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Evaluating Flexible Pavement Rutting Damage Caused by Heavy Traffic Loads

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***Abstract-* This research was under taken to evaluate road pavement sections experiencing serious rutting damage induced by heavy traffic vehicles and those experiencing little or no rutting damage. The research on the impact of heavy traffic loads on pavement rutting performance was conducted on HHI to Machinjiri junction (S137) road section using field investigations and surveys. The research incorporated traffic counts for heavy vehicles to confirm levels of heavy vehicle traffic on the road segment and to verify the high numbers of permits issued for truck loading. Field works on identification and quantification of pavement surface distresses by executing visual condition surveys were carried out allowing for the current pavement surface conditions to be rated using pavement condition degrees and severities. The research also utilized Dynamic Cone Penetrometer (DCP) test for rapid in situ measurements of the structural properties of the existing road pavement and therefore it accommodated the evaluation of the in situ properties of the materials in all pavement layers up to the depth of penetration of 800mm. Comprehensive analyses were undertaken on the collected data to evaluate the pavement rutting performance. The utilization of DN values and California Bearing Ratio (CBR) values generated from DCP test results presented a potential methodology for determining the proportion of pavement rutting deterioration attributable to heavy traffic vehicles. Identification and quantification of pavement surface distresses by executing visual condition surveys on a 200m stretch rated the pavement surface conditions as between light and warning, warning, and between warning and severe. The traffic count levels for heavy vehicles obtained for five days indicated an average of 507 heavy vehicles per day and therefore confirming high traffic loads for the road section.**

***Keywords* - Rutting, flexible pavement, heavy traffic loads, asphalt, Dynamic Cone Penetrometer (DCP)**

I. INTRODUCTION

Rutting describes the formation of depressions or cracks in the pavement surface attributed to wheel loads and high temperatures, combined with the character and design of the carriageway surface [6]. The paramount purpose of a paved road is to provide a functional surface for a specific transportation requirement. The fundamental function is to withstand loads under different traffic and environmental conditions without deforming since such distress conditions significantly reduce the functionality of the pavement [8]. A typical applied concept of flexible (or asphalt) pavement is that a layered structure with improved materials near the top would distribute the traffic loads in a way that the consequent stresses would not cause substantial deformation in the bottommost layer.

It is also a requirement that the material and thicknesses of the different layers must resist the effects of temperature and moisture arising as a consequence of changes in season. The subbase, in addition to providing structural support, must provide a platform for constructing the base and prevent the subgrade fine materials from contaminating the base layer [8]. In this regard, all layers have a function of spreading out the load on the surface and reduce its intensity with depth. When that situation occurs, pressure on the subgrade is considerably less than the pressure on the surface.

Naiel[10] found that one of the critical external factors which influences the development of pavement rutting is traffic loading. This factor is classified as an external factor that extensively causes rutting and full comprehension of it is required when designing or evaluating flexible pavements in an effort to forecast the pavement's functional and structural conditions over time.

II. LITERATURE REVIEW

A. Research on rut depth survey in selected Malawian paved roads

In Malawi, a detailed research was undertaken by [12] on performance review of design standards and technical specifications for low volume sealed road. One of the activities conducted in the course of this research was rut depth survey. The research on rut depth was carried out considering that rut depth measurements provide a precise indication of the structural condition of the road [5]. The rut depth survey was carried out in the more heavily loaded lane of each of the sections with the objective of determining the degree and extent of the occurrence of rutting in the outer wheel path of the road. The survey was carried out at 10m interval using a 2mstraightedge.

Rutting of various road sections was assessed in accordance with the degree and extent method of rating distress parameters which were summarized as follows:

Low	< 10mm
Moderate	10-15mm
Severe	> 15mm

The results of this survey were summarized as follows:

Table I. Results on Rut Depth Measurements

Road Section	Rut Depth (mm)	
	Mean Value	Range
Ntchisi (LVSR)	3.1	2-4
Ntchisi (Standard)	3.8	0-8
Dowa	3.7	0-12
Rumphi	4.4	2-6
Cape Maclear	2.9	1-4
Lilongwe ABC road	2.6	0-7

From the findings and observations of this survey, it was discovered that rutting on all sections was very low. Accordingly, this was reflective of pavement which was in sound condition and had not suffered from compaction or shear deformation in service through the actions of traffic which otherwise indicated the presence of a structural problem [12].

B. Research on CBR – Traffic volume method of assessing pavement failures

In Nigeria, Ekwuloconducted a comprehensive study of assessing pavement failures in various developing tropical countries using design procedure. The study involved the empirical and mechanistic design procedures for highway flexible pavements. The empirical approach is focused on the experimental results or experience while mechanistic approach is focused on the elastic or visco-elastic representation of the pavement structure [2]. For the latter, the design control of the pavement layer thickness and the material quality were ensured based on theoretical stress, strain or deflection analysis [7]. It was discovered that such analysis similarly enables the pavement designer to predict with a specific amount of certainty the pavement life.

The Nigerian (CBR) design method was methodically utilized to determine the structural thickness requirement. This method is a CBR-Traffic volume method and it revealed that the thickness of the flexible pavement structure is dependent on the anticipated traffic[4]. The method as an empirical approach uses the California Bearing Ratio and traffic volume as the sole design inputs [2]. Layered elastic analysis (mechanistic approach) was also utilized to investigate failure due to rutting deformation in flexible pavements designed by CBR procedures.

In the research, it was adopted by Nigeria as contained in [4] that the subgrade strength evaluation should be conducted in terms of CBR. It was evident that weak pavements concentrate the load over a small subgrade area compared to strong pavements and this consequently induces higher stresses. The method considered traffic in the form of number of commercial vehicles per day exceeding 29.8kN (3 tons).

The findings of this research subsequently recommended that the minimum asphalt pavement surface thickness be considered in terms of light, medium and heavy traffic as follows.

Table II. Asphalt Pavement Thicknesses

Level of Traffic	Pavement Surface Thickness
Light traffic	50mm
Medium traffic	75mm
Heavy traffic	100mm

C. Research on impact of Oversize/Overweight (OSOW) loads on pavement

Gillespie et al. [3] conducted an intense literature review and mechanistic analysis of truck loading characteristics and their effects on pavements, with specific emphasis on static and dynamic wheel and axle loading scenarios on both flexible and rigid pavements.

The analysis incorporated theoretical mechanistic calculations of pavement stress and strain for various tyre and axle loading situations, finite element (FE) simulations and a review of road test data. In his publication, apart from relying on the 4th power Equivalent Standard Axle Load (ESAL) methodology for some calculations of pavement wear, he also analyzed the significance of dynamic loading variations due to speed and driving behavior and it demonstrated the significance of uneven axle loading within and between axle groupings [10].

From this intense research, it was noticed that the main pavement distresses in flexible pavements were fatigue, cracking and rutting. The research also determined that the main attributable cause to such distresses is heavy axle loads.

III. OBJECTIVES OF THE RESEARCH

A. *Main objective*

The overall objective of this research was to evaluate road pavement sections experiencing serious rutting damage induced by heavy traffic vehicles and those experiencing little or no rutting damage. The assessment was conducted on the HHI to Machinjiri Junction road section in Blantyre City, Malawi.

B. *Specific objectives*

To accomplish this overall objective, the following were the specific objectives:

- Conduct traffic count survey for heavy vehicles
- Conduct visual condition survey on a 200m stretch to determine the degree and extent of rutting and other pavement distresses
- Conduct Dynamic Cone Penetrometer Test on a 200m stretch to evaluate the in situ strength of the pavement layers in relation to rutting
- Obtain tyre configurations and axial configurations of heavy vehicles

- Evaluate sections experiencing serious rutting damage and those experiencing little or no rutting damage

IV. METHODOLOGY

A. Field surveys/measurements

Field works conducted on the road section included 10-hour traffic counts of heavy vehicles on the road section. The traffic count process included the observation and characterization of trucks in terms of vehicle class, axles, and type of load carried.

Data collection through visual condition survey and DCP test was conducted to consider aspects of different pavement defects and in situ strength of the pavement respectively.

B. Desk studies

Layered elastic systems information was collected through reviews of literature based on assumptions and input requirements for the calculation of stresses, strains and deflections in a pavement structure. For a distributed load under a circular area, the responses were also found out by using layered elastic system by Boussinesq method. Vertical stresses, vertical strains and deflections were calculated on each site at a depth of 160mm at all the three sites. The modulus of elasticity for each layer which defined the material properties was calculated using the formula contained in [1] as shown below.

E = 1500 x CBR (psi)

For comparison and calculation purposes, a depth of 160mm was found to be contained in layer 1 in all the three sites and this is illustrated in Fig.7. The loading condition of 100kN was also specified in terms of the magnitude of the total force applied and the load geometry usually specified as being a circle of a given radius (a=100mm) as shown in Fig. 1. Law of Superposition of summing the effects of individual loads can also approximate the effects of multiple loads on a pavement structure.

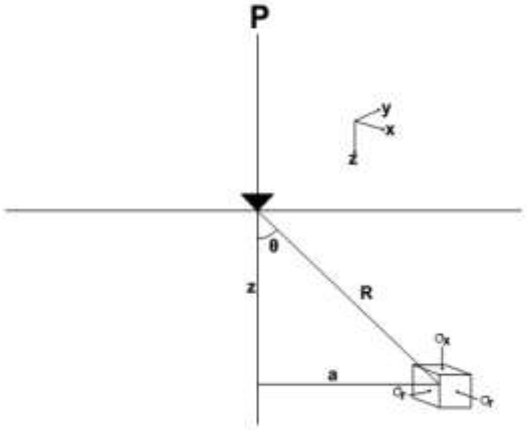


Fig. 1. Coordinate system and stresses for Boussinesq's method from [8]

Vertical strain at depth z is given by the following formula:

$$\varepsilon_z = \frac{(1+\mu)\sigma_0}{E}\left[\frac{z/a}{\{1+(z/a)^2\}^{3/2}} - (1-2\mu)\left\{\frac{z/a}{\sqrt{1+(z/a)^2}} - 1\right\}\right]$$

The deflections generated were calculated using the following equation:

$$d_z = \frac{(1+\mu)\sigma_0 a}{E}\left[\frac{1}{\sqrt{1+(z/a)^2}} + (1-2\mu)\left\{\sqrt{1+\left(\frac{z}{a}\right)^2} - \frac{z}{a}\right\}\right]$$

Where:

E is the elastic modulus

μ is the Poisson's ratio of value of 0.35 suggested by [9] to be representative of most pavement materials

σ_0 is the stress on the surface calculated as force per unit area

a is the radius of the circular area of the load

z is the depth below pavement surface

C. Consultations

Discussions with experts and experienced officials at Roads Authority, Road Traffic and Safety Services Department and Mwanza Border Weighbridge provided in-depth information and data valuable for road under the study.

V. PRESENTATION OF RESULTS

This section presents the results from the study conducted on HHI to Machinjiri junction (S137) road segment. Visual distress surveys conducted on a 200m stretch, heavy vehicle traffic counts and verifications, evaluation of pavement performance using DCP test as well a heavy vehicle axial configurations are all presented in detail.

The results are based on surveys and test conducted on road section particularly from chain age 3+162 to 3+362 and may not be appropriate in other roads in Malawi as materials, thicknesses, environment, traffic, and other factors are different than those analyzed in this study.

A. Traffic count survey

Traffic count data collection for heavy traffic vehicles consisting of standard large buses, 2 axle rigid trucks, 3 axle rigid trucks and articulated trucks was conducted for five days and the results can be summarized in the Fig. 2.

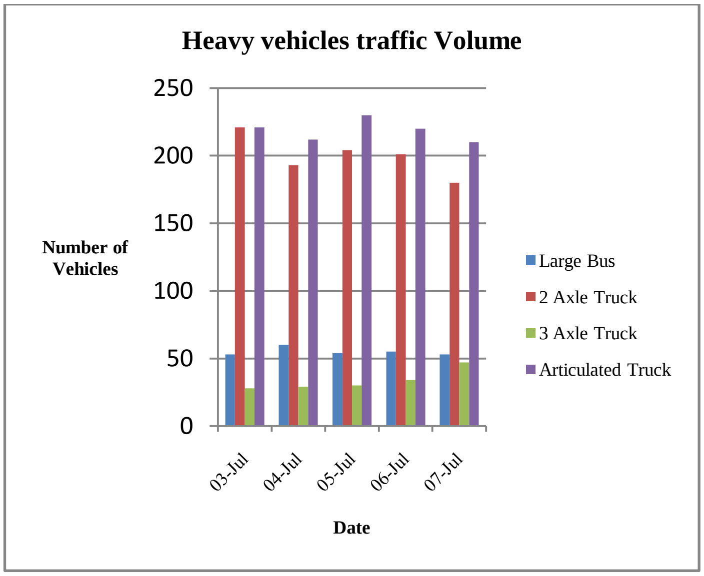


Fig. 2. 10 hour daily traffic count for heavy vehicles

B. *Visual condition survey*

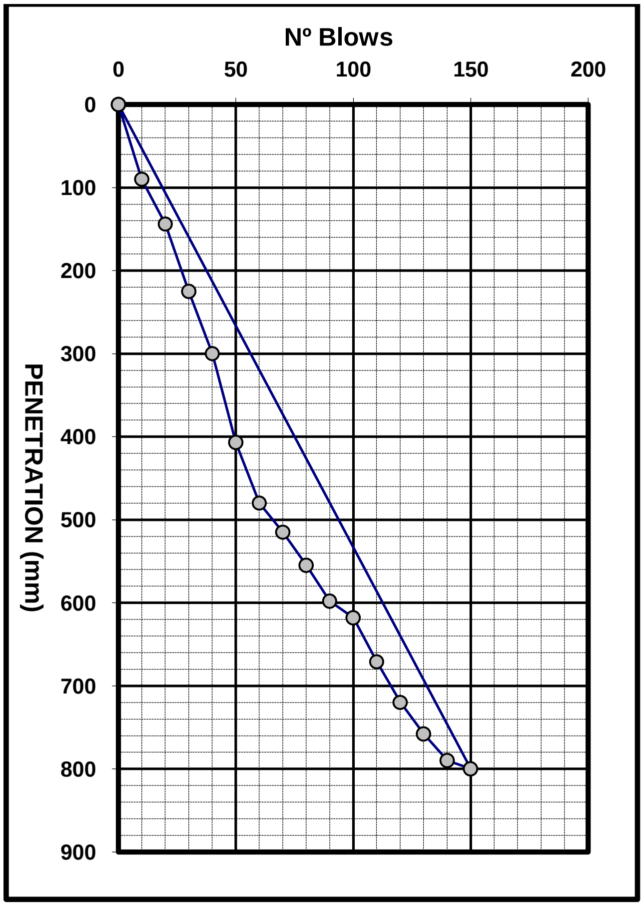
Summarized data of visual condition survey formulated from detailed visual condition survey chiefly exhibited predominant rutting distresses notable with respect to possible consequences and isolated failures with raveling and rutting.

Typical rutting distress at site # 2 has also been presented in Fig. 3.

Fig.3. Typical rutting distress at site # 2 (Chainage 3+262)

C. *Dynamic Cone Penetrometer Test Results*

The values of DCP Numbers were also calculated and Fig. 4shows the relationship among the values for site no. 3.



Chainage 3+362

Fig. 4. Line graphs for no. of blows against penetration for site no. 3

VI. ANALYSIS OF RESULTS

A critical analysis and evaluation of the results in terms of pavement rutting performance is presented in this section. Discussions on the results for various pavement properties in relation to rutting damage are also presented.

A. *Traffic Count Analysis*

The average 10-hour daily traffic count was found to be 507 and vast majority of the heavy vehicles were loaded. Approximate pavement structural design capacity and traffic classes were related to number of heavy vehicles illustrated in Table III [14].

TABLE III TRAFFIC Classification

Measure of traffic intensity		Traffic class
Number of heavy vehicles/lane/day	Approximate pavement structural design capacity	
<80	< 1 million ESALs	Light
80 to 200	1 to 3 million ESALs	Medium
200 to 700	3 to 10 million ESALs	Heavy
>700	> 10 million ESALs	Very heavy

The direction split of 50:50 was not implemented in this research as traffic count for this road section took into consideration both directions of HHI to Machinjiri junction and Machinjiri junction to HHI. It was noted that the number of heavy vehicles in each lane for any day ranged from 218 to 315. This range is within the provided range of 200 to 700 which exhibits a classification of heavy traffic for the road section. Considering that the traffic count was conducted for 10 hours daily, it can be suggested that a 24-hour heavy traffic count survey would yield high numbers of heavy vehicles close to the upper value in the provided range for heavy traffic class.

B. *Axle Configurations*

Pearson [11] presented one of the most essential findings from the AASHTO Road test which show that the damaging effect of an axle, with a given axle load W, can be related to that of the reference axle, with axle load Wo, with a load equivalence factor (LEF) according to the following equation:

$$N = (W/Wo)^4$$

It was indicated that calculations based on heavy vehicles with high axle weights presented high damaging factors. This underlines the great damaging effects of heavy vehicles which lead to high rutting damage. Fig. 5 can be used to illustrate that damaging effects of light vehicles are negligible for pragmatic purposes as compared to heavy vehicles.

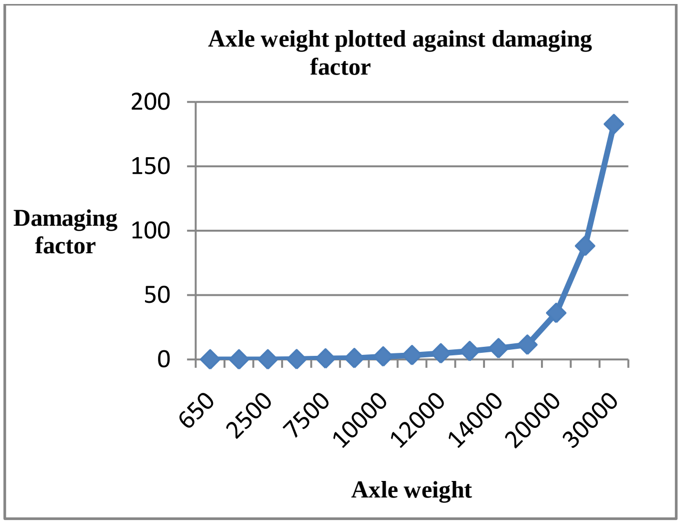


Fig. 5.Damaging factors for different vehicle axial weights

C. *Visual Condition Survey Results*

The data from visual condition survey confirmed that rutting distress was a predominant class of deformations on this 200m stretch. With regard to rutting and other distresses, the road section fell under the following degrees; between light and warning, warning, and between warning and severe of which the predominant degrees were warning and between warning and severe as illustrated in Fig.6.

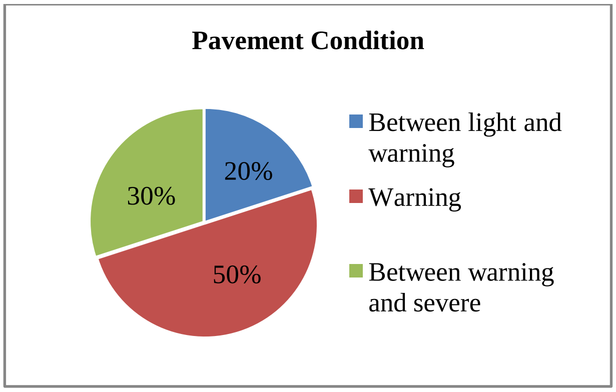


Fig. 6. Summary of pavement condition for a 200m stretch

It can be noted as contained in Fig. 7 that the most consistent indicator of trends in rutting damage is the gradient of graphs (DN value) shown in Fig. 4. This gradient of the graph indicates the strength differences among different layers of the pavement. For instance, at chainage 3+362, high degree of rutting damage was observed and it was felt that high DN value – Penetration graph might have provided this wider degree of rutting. The opposite to this was observed at chainage 3+162 and the comparison of data suggests that penetration rate and rutting degree were both low at this chainage.

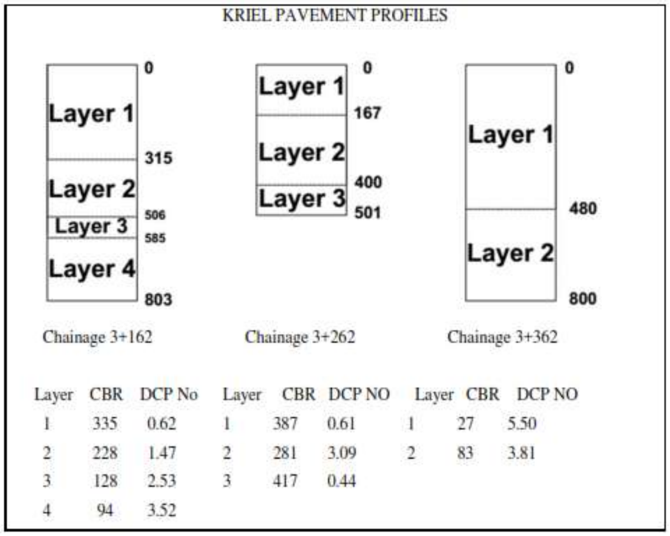
The analyses of this data evidently support the contention that rutting susceptibility is related to DN value. DCP data available shows that strength of pavement provides a logical explanation for the observed relationship between rutting susceptibility and visual rutting distress. This phenomenon will be expounded and furthered in the analyses of the DCP test results.

D. *Dynamic Cone Penetrometer (DCP) Test*

This section addresses the utilization of the Dynamic Cone Penetrometer test in the context of rutting performance investigations and the data obtained and analyzed in the locations of various pavement layers. According to Thompson [13], DCP test is ideally suited to the evaluation of existing pavements. Therefore, in this research, the test was used to address the context of structural rutting performance investigations for the road section. Data for Californian Bearing Ratio (CBR) was generated from the DCP investigations using the following formulae:

- $CBR = 410 \times DN^{(-1,27)}$ for DN values greater than 2mm/blow
- $CBR = 66.66\ (DN)^2 - 330\ (DN) + 563.33$ for DN less than or equal to 2mm/blow

The pavement profiles and corresponding CBR values of each layer as uniquely determined from the DCP analysis are presented for three sites as shown in Fig. 7 and discussed in the proceeding sub-sections.



Layer	CBR	DCP No	Layer	CBR	DCP NO	Layer	CBR	DCP NO
1	335	0.62	1	387	0.61	1	27	5.50
2	228	1.47	2	281	3.09	2	83	3.81
3	128	2.53	3	417	0.44			
4	94	3.52						

Fig. 7.Kriel Colliery pavement profiles determined by DCP analysis from [13]

Site 1 (Chainage 3+162)

Four structural layers were discerned at site 1; a strong layer to a depth of 315mm, a medium strong layer 191mm in thickness, weak layer to a depth of 585mm and very weak selected layer to a depth of 803mm. The average CBR values computed for the layers correlated closely to recorded values of DN values as shown in Fig. 7.

Small DN values and higher CBR values were observed on this site. Light rutting damage was also observed more especially RHS position in the direction of HHI to Machinjiri junction.

Site 2 (Chainage 3+262)

Three structural layers were discerned at site 2; a strong layer to a depth of 167mm, a weak layer 233mm in thickness and then followed by very strong layer to a depth of 501mm. The focus of achieving an 800mm depth was not successful due to the presence of rock deposit beyond 501mm. In addition, the surrounding section showed the presence of excavated rocks on both sides of the road. This may illustrate the evidence that rutting deformation was confined to upper layers of the pavement.

The average CBR values computed for the layers closely correlated to recorded values, except in the case of the transition in layer 2 which seemed to give a large DN value than expected. The reason attributed to this was that high penetration value of 60mm from 180 to190 blows increased the DN value. From here, it appears that layer 2 likely contributed to rutting on this site than the other 2 layers.

Site 3 (Chainage 3+362)

Two structural layers were discerned at site 3; a very weak layer registering a DN value of 7.33mm/blows to a depth of 480mm followed by a relatively weak layer 221mm in thickness. This is an indication of inadequate compaction of the layers consequently leading to rutting deterioration.

Serious rutting distress of degree 4 observed through visual condition survey at this site reasonably supported the CBR and DN values. This appears to be an indication that rutting damage was significantly increased as a result of weak pavement denoted by large DN values and low CBR values.

E. Layered elastic systems

This section presents detailed analysis of mechanistic analyses of data for all three sites. For comparison purposes, the analyses were based on Boussinesq method for one layer system.

Site 1(Chainage 3+162)

Site 1 exhibited a low deflection of 1.57mm and minimum strain of approximately 0.028 using Boussinesq method of layered elastic theory and this portrays layer 1 to be strong. Fig. 7 shows CBR and DN value of 335 and 0.62 respectively and also confirms layer 1 to be a strong layer. There is a strong trend at this site that the low deflection and DN values resulted in decrease in rutting damage.

Site 2(Chainage 3+262)

Site 2 exhibited a low deflection of 1.36mm using Boussinesq method of layered elastic theory and this remarkably portrays layer 1 as a strong pavement layer. Figure 7 indicates CBR and DN values of 387and 0.61 respectively thereby; confirming layer 1 as a strong layer. The mechanistic analysis also reveals that the layer was subjected to minimum vertical strains of approximately 0.025 and this typically implies that much of the rutting deformation was not caused by this layer. The results from visual condition survey however show that rutting degree was at warning stage at this site. It can be suggested that the likely contributor to rutting damage at this site was layer 2 and DN value of 3.09mm/blow in this layer explains well why rutting degree was at warning stage. Layer 3 had a low DN value of 0.44 mm/blow and a CBR value of 417 thereby indicating that the layer did not contribute much too rutting damage.

Site 3(Chainage 3+362)

Site 3 was observed to be problematic as regards to structural rutting performance. Typical large deflections in excess of 7mm was computed on this site. Extensive rutting distresses were noticed at this site. Moreover, CBR and DN values as contained in Fig. 7 provide a clear indication that the layers at this site were very weak and it is for these reasons that rutting damage on this site was extensive. The mechanistic analysis also reveals that this weak layer was subjected to maximum vertical strains of approximately 0.355 and this significantly explains why serious rutting deformation was observed at this site.

VII. CONCLUSIONS

Analyses of the pavement condition indicate that rutting on the section is increasing, and that this increase is attributable to increased loading intensity. The analyses also indicate that rutting varies geographically and that this variation can be explained by quality of materials and amount of compaction used on different sections during the construction.

Categorization of structural performance using DCP tests and assessment of rutting damage through visual condition survey has shown that results from both criteria correlates well with the rutting damage. It has been seen using Fig. 4 and Fig. 7 that decrease in DN value indicates a strong pavement which correlates with low rutting damage observed. With regard to the CBR values, excessive rutting damage and vertical strains were generally associated with low CBR values.

Mechanistic analysis of existing pavement using Boussinesq method has also provided a strong link between rutting damage and the calculated strains and stresses. It has been made clear that rutting damage was minimal in sections where amounts of deflections and strains are low. In other words, rutting initiation is enhanced in sections with high vertical strains and deflections.

VIII. RECOMMENDATIONS

Based on the experimental observations and the results obtained during this research project, the following suggestions are recommended. The majority of the sections on this 200m stretch are heavily rutted as it can be observed from results of visual condition survey. It is therefore recommended that sections with degrees of rutting of 3 and 4 should be over layed. Slight ruts with the degree of 2 can generally be left untreated.

As previously indicated, some layers through DCP results showed that they were not adequately compacted. Therefore, compaction of pavement layers should be more carefully done and given full attention to ensure that compaction requirements that achieve the pavement design objectives are met. On heavily traveled roadways (particularly those trafficked with heavy vehicles) compaction requirements for binder mixes should be the same as surface mixes.

Some sections showed that rutting damage was of plastic deformation type. This suggested that surface mixes were not the same on the stretch. It is vital that the use of asphalt mixes, particularly in conjunction with overlays, should receive further study. This further study should focus on construction control procedures that will prevent excess asphalt mixes that could soften the overlay and increase rutting susceptibility.

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