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MONITORING PERFORMANCE OF LATERITE BASE TRIAL SECTION: A CASE OF ADDIS ABABA, ETHIOPIA

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ABSTRACT
This paper is aimed to present an overview of the provision of a demonstration/research trials with particular reference to pavement performance of a laterite base under a double bituminous surface treatment (DBST) as part of a long-term pavement performance (LTPP) monitoring in Ethiopia. The research components were aimed at increasing the use of locally available materials and solving specific problems related to the performance of some roads constructed with thin asphalt seals. In Ethiopia, most roads are built using crushed rock for road base. The project aim was to demonstrate that whether laterite can be used for base course, assess and evaluate the effect of sealed and unsealed shoulder in cut and fill sections. Out of the various field data measurements carried out in each monitoring period (wet and dry season) the paper reviews the in-situ dynamic cone penetrometer (DCP) test results and visual condition assessment observations. It is demonstrated that for such low volume roads laterite base trial sections are performing well, however DCP test results in these sections reveals that the crushed base control sections perform slightly better than the laterite base trial sections and the sections in cut are stronger than in fill while the shoulder sealing doesn't provide consistent effect on the layer strengths.

Keywords: laterite, pavement performance, field monitoring, trial section

1. INTRODUCTION
Four research projects have been initiated in Ethiopia under ReCAP/AFCAP program in collaboration with the Ethiopian Roads Authority – Road Research Center. Each of the four projects involved the construction of trial sections aimed at demonstrating alternative technology for road provision developed elsewhere. The research components were aimed at increasing the use of locally available materials and solving specific problems related to the performance of some roads constructed with asphalt seals. The overall goal of the research is to reduce costs and help increase cost-effective, safe and sustainable road provision in Ethiopia, which are the core objectives of ReCAP/AFCAP.

Research carried out by TRL in southern Africa on behalf of the UK Department for International Development (DFID), (Gourley & Greening, 1999), clearly indicated that existing standards and specifications for sealed roads carrying relatively low levels of traffic (approximately 200vpd) were generally too conservative and impeding rural road provision and development. Included in this research were roads that had been constructed with lateritic material as base course. [Whilst the use of lateritic material for sub-base is fairly common, it often fails to meet the required specifications for base course and, when it used, it is usually modified with cement, or more commonly with lime]. The roads with laterite base course included in the research had performed exceptionally well although not meeting a number of the 'standard' specifications for road base such. as plasticity, strength or grading.

Some roads had also been subjected to overloading and some had received no maintenance in the form of a reseal since construction and had still performed well (Greening, 2014).

In Ethiopia, most roads are built using crushed rock for road base. On road bases that have been constructed with natural gravel, they are usually surfaced with asphalt rather than a thin bituminous seal. Both these options (crushed rock for base course and asphalt surfacing) are more expensive than using natural lateritic gravel for base course plus a surface treatment which is the normal design for the relatively lightly trafficked rural roads in most developing countries.

The project has the following main objectives: demonstrate that laterite can be used for base course, evaluate the relative effects of sealed shoulders (in fill and cut) on pavement moisture, assess the benefit of designing road bases on the strength of materials at their in-situ moisture content. The trial section was constructed in the middle of the standard road construction, Assosa – Kumruk road project in Ethiopia, so that the performance can be easily compared. The project road was constructed using DBST, 200mm Crushed Stone Base and 150mm Selected Laterite Sub-Base. The base was replaced with laterite of 200mm thickness on a laterite sub-base of 150mm for the trial sections. As part of the long-term pavement performance (LTPP) monitoring, four monitoring cycles has been carried out so far in two years 2017 and 2018 representing wet and dry season in each year in addition to the baseline monitoring carried out in 2012 (Otto and Greening, 2012).

2. MATERIAL AND METHOD

2.1 Laterite Material

Laterite, first defined by Buchanan (1807) as "a massive, vesicular or concretionary ironstone formation" is mainly found in wet tropical and subtropical areas. It is a group of highly weathered soils formed by the concentration of hydrated oxides of iron and aluminium. This concentration may be by residual accumulation or by solution, movement and chemical precipitation. In all cases it is the result of secondary physico-chemical processes and not of the normal primary process of sedimentation, metamorphism, volcanism or photoism (Molenaar, 2005). The accumulated hydrated oxides are sufficiently concentrated to affect the character of the deposit in which they occur (Araya, 2011).

Laterite formation requires particular conditions which concentrate the iron- and aluminium rich weathering products sufficiently to allow concretionary development, often progressing to a cemented horizon within the weathering profile (Netterberg, 2014). According to Charman (1988), before the concretionary development of true laterite can take place, an additional process is required – the concentration of the weathering products within the residual soil/completely weathered zones. The hardening or concretionary development after the iron enrichment seems to proceed by a number of mechanisms including chemical precipitation, loss of water of crystallization (dehydration) and the development of a continuous fabric of cementing materials (Alexander and Cady, 1962).

Laterite soils are formed in situ from the intense weathering of parent material, whether primary or sedimentary, in the tropical and subtropical climate environment (Aginam et al, 2015). This weathering process primarily involves the progressive chemical alteration of primary minerals, the release of iron and aluminium sesquioxides, increasing loss of silica and the increasing dominance of new clay materials (such as smectites, allophones, halloysite, and as weathering progresses, kaolinite) formed from dissolved materials (Northmore et al, 1992). Tuncer et al, (1977), described the genesis of laterite as the weathering process which involves leaching of silica, formation of colloidal sesquioxides, and precipitation of the oxides with increasing crystallinity and dehydration as the soil is weathered.

The laterite soils used in the project are generally coarse non plastic materials, their gradation compared to the Ethiopian Road Authority gradation specifications for base and subbase material is shown in Figure 1. Compared to the gradation specification for base material, the laterite falls out of specification before and after compaction. The laterite however falls within gradation specifications for subbase both before and after compaction (Otto and Greening, 2012).

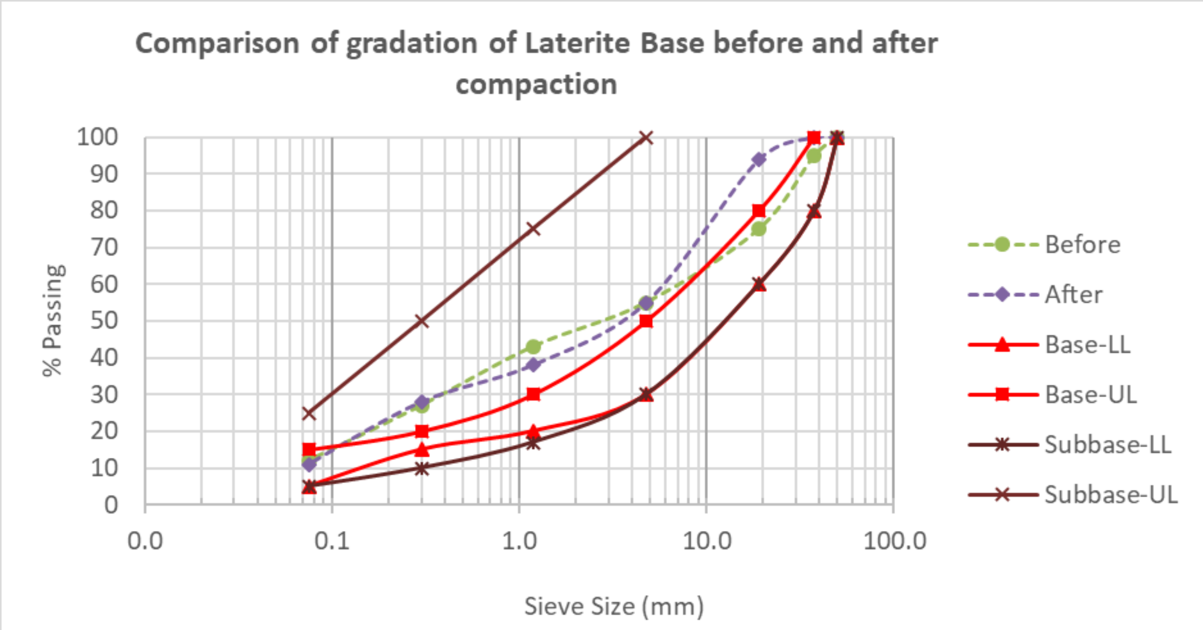

Figure 1. Gradation of laterite base as compared to the design specifications

3. MONITORING TRIAL AND CONTROL SECTIONS

To maximise the benefits of any experimental, trial, demonstration, or LTPP sections, it is essential that the design is such that the trial produces the results that are desired. Trial sections can be developed for several purposes, the main ones of interest in this monitoring being to prove the technical viability of an innovation compared with conventional alternatives.

Generally, the following are typical types of experimental sections requiring long-term monitoring (Paige-Green, 2016):

- Replacement materials for traditional ones in structural layers, e.g. an alternative material such as slag or industrial waste
- Innovative treatment of sub-standard materials in structural layers to improve their quality, including the use of mechanical, traditional or non-traditional stabilisation.
- Innovative treatment of subgrades to reduce common subgrade problems, e.g. collapsible, expansive or saline materials
- Different pavement structures such as thinner layers or even omission of specific layers, e.g. For low volume roads
- Alternative surfacing such as Otta and sand seals, polymer slurry seals, hand-laid cold-mix asphalt, etc.
- Different construction methods, e.g. conventional versus in-place recycling

The monitoring sections on Assosa-Kurmuk Road the conventional crushed aggregate base under double bituminous surface treatment (DBST) is replaced with natural laterite base. Seven trial sections with laterite base and two control sections with crushed base are developed as shown in Table 1. The sections are developed in such a way that effect of shoulder sealing condition and section location in the performance of the laterite base can be demonstrated. The fill embankments are up to 10m high whereas the cuts up to 6m deep.

Table 1. Monitoring Sections on Assosa-Kurmuk Road

Chainage	Section ID	Length (m)	Pavement Surfacing	Shoulder condition	Location (Cut/Fill)	Remark
Section 1: 49+140 – 49+225	UC1	85	DBST, Laterite Base	Unsealed	Cut	
Section 2: 49+225 – 49+292	UF1	67	DBST, Laterite Base	Unsealed	Fill	
Section 3: 49+292 – 49+445	SF1	163	DBST, Laterite Base	Sealed	Fill	
Section 4: 49+445 – 49+558	SC1	103	DBST, Laterite Base	Sealed	Cut	
Section 5: 49+558 – 49+668	UC2	110	DBST, Laterite Base	Unsealed	Cut	
Section 6: 49+668 – 49+768	SF2	100	DBST, Laterite Base	Sealed	Fill	
Section 7: 49+768 – 50+026	UF2	258	DBST, Laterite Base	Unsealed	Fill	
Section 8: 60+000 – 60+200	CS1-UC	200	DBST, Crushed Base	Unsealed	Cut	Control section
Section 9: 60+200 – 60+400	CS2-UF	200	DBST, Crushed Base	Unsealed	Fill	Control section

3.1 Field Measurements

The objective of the monitoring program is to provide performance-based evidence which will contribute to the establishment of appropriate standards for Low Volume Sealed Roads in Ethiopia.

Field measurements and characterisation of the performance of paved roads usually requires an evaluation of the road roughness, rut depths, deflection, pavement strength (usually using a DCP), moisture contents and regular visual assessments following a standard technique. The monitoring requirements, however, vary depending on the type of pavement and surfacing as well as whether the factor of interest is functional (mostly surfacing type) or structural, related to pavement strengths and layer thicknesses.

The assessment of the performance of bituminous surfaced roads depends on the nature of the experimental section. For the monitoring section various field data measurements has been carried out in each monitoring period (wet and dry season); such as rutting, surface deflection, in-situ DCP test, trial pit for field moisture and density, visual condition assessment in addition to the traffic count, axle load measurement, sampling for laboratory tests. This paper will, mainly, focus on the analysis of the in-situ DCP test measurement and visual condition assessment.

The original development of the DCP dates back to the mid-1950s in Australia based on an older Swiss original, and was used initially as a non-destructive testing device to evaluate the shear strength of a material in a pavement. The use of the DCP for pavement design purposes was further enhanced in the mid-1960s and 1970s in South Africa where results from back analysis of some 57 roads in different traffic and climatic environments, together with some accelerated pavement testing with the Heavy Vehicle Simulator (HVS) were used to verify the concepts used in the design method and to establish expected life versus DCP penetration curves (Kleyn and van Zyl, 1988, TRL, 1993, MTPW, 2013).

3.2 DCP Tests

On all of the monitoring trial and control sections DCP tests are performed using 60-degree cone DCP test equipment. For each Long term pavement performance (LTPP) panels, the nine sections in Table 1, five DCP test points are marked and tests were carried out across the road as follows: Outer wheel path left (OWL), Inner wheel path left (IWL), centreline (CL), Inner wheel path right (IWR) and Outer wheel path right (OWR).

The results of the DCP tests carried out on the monitoring sections for one representative the fourth monitoring period is summarised in Table 2. In the next result and discussion section summary of average of each panel are presented for the various section conditions. It is customary to predict the CBR strength from the DCP rate of penetration into gravel and soil layers (i.e. the DN value in mm/blow) using various equations developed elsewhere (Kleyn, 1982, TRL, 1993) that relates CBR and DN values. However, it is used directly and compare the DN values of the base and subbase for the respective pavement layers, and the DSN values (#blow) of DSN450 and DSN800 which are the cumulative number of blows required to penetrate the pavement to a depth of 450mm and 800mm from the top of the base layer.

DCP number (DN): The DCP measures the penetration per blow into a pavement through each of the different pavement layers. This rate of penetration in mm/blow (the DN value) is a function of the in-situ shear strength of the material at the in-situ moisture content and density of the pavement layers at the time of DCP testing.

DCP structure number (DSN): The DCP structure number is the number of DCP blows required to penetrate a pavement structure or layer. For example, the DSN800, a parameter which allows the bearing capacity of different pavements to be compared, is the number of blows required to penetrate the pavement to a depth of 800 mm.

From a knowledge of the DN values of various pavement layers, those of relatively high and relatively low strength can be distinguished from each other and the balance of the pavement at any depth can be evaluated. This has led to the development of a pavement classification system in which shallow, deep and inverted pavements can be distinguished from each other and further differentiated in terms of whether they are well-balanced, averagely balanced or poorly balanced.

Table 2. DCP tests on the Assosa – Kurmuk 4th round monitoring [11-2018 wet season]

Section ID	Location	DN-Base	DN-Subbase	DSN450	DSN800
UC1	OWL	4.5	5.5	83	111
	IWL	4	6.5	93	141
	CL	5	6.5	88	136
	IWR	5	8	82	116
	OWR	6.5	6	71	95
	Average	5	7	83	120
UF1	OWL	6	8.5	58	88
	IWL	6	12	55	81
	CL	4.5	18	68	93
	IWR	7	10.5	55	79
	OWR	7.5	10.5	47	68
	Average	6	12	57	82
SF1	OWL	6	14	63	81
	IWL	5.5	13	62	81
	CL	7	11.5	53	77
	IWR	8	14	55	78
	OWR	8	13	55	83
	Average	7	13	58	80
SC1	OWL	8	10.5	54	120
	IWL	7.5	10.5	55	140
	CL	6	10.5	61	145
	IWR	8	11.5	49	115
	OWR	9	10	48	106

	Average	8	11	53	125
UC2	OWL	7	7	83	173
	IWL	4	5	89	178
	CL	6	8	72	104
	IWR	6	8.5	66	125
	OWR	7	9	54	84
	Average	6	8	73	133
SF2	OWL	9.5	12.5	51	82
	IWL	4	5.3	105	210
	CL	5	6.5	83	143
	IWR	6	6.5	78	155
	OWR	8.5	7	56	87
	Average	7	8	75	135
UF2	OWL	10.5	13	40	70
	IWL	10.5	9.5	45	84
	CL	6.5	10.5	53	91
	IWR	6	10.5	48	77
	OWR	12	21	50	61
	Average	9	13	47	77
CS1-UC1	OWL	2	4	160	230
	IWL	2.5	4	135	185
	CL	3	5	125	190
	IWR	3	8	96	122
	OWR	3	5.5	130	195
	Average	3	5	129	184
CS1-UC2	OWL	2.5	6	145	220
	IWL	2.5	6.5	104	131
	CL	2.5	6	141	170
	IWR	3	5	125	190
	OWR	3	6	115	177
	Average	3	6	126	178
CS2-UF1	OWL	2.5	4	140	170
	IWL	3	5	130	173
	CL	3	5.5	140	176
	IWR	2.5	4	144	170
	OWR	2.5	6	116	155
	Average	3	5	134	169
CS2-UF2	OWL	6	8.5	62	95
	IWL	6	9	81	104
	CL	4	6	100	146
	IWR	10	15	36	61
	OWR	12	15.5	33	56
	Average	8	11	62	92

4. RESULTS AND DISCUSSION

The DCP test result, DN and DSN values, are compared for the different conditions of the demonstration section. The following comparisons are tabulated and discussed i.e.: average DN values for laterite base trial sections vs crushed stone base control sections, sections in cut vs sections in fill and sections with sealed shoulders vs unsealed shoulders.

These measured results have been demonstrated for the average of all values and the average of the outer wheel track values only.

4.1 Average DN values of all wheel tracks and centreline

Table 3 demonstrates DN value comparison for the various sections based on the average of all values for the four monitoring cycles or rounds i.e. 1st round 2017 dry, 2nd round 2017 wet, 3rd round 2018 dry and 4th round 2018 wet season.

Table 3. DCP tests on the Assosa – Kurmuk [04-2017 / dry season]

Monitoring round	Section	DN-Base (mm/blow)	DN-Subbase (mm/blow)	DSN_{450} (#blow)	DSN_{800} (#blow)Monitoring round/ Season
Laterite Base Trial Sections vs Crushed Stone Control Sections					
1st round	Average Laterite Base Trial Sections	6	10	60	93
	Average Crushed base Control Sections	4	9	84	120
2nd round	Average Laterite Base Trial Sections	7	10	65	96
	Average Crushed base Control Sections	6	9	65	129
3rd round	Average Laterite Base Trial sections	6	10	71	110
	Average Crushed base Control Sections	3	7	117	146
4th round	Average Laterite Base Trial Sections	6	10	66	113
	Average Crushed base Control Sections	4	7	113	156
All rounds	Average Laterite Base Trial Sections	6	10	65	103
	Average Crushed base Control Sections	4	8	95	138
Sections in Cut vs Sections in Fill					
1st round	Average Sections in Cut	5	9	73	107
	Average Sections in Fill	6	10	65	98
2nd round	Average Sections in Cut	6	9	70	113
	Average Sections in Fill	6	9	66	104
3rd round	Average Sections in Cut	5	9	81	120
	Average Sections in Fill	5	9	91	120
4th round	Average Sections in Cut	5	7	93	148
	Average Sections in Fill	7	10	72	106
All rounds	Average Sections in Cut	5	10	65	103
	Average Sections in Fill	4	8	95	138
Sections with Sealed Shoulder vs Sections with Unsealed Shoulder					
1st round	Average Sections with Sealed Shoulder	7	12	49	76

	Average Sections with Unsealed Shoulder	5	9	68	104
2nd round	Average Sections with Sealed Shoulder	8	12	55	79
	Average Sections with Unsealed Shoulder	5	7	81	117
3rd round	Average Sections with Sealed Shoulder	6	11	65	96
	Average Sections with Unsealed Shoulder	6	10	72	112
4th round	Average Sections with Sealed Shoulder	7	10	62	114
	Average Sections with Unsealed Shoulder	7	10	65	103
All rounds	Average Sections with Sealed Shoulder	7	11	58	91
	Average Sections with Unsealed Shoulder	6	9	71	109

4.2 Average DN values of the outer wheel track only

Table 4 demonstrates DN and DSN value comparison for the various sections based on the average of the outer wheel track values only for the four monitoring cycles or rounds.

Table 4. DN and DSN for sections based on average of the outer wheel track values only

Monitoring round	Section	DN-Base (mm/blow)	DN-Subbase (mm/blow)	DSN_{450} (#blow)	DSN_{800} (#blow)
Laterite Base Trial Sections vs Crushed Stone Control Sections					
1st round	Average Laterite Base Trial Sections	6	10	60	93
	Average Crushed base Control Sections	4	9	84	120
2nd round	Average Laterite Base Trial Sections	7	10	65	96
	Average Crushed base Control Sections	6	9	65	129
3rd round	Average Laterite Base Trial sections	6	10	71	110
	Average Crushed base Control Sections	3	7	117	146
4th round	Average Laterite Base Trial Sections	6	10	66	113
	Average Crushed base Control Sections	4	7	113	156
All rounds	Average Laterite Base Trial Sections	6	10	65	103
	Average Crushed base Control Sections	4	8	95	138
Sections in Cut vs Sections in Fill					
1st round	Average Sections in Cut	5	9	73	107
	Average Sections in Fill	6	10	65	98

2nd round	Average Sections in Cut	6	9	70	113
	Average Sections in Fill	6	9	66	104
3rd round	Average Sections in Cut	5	9	81	120
	Average Sections in Fill	5	9	91	120
4th round	Average Sections in Cut	5	7	93	148
	Average Sections in Fill	7	10	72	106
All rounds	Average Sections in Cut	5	10	65	103
	Average Sections in Fill	4	8	95	138
Sections with Sealed Shoulder vs Sections with Unsealed Shoulder					
1st round	Average Sections with Sealed Shoulder	7	12	49	76
	Average Sections with Unsealed Shoulder	5	9	68	104
2nd round	Average Sections with Sealed Shoulder	8	12	55	79
	Average Sections with Unsealed Shoulder	5	7	81	117
3rd round	Average Sections with Sealed Shoulder	6	11	65	96
	Average Sections with Unsealed Shoulder	6	10	72	112
4th round	Average Sections with Sealed Shoulder	7	10	62	114
	Average Sections with Unsealed Shoulder	7	10	65	103
All rounds	Average Sections with Sealed Shoulder	7	11	58	91
	Average Sections with Unsealed Shoulder	6	9	71	109

4.2.1 Comparison of DN values for the different sections

As stated above the structural strength of the pavements (DN and DSN values) comparisons have been demonstrated for the average of all values and the average of the outer wheel track values only.

In the comparison of laterite base trial sections and crushed stone base control sections all section in cut and fill as well as with sealed shoulder and unsealed are averaged as shown in Figure 2. It is clearly demonstrated that the DN and DSN value of the control sections with crushed stone base are stronger than the trial sections with laterite base. Even the DN value of the laterite subbase shows significant difference that the laterite subbase under the control section is stronger than under the lateritic base. Moreover, it is noted that the difference between the control section and the trial section DN and DSN values it is slightly higher in the outer wheel track than all average.

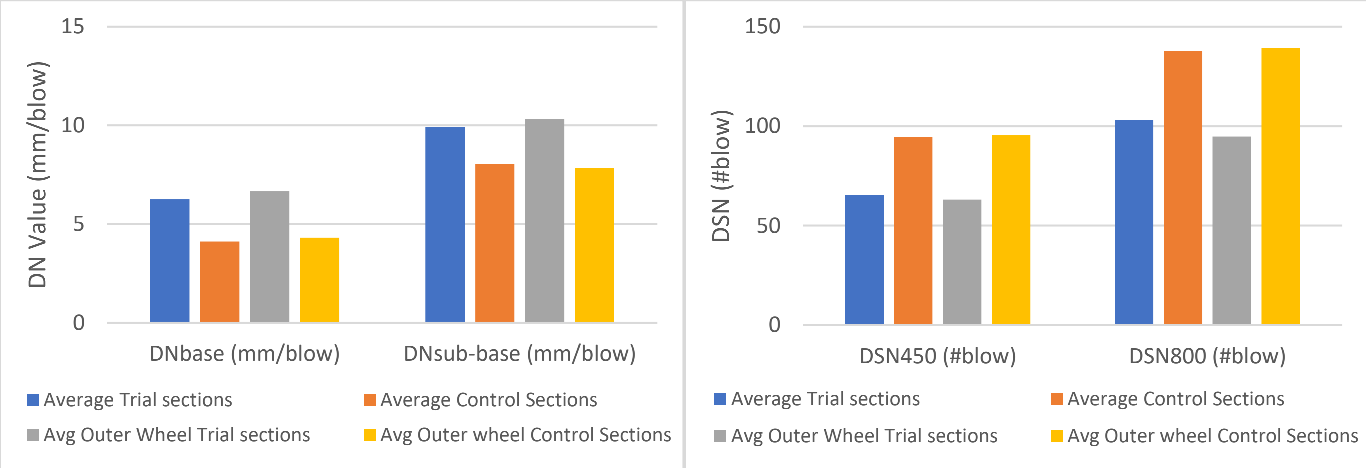

Figure 2. Laterite Base Trial Sections vs Crushed Base Control Sections

In the case of sections in cut and sections in fill comparison both trial and control sections as well as sealed and unsealed sections are taken into account and averaged. It is clearly demonstrated that for both the base and subbase the DN and DSN value of the sections in cut are stronger than the sections in fill as shown in Figure 3. Slight difference in DN and DSN average values is shown between all average and the outer wheel track only for the fill sections, while it is no significant difference for the cut section.

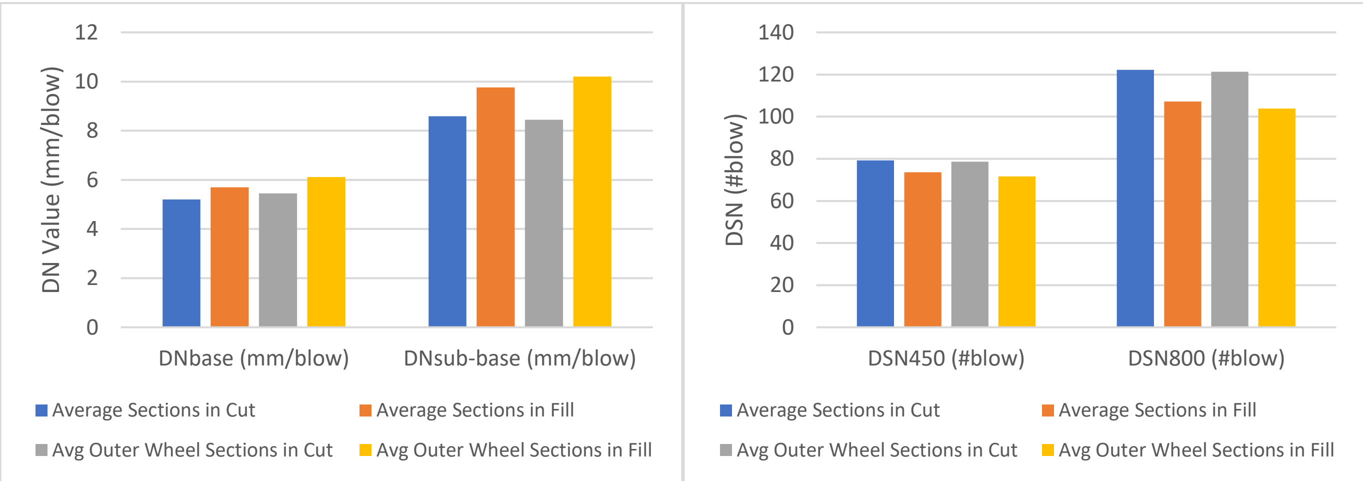

Figure 3. Sections in Cut vs Sections in Fill

In the case of sections with sealed and unsealed shoulders comparison, sections in cut and fill in the laterite base trial sections is taken into account excluding the crushed base control sections to avoid any bias as both the control sections are only with unsealed shoulder. The result seems opposite to what is expected for both the base and subbase layers, the DN and DSN value of the sections with unsealed shoulder shows more stronger than the sections with sealed shoulder, see Figure 4. Looking in details especially for the 3rd and 4th round monitoring for both all average and the outer wheel track only no difference in DN values is observed specially for the base layer. This is not the case however for the 1st and 2nd round monitoring, which can be attributed to some errors in proper location of the sections in the earlier rounds.

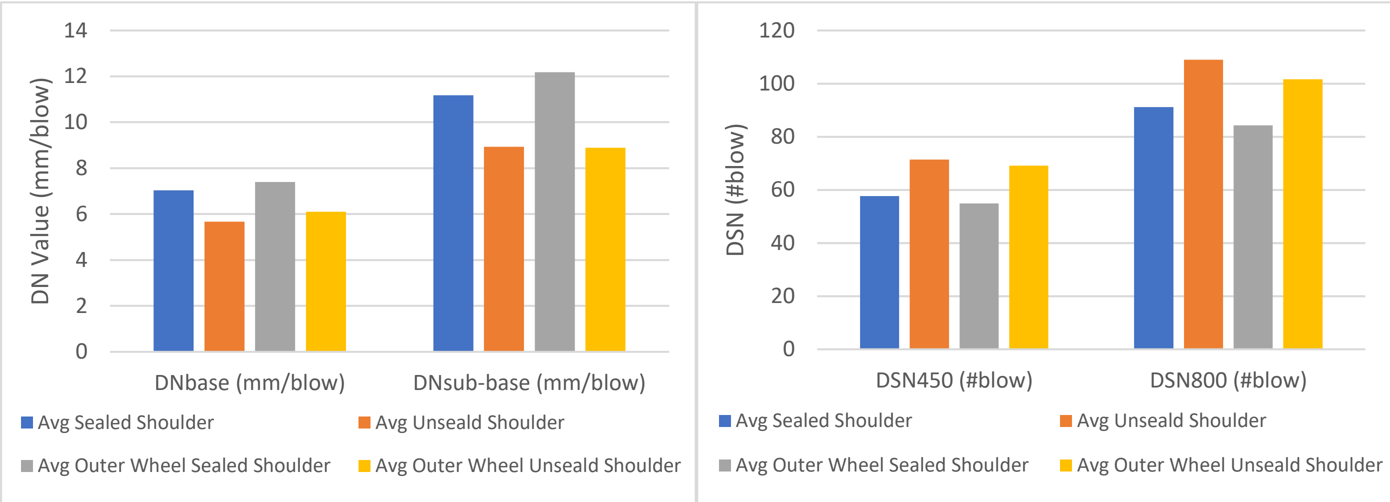

Figure 4. Laterite Base Sections with Sealed Shoulder vs Sections with Unsealed Shoulder

4.3 Visual Condition Assessment

Visual condition assessment has also been carried out on the trial and control sections. Generally, most sections of the monitoring are in a good condition, without significant or visible defects. In terms of performance between cut and fill sections as well as with sealed and unsealed shoulder section no significant difference is observed. However, with slight difference a better surface performance is visually observed in the crushed base control sections comparing to the laterite base trial sections.

Typical photographs of defects on the monitoring section during 4th round is shown in Figure 5 for each section. From the visual condition assessment commonly observed defect types are rough surface texture, ravelling and to some extent beginning of minor surface crack. However, there was no significant structural related defects such a rutting or crocodile cracking even for the laterite base unsealed section in both cut and fill sections.


Roughness surface texture


Ravelling

Unsealed Shoulder Cut Section 1 – UC1


Ravelling/ rough texture

No defect

Unsealed Shoulder Cut Section 1 – UF1


Start of minor/surface crack


No defect

Sealed Shoulder Fill Section 1 – SF1

 Start of ravelling	 No defect
Sealed Shoulder Cut Section 1 – SC1	
 No defect	 Rough surface texture
Unsealed Shoulder Cut Section 2 – UC2	
 No defect	 Potential wheel path ravelling
Sealed Shoulder Fill Section 2 – SF2	


Start of stone loss


No defect

Unsealed Shoulder Fill Section 2 – UF2


Rough surface texture


No defect

Control Section 1 - Unsealed Shoulder Cut Section – CS1-UC


No defect


Potential wheel path ravelling

Control Section 2 - Unsealed Shoulder Fill Section – CS2-UF

Figure 5. Illustrative typical defects

5. CONCLUSION

Generally, it can be stated that to reach on a sound comparative performance and comprehensive analysis of results on the long-term pavement performance an extended monitoring period of several years is needed. However, the following brief comparative performance is provided from the measurements and observations made so far.

Although the traffic volume in this trial section road is low, including all classes of trucks; both in terms of DCP structural test and visual assessment, except some minor surface texture defects, all of the laterite base trial sections are performing well. To a certain extent the crushed base control sections are performing better.

DCP test results in these sections reveals that the crushed base control sections perform better than the laterite base trial sections and the sections in cut are stronger than in fill while the shoulder sealing doesn't provide consistent effect on the layer strengths.

From this monitoring section, it can be demonstrated that for such low volume roads especially in areas where hard rock for crushed aggregate is scarce, a good performing pavement can be designed and constructed with such available natural gravel as base material in addition to its use as a subbase.

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