugar has various component groups and hydroxyl (OH) group was unique and responsible for the properties of sugar and thus those of molasses. Through the hydroxyl group molasses is capable of hydrogen bonding. Hydrogen bonds are intermolecular bonds caused by presence of hydrogen atoms directly attached to electronegative elements like oxygen which resulted in partial positive and partial negative charges that attracted. The attractive force due to presence of hydrogen therefore, makes molasses adhesive. As molasses is positively charged it is easily attracted to the surface soil mineral particles as they are negatively charged.

2.2. Methodology

The research design involved evaluating determination of strength and properties of gravel wearing course (lateritic gravel) material to be stabilized using molasses. The tests carried out included:

- Particle Size Distribution: This was done to determine the percentage particle size distribution of a given sample of lateritic gravel. The particle size distribution in a material down to the fine sand size was carried out in accordance with BS 1377; Part 2; 1990 – Wet sieving method.
- Atterberg Limit Tests: The Atterberg Limits determined included Plastic Limit, Liquid Limit and Plasticity Index. The liquid limit and the plastic limit was obtained in the laboratory according to BS 1377; Part 2; 1990, from which the plasticity index was determined. Plasticity Index was calculated using the following equation: $PI = LL – PL$
- Compaction Test (Proctor): This test was done to determine the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) of the neat and treated lateritic gravel. The test was carried out in accordance to BS 1924; Part 2; 1990, using a 2.5 kg rammer in accordance with AASHTO T 99 except in place of 4.75mm and 19.0mm test sieve, the 5.00mm and 20.0mm test sieves were used.
- California Bearing Ratio: CBR Test was done to determine the strength of the lateritic gravel and how it would behave when subjected to loading. The test was carried out according to BS 1924; Part 2; 1990, where CBR moulds complying with AASHTO M193 were used instead of the BS moulds.
- Unconfined Compressive Strength: This test was done to determine the Unconfined Compressive Strength of the soils stabilized with molasses additive which binds the particles together. The test was carried out in accordance with BS 1924; Part 2; 1990. The specimens were compacted to pre-determined density.

3. Results and Discussion

3.1. Chemical Properties of Molasses

The chemical properties of molasses were found out to be as follows:-

S/No.	Chemical Composition	Description	Molasses
1.	MnO	Manganese Oxide	0.37
2.	TiO_2	Titanium Oxide	0.55
3.	S	Sulphur	4.66
4.	C1	Chlorine	1.47
5.	P_2O_3	Phosphorus Oxide	2.64
6.	$Si\ 0_2$	Silicon Oxide	5.77
7.	$K_2\ 0$	Potassium Oxide	39.11
8.	Ca 0	Calcium Oxide	26.12
9.	Mg0	Magnesium Oxide	13.54
10.	Na 0	Sodium Oxide	0.07
11.	$Fe_2\ 0_3$	Iron Oxide	2.44
12.	AI_20_3	Aluminum Oxide	2.95

Table 1: Chemical Composition of Molasses

- Particle Size Distribution: In this research it was found that the grading after compaction of the lateritic gravel was well within the standard particle size distribution envelope for gravel wearing course material requirements as set out in the Road Design Manual part III for Materials and Pavement Design published by the Ministry of Transport and communication 1987, The quantitative determination of the particle size distribution in the lateritic gravel soil from the coarse sand down was carried out in Accordance with the BS 1377; Part 2; 1990, and the results are as shown in figure 1 below.

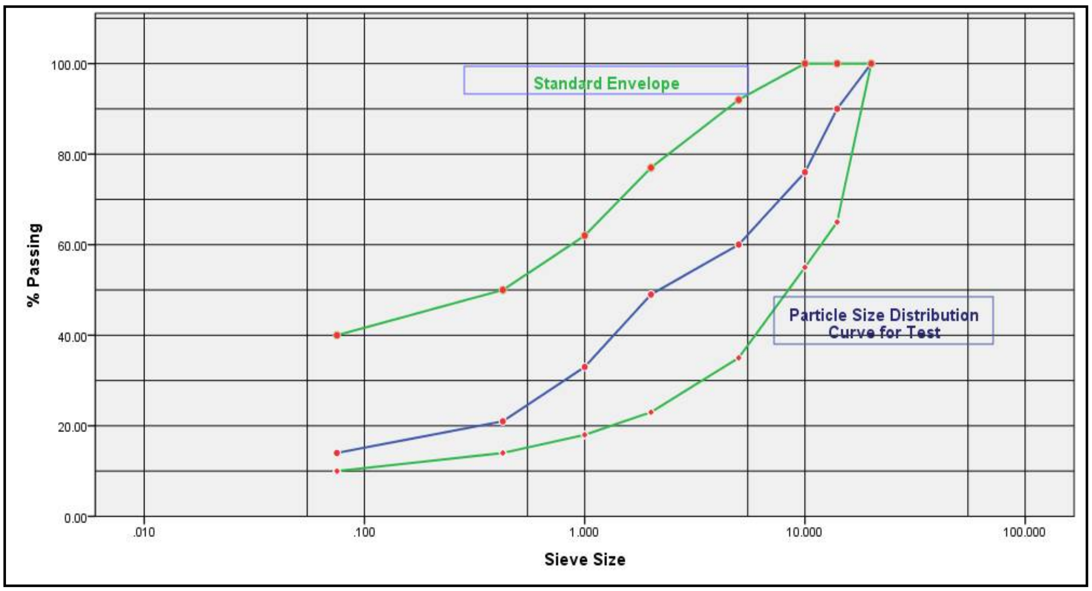

Figure 1: Particle Size Distribution curve comparison

It was found out those particles above size 20 mm had 100% passing whereas 90% of the particles were passing on the 14-mm sieve. The 10-mm sieve had 76% of the particles passing through each as the 5 mm and 2 mm sieve had 60% and 49% passing them respectively. The finer material had 33%, 21% and 14 % of them passing the 1 mm, 0.425 mm and 0.075 mm sieves respectively.

- Atterberg Limits: Molasses when added to lateritic gravel as a stabilizing agent led to particle aggregation which led to lowering of the liquid limit of the soil while the plastic limit was raised (Mogute, 2014). The results are presented in figure 2 below. It was found that, with additions of 1 % molasses to the lateritic gravel, the liquid limit for the samples gave an average of 37.8 % while the plastic limit gave an average of 22.9 giving a plasticity index of 14.9 % i.e. (PI=LL-PL) 14.9 =37.5-22.9. The addition of 2 % molasses resulted in a PI of 10.7 i.e. LL of 33.5 – PL of 22.8. The addition of 3 % molasses resulted in a PI of 22 after giving an LL of 37.7 and PL of 15.7. Finally, the addition of 4 % molasses resulted in an increase of PI of 31.6. According to the Road Design Manual part III published by the Ministry of Transport and communication 1987, which sets forth the policy and standards to be adopted for the design of roads in Kenya, the plasticity requirements for gravel wearing course materials show that, in wet areas, the Plasticity Index should range between 5 and 20, whereas in dry areas it should range between 10 and 30.

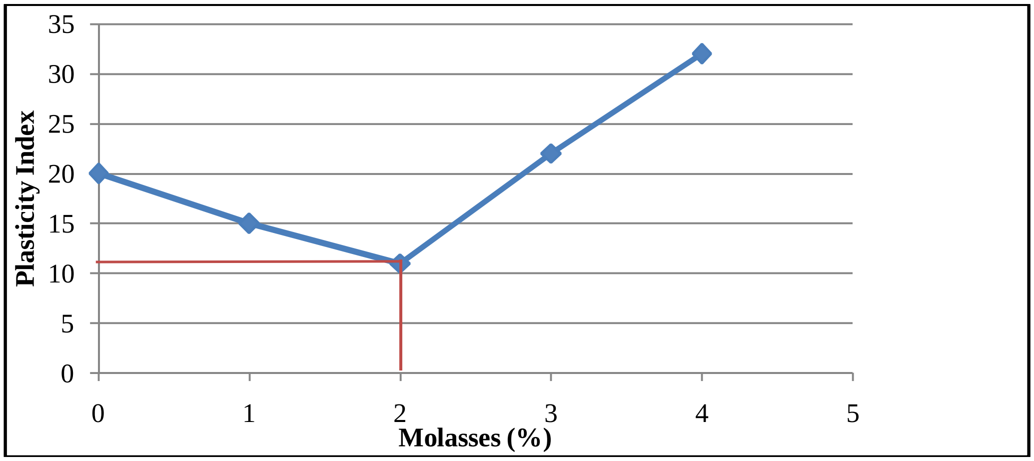

Figure 2: Optimum Molasses Required

- Compaction: The values for MDD were noted to significantly increase with the addition of molasses from a neat value of 1720 kg/m^3 to a maximum value of 2100 kg/m^3 attained with a 3% molasses after which it falls to 1705 kg/m^3 with a 4% molasses addition. The optimum value of 3% molasses represents the optimum percentage of molasses required for stabilization. The MDD increased with the increase in molasses percentage but with excess molasses of 4% there was a drop in the MDD. The OMC was found to increase from 10.13% to 18.75% with addition of 1% to 4% molasses, after the 7days cure and 7days soak period.

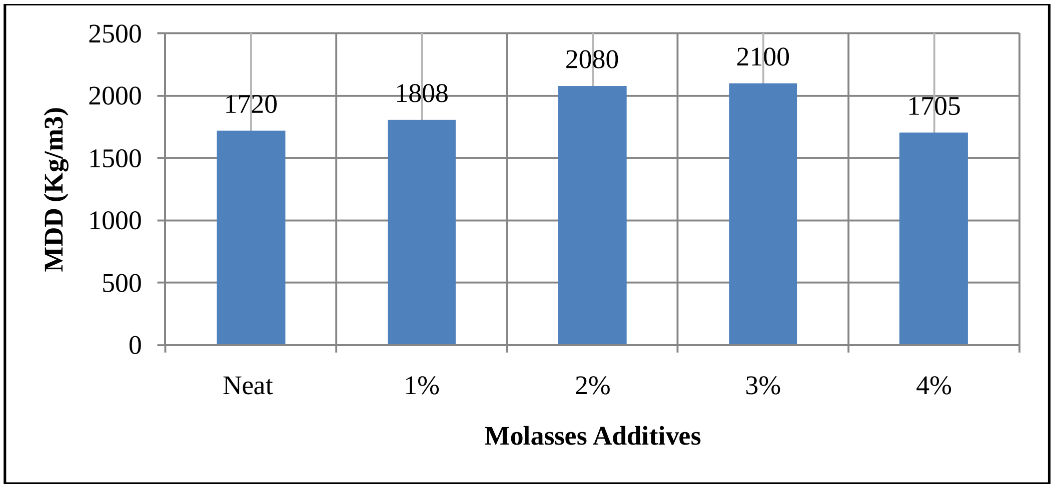

Figure 3: Maximum Dry Density Chart

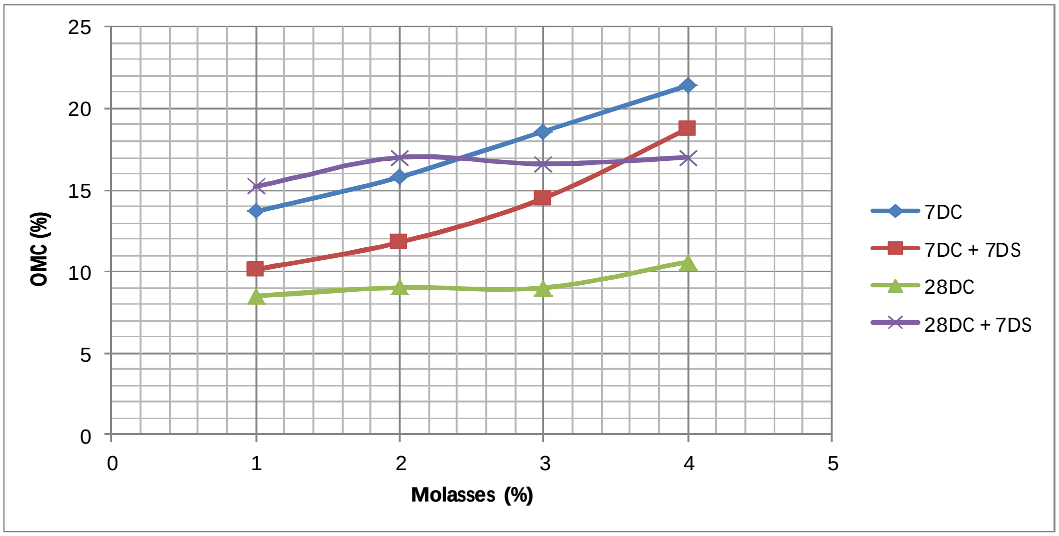

Figure 4: Optimum Moisture Content

- Unconfined Compressive Strength: The results of the Unconfined Compressive Strength (UCS) of the stabilized gravel soils are presented in figure 5 below. It was a general observation that the UCS for the cured lateritic gravel soils were higher than the uncured ones, it was also observed that as the soils were stabilized their UCS continued to increase to a certain level of stabilization percentage, however as more molasses was added to the samples i.e. 3% and 4% the UCS for both cured and uncured soils reduced considerably.

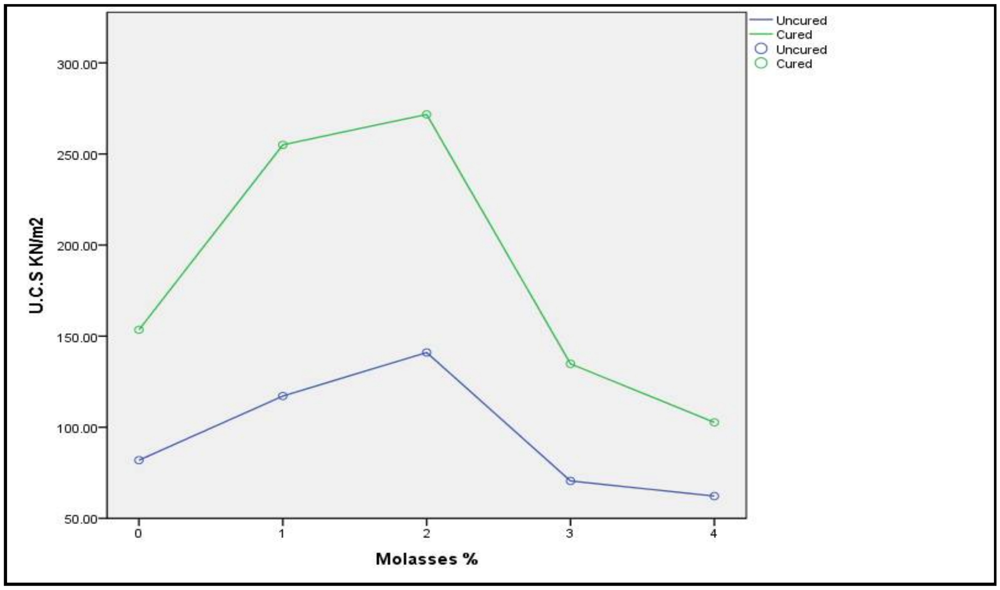

Figure 5: Unconfined Compressive Strength of soils

For uncured samples, the U.C.S increased to 141kN/m^3 after addition of an optimum amount of 2% molasses after which subsequent additions resulted to a drop in U.C.S. Similarly, for the cured samples the U.C.S increased to 271.70kN/m^2 after addition of 2% molasses, after which subsequent additions resulted to a drop in the UCS. The compressive strength values for the cured stabilized samples gained strength over time; this was because the moisture which was lubricating the contact areas of the stabilized soil had been released by curing thus increasing the friction between the particles. Therefore, a higher load was required to deform the cured samples. It was found out that the optimal values for the uncured and cured were obtained with a 2% molasses addition at U.C.S 141kN/m^3 and 271kN/m^3 respectively.

- California Bearing Ratio (CBR): The results for CBR covered tests ranging from neat gravel soaked for 4 days. It also covered gravel which was soaked for 7 days and cured for 7 days after addition of 1% to 4% molasses. Finally, the tests included those carried out on lateritic gravel after addition of molasses in percentages ranging from 1% to 4% and subjecting them to 28 days cure and 7 days soak. It was a general observation that the values for lateritic gravel soil stabilized with optimum molasses content were generally higher than those of neat sample under similar conditions.

The molasses content and curing duration of the specimens before testing had an effect on CBR values. Increasing the molasses content in the soil resulted in increased CBR values of the soils. This trend conforms to findings of Shankar et al. (2009), who found that the CBR value of the lateritic soil increased by 300% after four weeks of curing the molasses and bio-enzyme mix. However, further increase beyond 2% molasses resulted in the reduction of CBR values. It was also observed that the higher the optimum moisture content, the lesser the CBR value.

The moisture content therefore was a major factor which caused detrimental effect on load- bearing capacity of the lateritic gravel soil. It was visualized that free water which was absorbed into the soil specimens during soaking increased the water content of compacted soil specimens. It occupied the pore spaces within the compacted soil mass. When the load was applied to bear on the soil during testing, pore pressures were increased. They therefore pushed soil particles apart and in so doing, reduced the contacts between them.

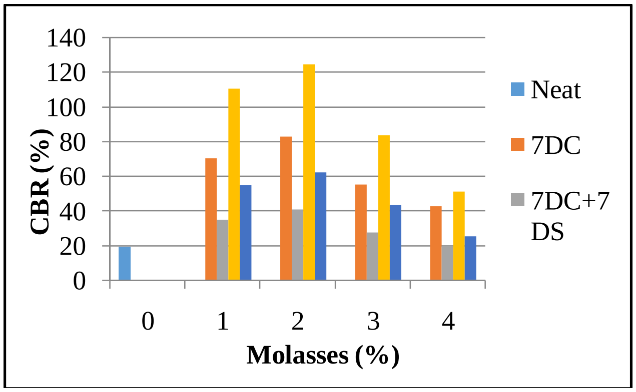

Figure 6: Summary of CBR Test Results

4. Summary

Industrial wastes like molasses can be utilized on unpaved roads in order to alleviate poverty through provision of standard unpaved roads which will ensure smooth operation of vehicles and reduce dust pollution within the Butere-Mumias Sugar Cane growing areas. According to Shirsavkar et al. (2010), molasses when used to stabilize lateritic soils can help save on costs incurred on unpaved road maintenance as the molasses binds the soil particles more stronger than if the soils were used alone.

5. Conclusions

1. Stabilization of lateritic soils with molasses increased the CBR, UCS and Compaction Values (MDD) thus the load bearing ability of the soil to 40.9%, 141kN/m^3 and 2070kg/m^3 respectively. The PI reduced from 20.27 to 10.0This conformed to the Road Design Manual part III for Materials and Pavement Design for new roads in Kenya, published by the Ministry of Transport and communication 1987, which sets a minimum CBR of 20% and PI of between 5 and 20 in wet areas and 10 to 30 in dry areas. Addition of beyond 2% molasses renders the lateritic soils unsuitable as wearing course surfaces.
2. The optimal value was found to be 2%
3. It was also observed that molasses contained major mineral elements which are active in causing chemical reaction involving cation exchange. According to Levett(1992), such elements included Calcium, Magnesium and Potassium. These elements are known to react so actively with lateritic soils to bring about stabilization

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