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EFFECTS OF INSITU MOISTURE CONTENT ON PAVEMENT OF LOW VOLUME SEALED ROADS

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Abstract

Purpose: This paper seeks to assess the effects of the in-situ moisture on pavement and subgrade strength. This is done through determination of in-situ CBR and DCP correlations at varying moisture regimes. When tested using the DCP device to assess the in-situ conditions the information can be used to identify uniform section, the layer strength diagrams and this can be used to determine layer depth, quality and in-situ moisture.

Methodology: Two roads with varying climatic conditions, soil types but almost similar traffic levels were identified for this research. The Road sections were D470 Kyeni – Karurumo and E628 Wamumu Karaba. The tests on the roads pavement were carried out in three stages: Before construction, During construction and After allowing traffic to flow. Samples were taken from the road section before any improvement for testing. The test included; Classification test including grading, atterberg limits and linear shrinkage, Compaction test including MDD and OMC, Strength test including CBR soaked, OMC and 0.75 OMC, Pavement layer properties including IDD and MC, Field confirmation of road side drainage

Findings: The study found out that that the more the in-situ moisture is reduced from the pavement structure the stronger the pavement. Knowledge of the inter relationship between the moisture, density and strength of the material used in the construction of LVSRs provides critical insight into how to use such materials to ensure good performance in the prevailing road environment.

Unique Contribution to Theory, Practice and Policy: The unique contribution of the research is acceleration of the improvement of road construction through correlation of DCP-CBR and allowing use of locally available materials.

Keywords: *In-Situ Moisture, DCP, CBR*

1.0 INTRODUCTION

Sustainable upgrading of unsealed roads to a low volume sealed standard is best accomplished by maximizing the use of the in-situ materials within the prevailing road environment. Over the years and under traffic loading, unsealed roads achieve a significant degree of subgrade compaction by which localized weak areas tend to become strengthened and an accumulation of residual gravel wearing course provides a sound support or foundation for the new road. Optimizing the use of these conditions usually results in a reduction in the need to import large quantities of virgin material (Paige-Green & Overby, 2010)

Appropriate testing with the simple Dynamic Cone Penetrometer (DCP) device can be used to assess the in-situ conditions including material quality and moisture regimes along the road alignment. This information can be used to identify uniform sections; the in-situ layer strength diagrams of each of these sections can then be analyzed to determine the layer quality and thicknesses for a sustainable design (Kleyn, 1984). In -situ moisture affects the performance of Low Volume Sealed Roads before, during and after construction and opening to traffic. Moisture will vary during the dry and wet seasons hence affecting the strength of the road under traffic loading.

The introduction and appreciation of the low volume sealed road technique in Kenya will herald a new era in more efficient and effective road network. In so doing it will make a substantial contribution to the improved infrastructure of the country and in the process enhance economic growth and reduce poverty.

Objective of the Study

This project’s objective is assessing the effects of changes that occur in the performance of low volume roads as a result of the environmental changes, to determine critical factors affecting the performance of low volume seals roads during design, construction and post-construction. This study will also determine the in-situ moisture content and pavement strengths, the pavement bearing capacity after traffic flow and the characteristics of all pavement layers and the subgrade of low volume sealed roads after traffic flow. I would therefore recommend the use of DCP tool in the design, construction and post construction of low volume sealed roads.

1.2 Typical Low Volume Road Pavement structures

Pavement conditions is monitored in terms of moisture, strength (in-situ CBR measured with DCP), density, riding quality (roughness), deformation (rutting) and deflection at the end of each wet and dry surface conditions.

According to Bradbury et al. (2005) Cross-sections within each test section were tested with the DCP. The number of measurement positions chosen depended on the width of the road, but always included the outer and inner wheel-tracks (OWT and IWT, respectively) and the Centre-line (CL). Further measurement positions were concentrated between the outer wheel-track and the shoulder. The longitudinal measurement position was relocated about one metre further along the road in each successive survey. Thus, over time, there were only relatively small variations in the measurement position, and results from successive surveys are comparable. The transverse measurements at these locations were always made at the same offset positions.

1.1.1 Road Level

The crown height of a LVSR, i.e. the vertical distance from the bottom of the side drain to the finished road level at the centre line, is a critical parameter that correlates well with the in-service performance of pavements constructed from naturally occurring materials. This height must be sufficiently great to prevent moisture ingress into the potentially vulnerable outer wheel track of the carriageway for which a minimum value of 0.75 m is recommended (SATCC 2003).

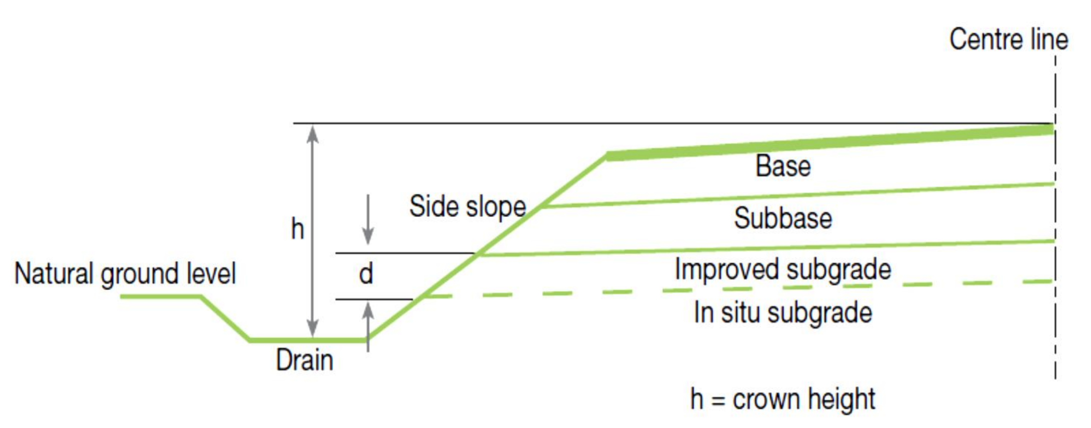

Figure 1: Crown height for LVSRs –SATCC 2013

The recommended minimum crown height of 0.75 m applies to unlined drains in relatively flat ground (longitudinal gradient, g, less than 1%). The recommended values for sloping ground (g > 1%) or where there is lined drains. In addition to observing the crown height requirements, it is also equally important to ensure that the bottom of the sub-base is maintained at a height of at least 150 mm above the existing ground level. This is to minimize the likelihood of wetting up of this pavement layer due to moisture infiltration from the drain. Because of the critical importance of observing the minimum crown height and minimum height of the bottom of the sub-base above existing ground level, along the entire length of the road, the measurement of this parameter should form an important part of the drainage assessment carried out during and before construction. This is to ensure that any existing drainage problems associated with depressed pavement construction, often observed on gravel roads that have evolved over time with no strict adherence to observing minimum crown heights are avoided (SATCC 2003).

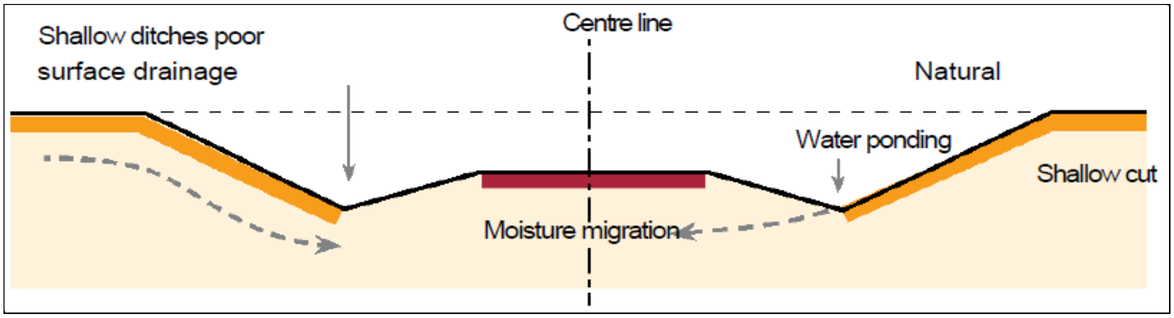

Figure 2: Potential drainage problems of LVRs - SATCC 2013

1.2 Traffic and loading

Accurate quantification of the traffic that the road will carry is essential. This, is however, considered to be a much bigger problem on lightly trafficked roads than on more highly trafficked roads. The main reason for this is that the small heavy vehicle counts normally obtained on such roads are dramatically affected by any intermittent or temporary (often seasonal) increases in traffic arising from the development of new infrastructure along the road, seasonal agricultural traffic and intermittent mining traffic. A sudden but small increase in heavy traffic can have a severe effect on the estimation of the overall cumulative standard axle estimation. It is thus vitally important that traffic counts capture all of the traffic using the road – this may require 24 hour counts, often during various seasons and at different times of the local commercial cycles, and should include axle weight surveys where necessary (Paige-Green & du Plessis, 2009).

Many better quality unsealed roads attract overloaded vehicles that avoid higher standard roads in order to minimize the possibility of being caught and prosecuted for overloading. Indeed, the possibility that unsealed roads may attract such traffic after sealing should also be assessed.

The traffic counts need to be converted to cumulative standard axles (in terms of 80 kN axle loadings), which will be used for classification of pavement structures within the design ‘catalogues’ or ‘Layer Strength Diagrams’ that will form the basis of the DCP design method. Research (Kleyn & Savage, 1982) has shown that, for balanced pavements (Paige-Green & du Plessis, 2009), the exponent (n) used to calculate the equivalency factor EF= $(P/80)^n$ can differ significantly from that normally used (i.e. 4.2

based on the AASHTO road test).

Recent studies (Paige-Green & Overby, 2010) have shown that roads on deep and strong subgrades can have n-exponents as low as between 1 and 2. This obviously has a major impact on determining a realistic cumulative axle count for the pavement design and will often reduce the estimated number of standard axles being carried significantly and a layer strength diagrams (LSD) for that traffic can be developed. This can be established from existing pavement design catalogues, although this is not really any more cost-effective than conventional pavement design as it would be based on traditional designs.

Typically, a series of catalogues or layer strength diagrams should be developed for specific roads, based on in situ moisture conditions (not soaked conditions, using the conventional CBR, assuming that the drainage standards are appropriate and drains are correctly maintained) and preferably making use of information collected from existing low volume roads in an area, such that the in situ conditions can be related to known performance.

1.3 The Design Process for LVR Pavements

The design fundamentals of low volume road pavements should not differ from any other pavement type. The standard procedures for appraising the pavement design loading, design strategy and analysis period must be followed (COLTO, 1996). It should, however, be noted that aspects such as traffic characterization may entail considerably more work. The actual design method still requires that the pavement structure bearing capacity must be appropriate for the estimated traffic that will be carried over the life of the road.

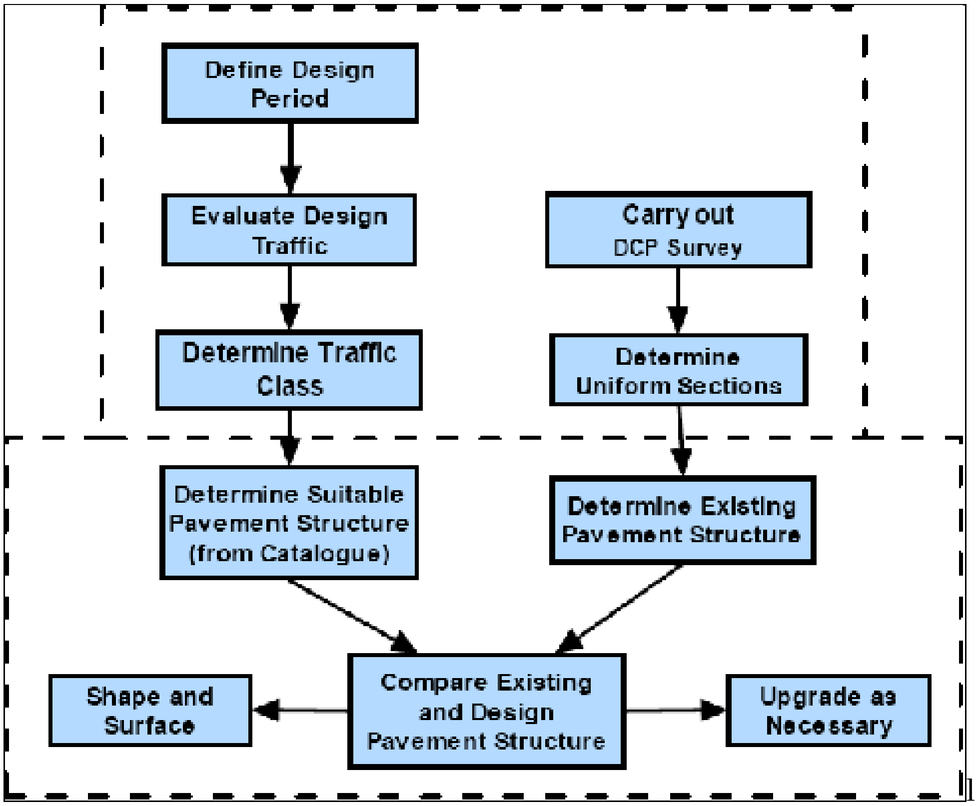

Figure 3: Flow chart of DCP pavement design process-Paige-Green 2012

1.3.1 Applicability of DCP Methods of Design

DCP-based methods, can be applied to most design situations found in practice in tropical and sub-tropical regions of the world. It should be noted, however, that the DCP method cannot be used directly if the proposed road is in cut or on fill, where the final formation level of the alignment would be outside the influence zone of an existing alignment DCP survey. In such cases, the material to be used for the embankment would need to be tested to determine its properties at varying densities and moisture contents. Fills can then be designed in accordance with the relevant catalogue to ensure that all the layers comply with the specifications of the respective design method. This will allow designers to go straight to design catalogues for contractual quantities (Paige-Green and Van Zyl, 2019).

As with all empirical methods of pavement design, the four main requirements of the design procedure are generally as follows; assessment of subgrade strength, design traffic loading, selection of pavement materials and determination of pavement layer requirements (thickness and/or strength) (Rolt and Pinard, 2016).

1.3.2 DCP-DN method

The DCP-DN design method is empirical in nature and the findings are currently based on measurements and observations on a range of soil types and environmental conditions prevailing in South Africa. The method is now being commonly and effectively used in a number of countries in Africa, including Malawi, Tanzania, Ghana and Kenya and could be effectively used in geotechnical environments similar to those countries. In dissimilar environments, further verification and performance monitoring may be required (Kleyn, 1984; Paige-Green and Van Zyl, 2018).

1.3.3 Assessment of subgrade strength

This is based on the strength (DN value) of the subgrade layer at the anticipated long-term equilibrium moisture content (EMC) of the road after it has been upgraded or rehabilitated to a paved standard. Depending on environmental conditions, the EMC in the subgrade may be expected to equilibrate above, at or below OMC when compacted to the highest practicable field density, i.e. refusal density or “compaction to refusal” which is a specific feature of the DCP-DN method (Paige-Green and Van Zyl, 2018).

Testing to ascertain the durability properties of the material is undertaken separately from the DCP-DN test based on appropriate durability testing. Determination of pavement layer requirements is specified in a single DCP-DN structural catalogue that prescribes the pavement layer thicknesses and strengths in 150 mm increments to a depth of 800 mm, i.e. the required strength profile. The layer strengths are varied in relation to traffic loading and increase (decreasing DN value) gradually in relation to an increase in design traffic loading. The design method can be adapted for any selected layer thicknesses or materials available (Kleyn and van Zyl, 1989) and (Paige-Green, 1994).

1.3.4 DCP-CBR method

Assessment of subgrade strength is based on the in-situ worst-case long term conditions similar to that obtained in the laboratory soaked CBR test. However, in a dry/moderate climate it is assumed that the subgrade CBR strength value is halved which is equivalent to a shift upwards of one subgrade class (Gourley, 2002).

The DN values are converted to CBR values, based on the TRL DCP-CBR correlation, for input into a CBR catalogue. It should be noted, however, that the ratio between soaked and unsoaked CBRs is significantly less than the research-based ratios developed by both Emery (Emery, 1985) and Paige-Green (Paige-Green et al, 1999). This is likely to lead to the use of higher quality/thicker/more costly pavement layers.

Selection of pavement materials is based on the laboratory soaked CBR test, regardless of climate, and at a specified density likely to be attained in the field. Requirements are placed on the allowable plasticity and grading of the material, the limits of which are related to the class of material, i.e. the higher the class, the more stringent the limits and the type of material, i.e. different for pedogenic and non-pedogenic materials. Determination of pavement requirements (thickness and/or strength) is based on the use of two structural design catalogues, one for dry-moderate climates (N-value > 4) and one for wet climates (N-value < 4). (Annex B). Pavement layer thicknesses are variable and range from 120 mm to 275 mm. For a given traffic loading, layer strengths and/or thicknesses are higher/greater in the wet zone than in the dry/moderate zone (TRL, 1993).

1.4 In-situ moisture content and pavement strength of low volume roads

Subgrade soil strength and/or stiffness are major factors that affect the design and performance of pavements, particularly low-volume pavements. A practical method of realistically estimating in situ moisture content significantly improves the determination of the appropriate resilient modulus to be used for pavement design. Because of the variability in soil properties and soil behavior under repeated traffic loads, environmental factors, geometric factors, and site conditions, and because of the complexity of moisture movement in soils, the prediction of subgrade moisture content has been unreliable and complicated.

The upper and lower equilibrium limits for subgrade moisture contents are estimated. These equilibrium values are independent of environmental factors and are solely dependent on soil properties and site conditions. Regression equations to predict upper and lower equilibrium values from soil properties are developed. It is shown that reasonable predictions of in situ moisture content may be developed, given the range of subgrade moisture content variation for a given soil type and the trends of moisture variation with temperature, precipitation, and depth. In addition, guidelines and issues to be considered when establishing a subgrade moisture content monitoring program are given. The information presented could provide agencies with responsibility for low volume roads valuable tools for obtaining reasonable estimates of subgrade moisture conditions without the need for extensive (and expensive) soil sampling and testing programs.

Drainage is undoubtedly one of the most important factors that affects the long-term performance of a LVR, given adequate construction practice, maintenance attention and control of overloading. Thus, the assumed long-term equilibrium moisture content (EMC) is critical in that it affects the strength of the material in the pavement layers and the subgrade.

For purposes of the pavement design and LCC analyses, it has been assumed that, for all four design methods under consideration, adequate drainage prevails. In terms of currently recommended practice, this means that the level difference between the crown of the road and the invert of the drain (gradient dependent), should be about 0.75 m on relatively flat ground and slightly less on steeper ground) and, where feasible, the level distance between the original ground level and the underside of the subbase layer should be about 0.15 m (Emery,1985).

1.4.1 Moisture Regime

The moisture regime in which a LVSR pavement must operate has a particularly significant impact on its performance due to the use of locally occurring unprocessed materials which tend to be relatively moisture sensitive. This places extra emphasis on drainage and moisture control for achieving satisfactory pavement life.

Each climatic zone will generally provide a different moisture regime which, other than in localized areas of micro climate, would be related to the Weinert N-value – the lower the N-value, the greater the availability of moisture during the year to wet up the pavement, and vice versa. The various sources of moisture infiltration into a pavement are illustrated in Figure 4.

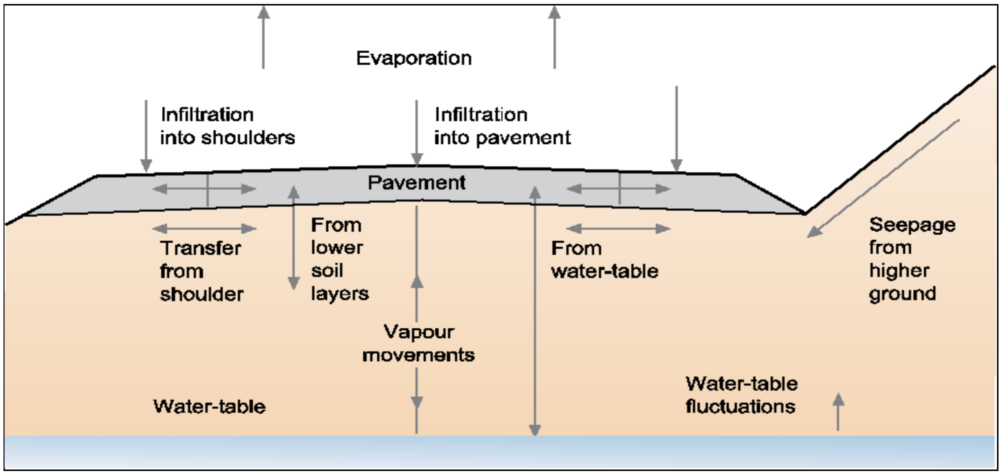

Figure 4: Moisture movements in pavements and subgrades -SATCC 2003

2.0 METHODOLOGY

Two roads with varying climatic conditions, soil types but almost similar traffic levels were identified for this research. The Road sections were D470 Kyeni – Karurumo and E628 Wamumu Karaba. The tests on the roads pavement were carried out in three stages: Before construction, During construction and After allowing traffic to flow

2.1 In-situ moisture and pavement strength of LVRs sections before improvement

Samples were taken from the road section before any improvement for testing. The test included; Classification test including grading, atterberg limits and linear shrinkage, Compaction test including MDD and OMC, Strength test including CBR soaked, OMC and 0.75 OMC, Pavement layer properties including IDD and MC, Field confirmation of road side drainage

2.2 In-situ moisture, pavement layer strength and improved subgrade strength of LVRs section during improvement

Samples were taken from the road section during improvement by adding subbase and base layers for testing. The test included; Classification test including grading, atterberg limits and linear shrinkage, Compaction test including MDD and OMC, Strength test including CBR soaked, OMC and 0.75 OMC, Pavement layer properties including IDD and MC, Field confirmation of road side drainage, DCP and CBR correlation

2.3 Determination of pavement strength and moisture after improvement to LVSR and traffic flow

Samples were taken from the road section after improvement for testing. The test included; DCP correlation, Visual assessment, Surface deflection test, Rut depth comparison, Skid resistance and riding quality

2.4 Compaction of samples

Some natural, particularly pedogenic, gravels (e.g. laterite, calcrete) exhibit a self-cementing property in service, i.e. they gain strength with time after compaction. This effect was evaluated as part of the test procedure by allowing the samples to cure prior to testing in the manner prescribed below.

The samples were thoroughly mixed and split each borrow pit sample into nine sub-samples for DN testing in a CBR mould at three moisture contents: (a) soaked, (b) at OMC and (c) at 0.75 OMC and three compactive efforts: (a) BS Light, (b) BS Intermediate and (c) BS heavy. The sample was allowed to equilibrate for the periods shown below before DN testing was carried out to dissipate compaction stresses and to allow the samples to cure.

a) 4 days soaked: After compaction, soak for 4 days, allow draining for at least 15 minutes, then undertaking a DCP test in the CBR mould to determine the soaked DN value.
b) At OMC: After compaction, seal in a plastic bag and allow to “cure” for 7days (relatively plastic, especially pedogenic, materials (PI > 6), or for 4 days (relatively non-plastic materials (PI < 6)), then undertake a DCP test in the CBR

mould to determine the DN value at OMC. The curing period is required to dissipate pore pressure generated during the compaction process).

c) At 0.75 OMC: Air dry the sample in the sun (pedogenic materials) or place the sample in the oven to maximum 50 degrees Celsius (non-pedogenic materials) to remove moisture. Check from time to time to determine when sufficient moisture has been dried out to produce a sample moisture content of about 0.75 OMC (it doesn't have to be exactly 0.75 OMC, but as close as possible). Once this moisture content is reached, seal the sample in a plastic bag and allow curing for 7 days (pedogenic materials) or for 4 days (non-pedogenic materials) to allow moisture equilibration before undertaking the DCP test at approximately 0.75 OMC. Weigh again before DCP testing to determine the exact moisture content at which the DN value was determined.

2.5 California Bearing Ratio (CBR)

The California bearing Ratio, popularly referred to as the CBR, is a special and simple strength test; it compares the bearing capacity of a material with that of a standard well-graded crushed stone. Actually, it is a comparative measure of the shearing resistance of a soil.

The CBR test is basically a laboratory penetration test. It is normally performed on samples compacted at 100% MDD (AASHTO T99) after 4 days soak where its swelling is monitored.

2.5.1 CBR Laboratory Test

For CBR compaction, batches of soil with stabilizer were prepared by mixing with the desired proportion of potable water (OMC) obtained from the moisture-density relationship. The mixes consisted of 0, 25, 50, 75 and 100 percent by weight of laterite soil. Also, a bigger mould measuring 150mm in diameter and 175mm high (2360cm^3 mould) and of known weight was used. However, a 50mm thick circular spacer disk was placed inside the mould to create a void at the bottom of the specimen. Then a filter paper, with details of the specimen written on it and facing down, was placed on top of the disk before using the same standard rammer weight and drop height to compact the soil in three equal layers. Each layer received 62 blows to allow for the larger surface area of compaction, trimming the final layer level with the top of the mould and then inverting the mould so that the void space came to the top. To obtain the compacted density, the mould with sample was weighted and moisture content of the soil determined.

The mould was assembled for soaking of the compacted sample in a water tank by inserting a swell plate in the void space and mounting a special tripod stand with dial gauge. The mould was raised from the tank base such that the specimen would imbibe water only from the bottom side of the baseplate. Water was carefully added to the tank to a level just below the top of the mould and swell monitored daily for 4 days, noting whether or not water would appear on the surface of the specimen within the first 3 days. If water did not appear by end of day 3, the specimen would be submerged in water for the whole of day 4.

3.0 DCP ANALYSIS BEFORE IMPROVEMENT

DCP tests for D470 and E628 roads were carried out in November 2016 in the middle of the rainy season. At the same time material samples were taken of the gravel and subgrade layers for determination of in situ moisture content and the CBR at various compaction efforts and moisture contents as shown in Table1below.

Table 1 Moisture Contents at various Compaction Efforts

					Road Name : D490						
Layer	**Atterberg Limits**				**Compaction T180**		**Moisture condition**	**CBR at various compaction levels**			**Increase from 93% to 98%**
	LL	PL	PI	LS	MDD (Kg/m^3)	OMC (%)		93%	95%	98%	
Lateritic Gravel (for base)	46	24	22	11	1890	13.6	4-Days soak	23	26	32	39%
							OMC	59	62	70	19%
							0.75 OMC	76	115	165	117%
Subgrade	56	26	30	15	1510	25.5	4-Days soak	6	7	8	33%
							OMC	60	68	82	37%
							0.75 OMC	100	110	125	25%

3.1.1 DCP Correlation

Correlation between the laboratory soaked CBRs and the DCP-CBRs gave a factor of 0.32 for the subgrade and 0.4 for the Lateritic gravel base layer.

It has been found that the moisture content of the pavement layers in a sealed road normally fluctuates between 0.75 of OMC and OMC. Non-standard, in situ materials used for Low Volume Sealed Roads, LVSR, have a significantly higher strength at these moisture contents compared to the 4-day soaked CBR values normally used in the pavement design. These materials have been found to perform well provided that they are adequately compacted and that the bituminous surfacing and drainage system prevents the materials from being soaked during the wet season.

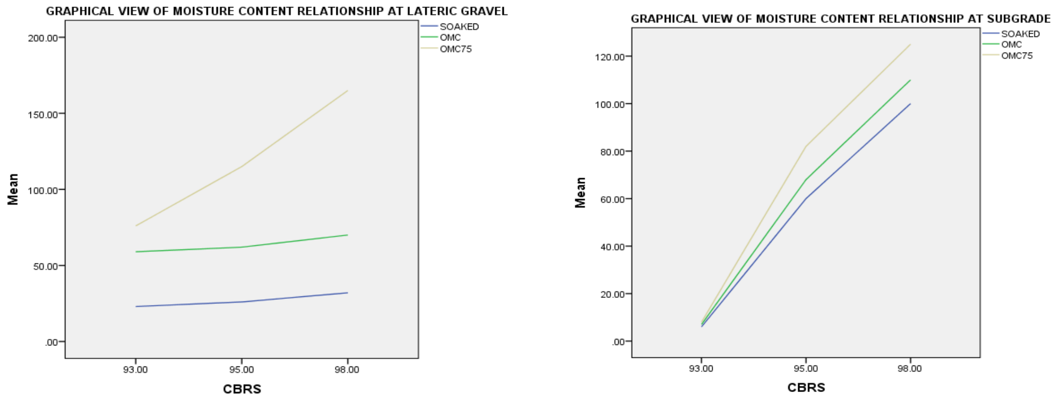

Figure 5: DCP correlations

3.2 Assessment of In- situ moisture, Pavement Layer Strength and Subgrade strength of LVRS during improvement

The DCP analysis for Wamumu-Karaba in soaked conditions gave the following results as given in Table 2 below

Table 2: DN values

Depth (mm)	0-150	151-300	301-450	451-600	601-800
DN (mm/blow)	≤3.2	≤6	≤12	≤36	≤50

The resulting layer strength diagrams as defined by the DN, the CBR and Pavement depth are as shown in Figure 6.

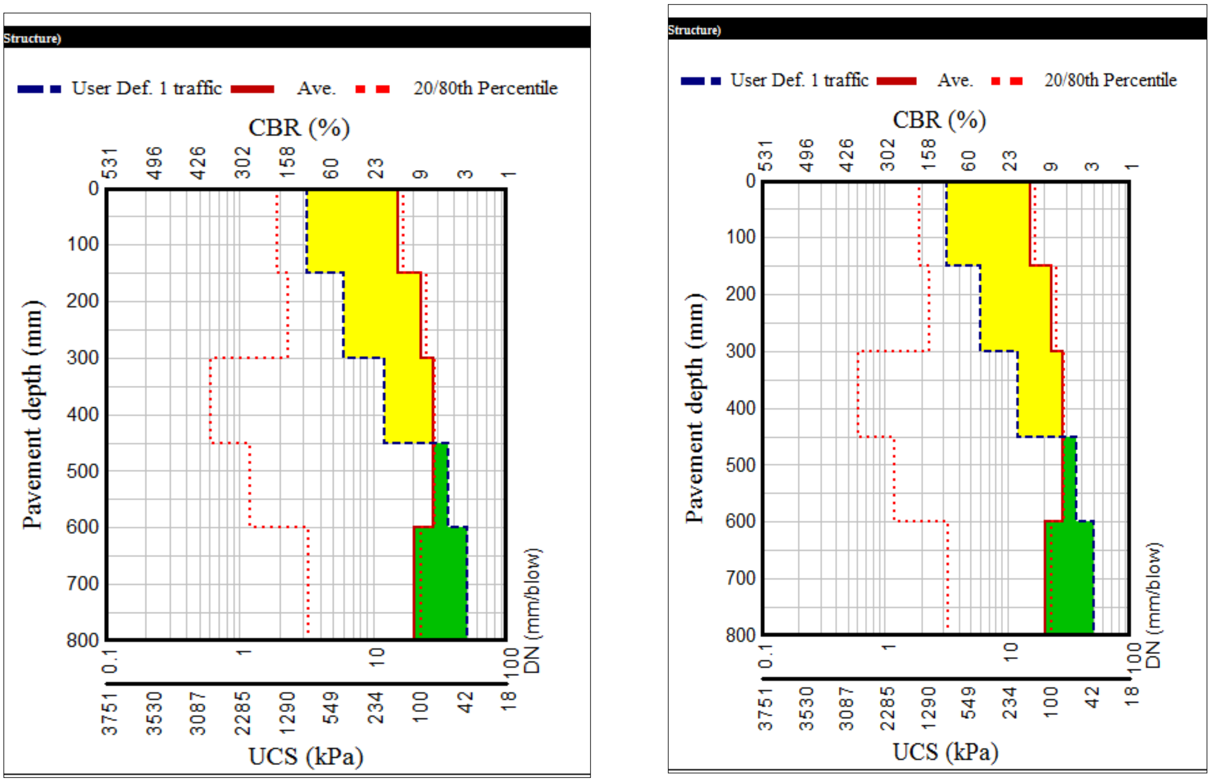

Figure 6: Layer Strength Diagrams during construction

From the layer strength diagram in Figure 6 a depth of 450mm had been constructed by adding an improved subgrade, subbase and base and this layer had reduced moisture through compaction and gained strength. It can also be seen that the moisture had not ingresses the lower sections beyond 600mm as they gained even more strength. Further improvement by sealing the road and improving the drainage would protect the layers from wetting and keep the road at the required strength.

From Table 4.4 the DCP tests showed a high variability in the DSN_{800} (the number of blows to penetrate to a depth of 800mm). From a visual assessment, the subgrade (500 – 600 mm) on the whole section is quite uniform. The variability is ascribed to the fact that due to the irregular surface, water was ponding in certain spots and effectively soaking the underlying layers. Other high spots on the other hand remained drier and consequently stronger. Some variability was also due to stones in the top layer.

4.0 CONCLUSIONS AND RECOMMENDATION

From this study it can be concluded from the studies that the more the in-situ moisture is reduced from the pavement structure the stronger the pavement. Knowledge of the inter relationship between the moisture, density and strength of the material used in the construction of LVSRs provides critical insight into how to use such materials to ensure good performance in the prevailing road environment.

It is also clear that during improvement by adding 150mm base layer and improving the drainage the pavement will no longer wet up and loose strength. Construction should ensure correct invert levels in the side drains (and hence a desired Drainage Factor) and proper grades in the drains. Compaction should be done (at or near OMC) until the material visibly no longer moves under the drum or the drum no longer leaves a mark on the surface of the layer. Compaction to refusal has then been achieved and it serves no purpose to specify additional passes. The project has shown that relative densities in excess of 100% can be achieved and this should always be the goal in particular for high PI or moisture sensitive materials like the ones used for the project.

It is also clear that after improvement by sealing using bitumen and opening to traffic moisture ingress into the pavement has been reduced and more strength is gained through exposure to traffic.

Recommendation

The effect of in-situ moisture on pavement strength can be used to measure LVSRs performance. The research recommends the use of DCP-CBR to determine required strength of the pavement for the different in situ soil strength and moisture conditions; The use of the locally available materials; The provision of proper drainage to ensure the design moisture condition of the pavement;

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