PERFORMANCE OF MECHANICALLY STABILISED SAND ROAD BASES IN MOZAMBIQUE.

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***Abstract* -In Mozambique only 20% of the classified road network is paved. Locally available materials for the base are often out of specification and the solution normally adopted for pavement layers is conventional chemical stabilization. The Agostinho-Neto to Mutamba Road in Inhambane Province was constructed under a programme of Targeted Interventions for Low Volume Roads. The objective of the programme was to find technical and economically viable options for local conditions. The road was constructed in 2015 and is 5.5 km long and 6.0m wide. The first 4.3 km section of the road comprises a base of blended sand and calcrete (50:50). The remaining 1.2 km has a base of neat red local sand armoured with crushed calcrete. The subbase is neat red sand throughout, and the road is surfaced with an Otta seal and slurry. Monitoring sections were established on each type of base to evaluate the road performance. Routine monitoring of these sections is being carried out according to a standard protocol developed for Mozambique. In general, the section with the armoured base is performing better than the blended base section, which shows cracks and deformation and has required extensive pothole repairs. The potholes are attributed to the higher moisture content in the base. This is related to the pavement/formation structure and whether there is a kerb. The research project has shown that the locally available sandy materials can be mechanically stabilized to provide an adequate base course without the high cost of conventional stabilization.**

Keywords—Blended Base; armoured base; otta seal;

I. INTRODUCTION

In Mozambique only 20% of the classified road network is paved. Locally available materials are often out of specification for pavement layers and the solution normally adopted is conventional chemical stabilization.

Inhambane is a coastal province about 450 km north of Maputo. The annual average precipitation is 938mm and the province is exposed to weather-related natural hazards such as droughts, floods and cyclones. The naturally occurring materials in Inhambane include soils with low strength (predominantly sand), but there are also extensive but erratic calcrete formations.

Experimental sections were constructed in Mozambique as part of a broader programme of Targeted Interventions for Low Volume Roads in Mozambique implemented by the National Road Administration (ANE). One of these sections was the Agostinho-Neto to Mutamba Road in Inhambane Province.

The objective of the Targeted Interventions project was to find technically and economically viable options for the local construction of rural roads. The Agostinho-Neto to Mutamba road was constructed in 2015 and is 5.5 km long and 6.0m wide. The first 4.3 km section of the road comprised a base of blended sand and calcrete (50:50). The remaining 1.2 km has a base of neat red local sand armoured with a layer of nominal size 50 mm crushed calcrete aggregate. The subbase is neat red sand throughout and the road is surfaced with an Otta seal and slurry.

The design traffic load was 150 000 E80s: the road is lightly trafficked, carrying mainly cars and 4x4s. The current cumulative traffic count is 45 000 E80s.

II. METHODOLOGY

To evaluate the performance of the experimental sections on the Agostinho Neto to Mutamba Road, a monitoring programme was established on each pavement design solution that was adopted (blended base and armoured base). Routine monitoring was carried out according to a standard protocol for monitoring experimental sections, which has been developed for Mozambique [1]. The setting up and monitoring process includes the following:

- Review of existing data;
- Identification of monitoring sections;
- Evaluation of engineering and structural properties of the pavement through measurements and materials testing; and
- Traffic counting.

A. *Review of existing data*

A review was carried out of existing data on the project road, including as-built data (test results) and the construction methodology. A site inspection was carried out. This provided a general overview of the constructed sections.

B. *Selection of the sites*

Two sections of 500m length were identified and marked as indicated in Fig 1. for long term monitoring. The panels A, B, C, D and E were reserved for destructive tests including test pits, density measurements, moisture content measurements, Dynamic Cone Penetrometer (DCP) tests, etc. The panels in between were reserved for non-destructive tests including roughness measurements, rut depth measurements and visual condition assessments.

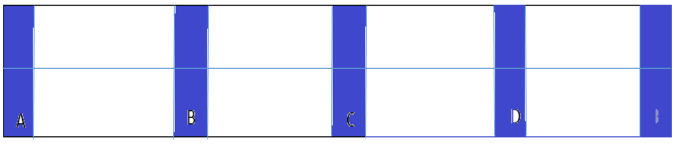

Fig. 1. Sketch of monitoring sections.

C. *Evaluation of the condition of the pavement*

The pavement condition was evaluated in two ways:

- Road user, where the condition of the road is appraised in terms of characteristics that affect quality of travel, comfort, safety and operation cost; and
- Road engineer, where the road engineer assesses the functional requirements of the road, viewing the pavement as a load bearing structure to be maintained in good condition and to remain serviceable at minimum overall cost [2].

D. *Pavement structure*

The pavement strength was evaluated by several methods as described below.

Dynamic Cone Penetrometer (DCP)

The DCP was used to evaluate the strengths and thicknesses of the layer materials using the standard 1 metre long lower shaft. The test data is manually recorded and stored electronically for analysis using suitable software [3].

Material investigations

The performance of the pavement is directly related to the layer material properties. To assess the layer thickness and material properties, two test pits were excavated on armoured (Fig-2) and blended (Fig 3) on each of the monitoring sections and samples of the materials were taken for laboratory testing. The following information was obtained:

- Soil profile [4];
- In situ density;
- In situ moisture content;
- Particle size distribution;
- Atterberg limits; and
- Laboratory CBR value.

Rutting

Rut depth measurements were carried out using the methodology described by ASTM [5]. The purpose was to obtain an indication of the deformation of the material in the pavement. Rutting on low volume sealed roads is indicative of potential problems such as shear failure, subgrade deformation and loss of material strength in the pavement.

E. *Functional assessment*

The serviceability of the road was assessed in terms of roughness and a visual condition description.

Roughness Measurements

The road sections were assessed in terms of comfort and safety for road users through roughness measurements. The measurements were taken with a MERLIN (Machine for Evaluating Roughness using Low-cost Instrumentation [6]) provided by TRL(UK). Two hundred measurements were taken on each 500m long monitoring section. The "D" value obtained from the graph of MERLIN measurements was used to calculate the International Roughness Index (IRI) with the formula:

$$\text{IPI} = 0.593 + 0.0471\ \Delta. \qquad (1)$$

Fig. 2. Armoured base.

Fig. 3. :Blended base

Visual Condition Index –VCI

The VCI provides a measure of the pavement condition. It can also provide an indication of maintenance needs. The visual assessment is carried out by walking the road section and noting the "degree" and "extent" of various defects observed on the road using a standard form [7].

Fig. 4. Illustration of the measurement of Roughness with the MERLIN.

F. *Traffic Count*

A seven day classified traffic count was carried out in October 2014 using the standard ANE traffic count process.

III. INITIAL INSPECTION AND TEST PIT LOGS

A. Armoured base

Armouring of the base was carried out by laying crushed calcrete with a nominal 50mm diameter on the surface and rolling it into the sand base.

The soil profile for the armoured base sections is shown in Table- I.

TABLE I. : PROFILE LOG ON ARMOURED BASE (PANEL A AND D).

	Thickness	Moisture	Colour	Consistency	Structure	Soil type	Origin
	20 mm		***Otta seal + slurry seal***				
	100 mm		***Calcrete (armouring)***				
	300 mm	Slightly Moist	Slightly Red, stained Sand	Medium Dense	Granular	Fine to medium silty Sand	Sandy soil of mixed origin
	150 mm	Slightly Moist	Slightly Red, stained Sand	Medium Dense	Granular	Fine to medium silty Sand	Sandy soil of mixed origin
	infenite	Slightly Moist	Slightly Red, stained Sand	Medium Dense	Granular	Medium Sand	Sandy soil o origin f mixed

The initial inspection of the road section showed the following:

- There was visible surface cracking, bleeding, and slight deformation where the road is on an embankment.
- The shoulder is narrow on some sections, with edge drop and edge break.
- Drainage is poor on a 250m section due to flat terrain (Fig. 6).
- On the embankment section, 170m on the right hand side of the road has asphalt kerbs and there is water accumulation alongside the road (Fig. 7).

Fig. 5. Armured base sections on embankment

Fig. 6. Armured base sections on flat terrain.

B. Bended base section

This consists of a blend of 50% calcrete and 50% granular sand. The purpose of blending is to improve the strength of sand base material.

The soil profile for the blended base sections is shown in Table- II.

TABLE II. : PROFILE LOG OF BLENDED BASE SECTION

	Thokn ess	**Moisture**	**Colour**	**Consistency**	**Structure**	**Soil type**	**Origin**
	20mm		***Otter seal+ slurry seal***				
	150mm	Dry	Blotched red and white/grey	medium dense	Granular		Crushed calcrete and local sand
	150mm	Dry	Red	medium dense	Granular	Medium Sand	Sandy soil of mixed origin
	infenite	Slightly moist	Brown	medium dense	Granular	Medium Sand	Sandy soil of mixed origin

The initial observations on this section were as follows:

- The blended base section includes a 244 m long section on a 2 m fill (panel A) and a 264 m long section on a 3 m fill with kerbs (Fig. 8)
- The section shows cracks and deformation and has required extensive pothole repairs (Fig.7).

Fig. 7. Patches along the section

Fig. 8. Kerbs on blended base section

IV. TESTING AND MONITORING RESULTS AND DISCUSSION

A. Armoured base

1) Armoured layer

The armoured layer consists of calcrete aggregate of 50mm nominal size with Aggregate Crushing Value (ACV) of 28.6%, a bulk density of 2500 kg/m^3 and water absorption of 3%.

2) In situ Moisture Content

The in situ (field) moisture content (FMC) was measured after the wet (April) and dry (October) seasons using a nuclear gauge. The results are shown in Tables- III nd IV.

From the moisture content results shown in Tables- III and IV, it is concluded that on panel A/B (flat terrain) the soils are drier (FMC/OMC below 50%) than on panel D, which shows a FMC/OMC ratio of 87% on the base and the lowest of 25% on subgrade) with more variable moisture contents in the layer.

TABLE III. : MOISTURE PANEL-A/B

Depth (mm)	**Wet Density (kg/m3)**	**OMC (%)**	**MDD (kg/m3)**	**In situ Moisture (%)**		**Relative Moisture**		**Dry* Density (kg/m3)**	**Comp. (%)**
				October	***April****	***October***	***April***		
150	2202	8.7	2050	1.8	3.92	0.21	0.45	2119	103
	2185			2.1	5.52	0.24	0.63	2071	101
	2183			2.2				2183	106
300	2103	9.8	1995	1.9	3.11	0.19	0.32	2040	99
	2061			1.8	3.03	0.18	0.31	2000	98
	2091			1.9				2091	102
600	2103	9.3	1808	1.9	4.05	0.20	0.44		
	2061			1.8	3.17	0.19	0.34		
	2099			1.9					

TABLE IV. : MOISTURE CONTENT ON PANEL-D (EMBANKMENT)

Depth (mm)	**Wet Density (kg/m3)**	**OMC (%)**	**MDD (kg/m3)**	**In situ Moisture (%)**		**Relative Moisture**		**Dry * Density (kg/m3)**	**Comp. (%)**
				October*	***April***	***October***	***April***		
150	2117	9	2030	7.8	5.97	0.87	0.66	1964	96
	2131			7.8	5.89	0.87	0.65	1977	96
	2061			7.5				1917	94
300	1925	9.8	2010	4.2		0.43		1847	90
	2115			3.9		0.40		2036	99
	1964			4.2				1885	92
600	1925	11		4.2	3	0.38	0.27	1847	90
	2115		1756	3.9	2.64	0.35	0.24	2036	99
	1964			4.2	2.71	0.25	0.25	1885	92

~~4)~~3) Sieve analysis and Plasticity Index

The sieve analyses and Atterberg limit results are presented in Table- V.

From the results shown in Table- V and Fig. 9, it is concluded that the base and subbase materials have similar properties and were taken from the same borrow pit. The subgrade and fill materials are in situ and slightly coarser.

The plasticity results obtained for material passing the 0.425 mm sieve indicate that the materials used on the armoured base section have a Plasticity Index (PI) of less of 6% and the subgrade and fill are non-plastic (NP). This is within the limits recommended in the SATCC Specification [8],

TABLE V. : INDICATORS (SIEVE ANALYSES AND ATTERBERG LIMITS)

Test Pit	**Depth (mm)**	**Opening size (mm) vs % of material passing**									**Atterberg Limits**		
											LL	**PL**	**PI**
		4.75	***2.00***	***1.19***	***0.60***	***0.42***	***0.30***	***0.21***	***0.15***	***0.07***	***(%)***		
A	0-300	100	100	100	98	95	82	62	32	21	21	15	6
	300-600	100	100	100	98	90	66	44	25	15	NP	NP	NP
	600-900	100	100	100	98	88	47	20	9	4	NP	NP	NP
D	0-300	100	100	100	98	95	83	63	33	21	20	15	5
	300-450	100	100	100	97	89	67	44	26	18	NP	NP	NP
	450-900	100	100	100	98	84	39	19	9	4	NP	NP	NP

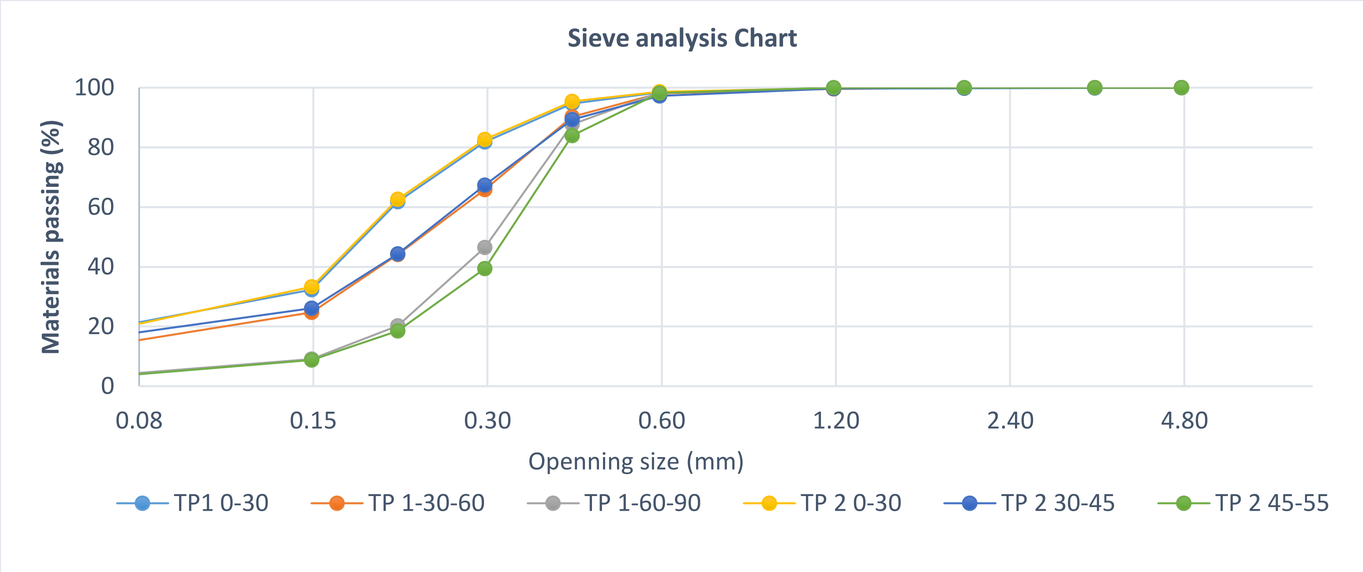

Fig. 9. : Sieve analysis graph.

~~5)~~4) *CBR*

The material strength expressed as CBR was evaluated according to TMH 1[9], and the Optimum Moisture Content determined by the compaction test [10].

The Maximum Dry Density (MDD) results are shown in Table- III and IV, and the CBR results are shown in Table -VI.

TABLE VI. : CBR RESULTS

Effort (%) Mod *AASTHO*	Depth (mm)		
	0-300	*300-600*	*600-900*
	CBR (%)		
100	52	28	32
98	47	22	28
95	35	18	22
93	27	16	18

From the results presented in Table- VI, it is concluded that the materials used for the base are outside the SATCC specifications in terms of strength which specifies a minimum CBR of 80% at 98% Mod AASHTO [11] (for Trunk roads).

From the CBR results, the materials used on the armoured base and subbase (0-300mm) are classified as G5 [11] and are not recommended for use as road base for conventional roads. They would, however, often be considered suitable for low volume roads.

The subgrade materials are classified as SG1 class (Subgrade *CBR* classification for structural design), (G7 in TRH 14) and are thus suitable.

~~6)~~5) *DCP*

The DCP results for the armoured base are shown in Table 4.6 and Table VII.

According to the DCP results shown on Table -VII and Table VIII, the equivalent CBR shows that the pavement structure is poorly balanced. In a well-balanced pavement, the strength should decrease uniformly from base to subgrade. This is especially true for panel A where the pavement seems to be stronger from 250-400mm. On panel A, the in situ CBR values are lower than expected from the laboratory soaked CBR,

TABLE VII. : RESULTS OF DCP-PANEL A

October/2017		
Layer (mm)	*Weighted DN (mm/blow)*	*Equivalent CBR (%)*
0-160	3.21	93
161-300	3.2	94
300-450	1.46	223
451-600	2.15	155
601-800	2.4	132
May-18		
Layer (mm)	*Weighted DN (mm/blow)*	*Equivalent CBR (%)*
0-270	3.01	101
271-540	2.49	108
541-800	2.66	100

TABLE VIII. : RESULTS OF DCP-PANEL D

May-18		
Layer (mm)	*Weighted DN (mm/blow)*	*Equivalent CBR (%)*
0-350	1.66	207
351-415	0.41	380
416-570	0.97	257
571-800	1.38	85

~~7)~~6) *Rutting*

The rut depth results are presented in Fig.10 taken from each of the 20m panels (numbered 1 to 20). The highest rut depth is

14 mm at KM 5+130 on the left side and it can be attributed to settlement of the layer on the embankment

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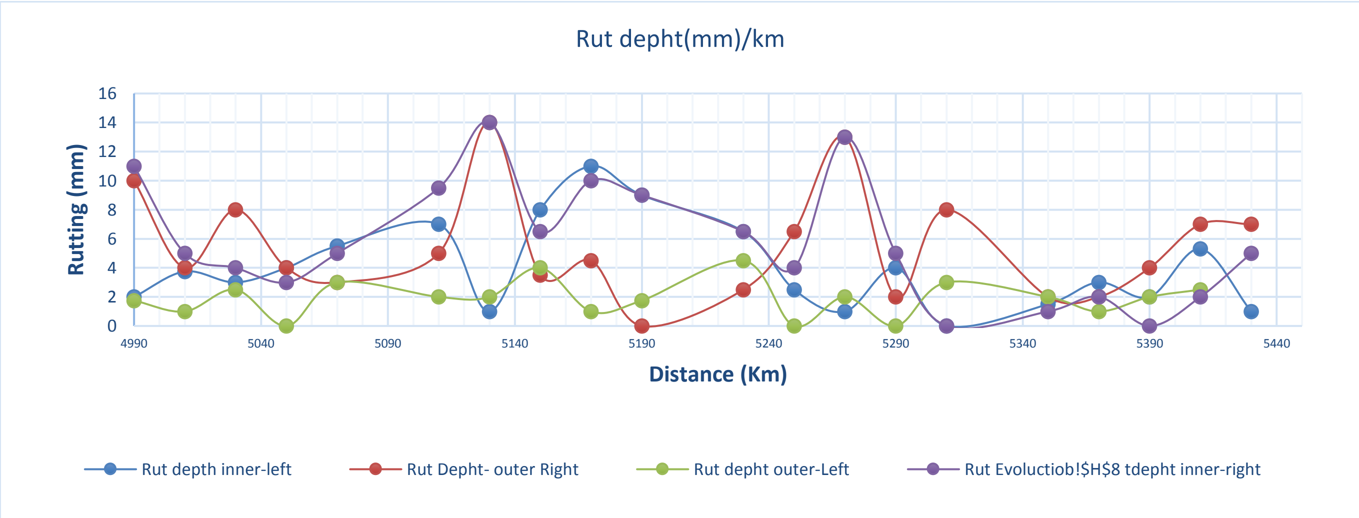

Fig. 10. Graphical representation of the rut depths

8)7) Visual Condition Index (VCI)

The VCI results on the armoured base are shown in Table 9.

TABLE IX. VCI SUMMARY RESULTS

From	To	Length	VCI
5+000	5+080	80	91
5+080	5+200	120	89
5+200	5+300	100	88
5+300	5+400	100	91
5+400	5+440	40	92

The VCI results on this section are all above 85% which shows the road is still in a good condition. At Km 5+080 to 5+300, the VCI is slightly lower, showing that maintenance interventions may soon be required.

9)8) Roughness

The results of IRI roughness measured on each 250m long section in the outer wheel path in each lane are presented in Fig.11.

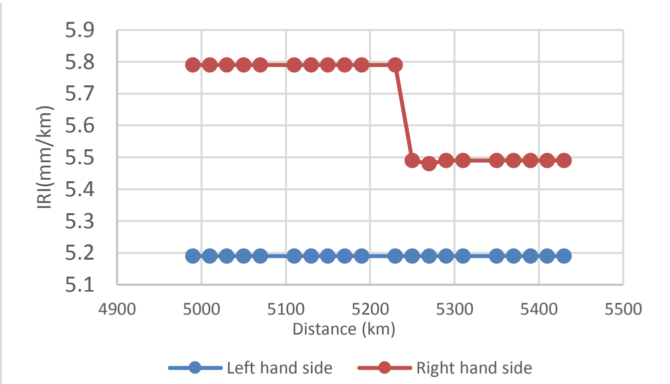

Fig. 11. : IRI results.

B. Blended base

1) In situ Moisture Content

The Maximum Dry Density and moisture content of the blended base are presented in Table X and XI.

TABLE X. : MOISTURE CONTENT ON ON PANELA LEFT SIDE OUT PATH

Depth (mm)	Wet Density (kg/m3)	OMC (%)	MDD (kg/m3)	in situ Moisture(%)		Relative Moisture		Dry Density (kg/m3)	Comp. (%)
				*October**	*April*	*October*	*April*		
150	1911	7	2073	5.7	10.2	0.81	1.46	1808	87
	1904			5.4	9.7	0.77	1.39	1806	87
300	1963	6.3	2090	4	11.7	0.63	1.86	1888	90
	1962			4.2	10.5	0.67	1.67	1883	90
600	1862	7.8		4.4		0.56		1727	
	1866		2074	3.6		0.46		1731	83

TABLE XI. MOISTURE CONTENT ON PANEL - E LEFT SIDE OUTER PATH (PROTECTED BY KERBS)

Depth (mm)	Wet Density (kg/m3)	OMC (%)	MDD (kg/m3)	In situ Moisture (%)		Relative Moisture		Dry Density (kg/m3)	Comp. (%)
				October	*April*	*October*	*April*		
150	1939		2192	6.1	6.7	0.87	0.96	1828	83
	1916	7		5.7	6.3	0.81	0.90	1813	83
300	1945		2103	3.1	4.8	0.40	0.62	1887	90
	1942	7.7		2.8	5.7	0.36	0.74	1889	90
	1918			2.8		0.33		1866	90
600	1889	8.5	2080	5.7		0.67		1787	86

From the moisture content results shown in Tables- X and XI, it is concluded that on both panel A and E the moisture contents in the layer are homogenous. However on panel A sections the moisture is higher than what would be expected from OMC which makes the soils unstable and susceptible to deformations (rutting). On–panel E (3 meter fill/Kerbs), the results show the MC/OMC ratio on the base of 96% in October and 87% in April, according to both results (Octobers and April) it is concluded that in situ moisture are around OMC.

2) Sieve analysis and plasticity Index

The sieve analysis results of six samples collected from the test pits are presented in Table XII and Fig.13.

TABLE XII. : INDICATORS (SIEVE ANALYSIS AND PLASTICITY INDEX)

Reference		Sieve opening (mm) vs % passing													Atterberg Limits		
															LL	LP	IP
Test Pit	Depth(mm)	37.5	25.4	19	12.5	9.5	6.3	4.75	2	0.6	0.425	0.3	0.15	0.075	(%)		
A	0-150	100	98	96	92	89	85	83	76	69	62	38	20	16	35.2	19.7	15.6
	150-300	100	100	100	100	100	100	100	100	98	90	66	14	7	NP	NP	NP
	300-800	100	100	100	100	100	100	100	99	97	87	55	22	15	NP	NP	NP
E	0-150	100	96	94	92	90	88	86	81	76	71	40	22	18	29.4	18.3	11.1
	150-300	100	100	100	100	100	100	100	99	99	92	74	20	10	NP	NP	Np
	300-800	100	100	100	100	100	100	100	100	100	94	77	15	8	NP	NP	NP

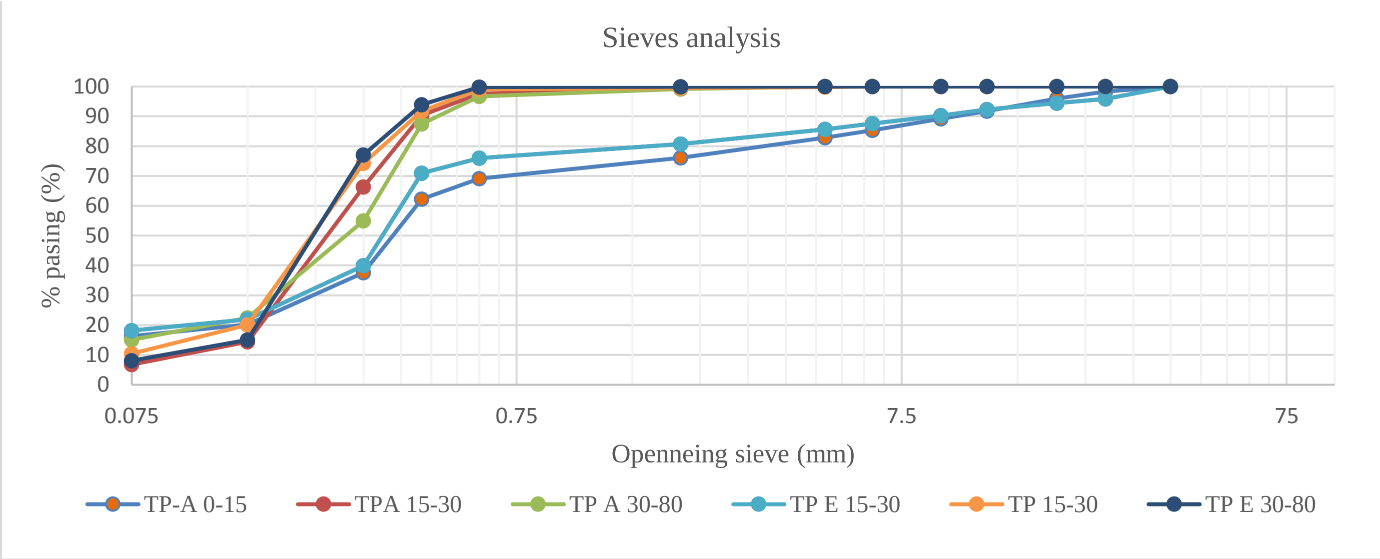

Fig. 12. Graphical Representation of the Sieve Analyses.

The sieve results show that calcrete is included in some samples of the material, taking the sample to a nominal size of 12.5mm and a maximum size of 25.4mm. However, the sieve curves (Fig.13 and Table XII) indicate that the grading of the calcrete contains more fine particles than crushed calcrete stones. Therefore, it does not contribute fully to improving the grading of blended material.

3) CBR

The CBR results are presented on Table XIII.

From the results presented in Table XIII for the blended material, it is concluded that the materials used for the base are outside of the specifications in terms of strength which require 80% @98% Mod AASTHO.

- The materials used for the armoured base (0-300mm) are classified in terms of strength as G5 according to TRH14 and are not recommended for use as road base for conventional roads.
- The materials used for the subgrade are classified as SG1 class (Subgrade *CBR* classification for structural design), (G6 on THR 14), indicating relatively strong support for the pavement.

TABLE XIII. : CBR RESULTS

Effort % Mod AASTHO	**Depth (mm)**		
	0-300	***300-600***	***600-900***
	CBR (%)		
98	54	47	33
95	35	41	31
93	17	36	29
90	10	27	26

4) DCP

The in situ strength was measured using the DCP in panels A and E. The results are given in Table XIV and Table XV:

On panel E, the in situ CBR (Table XV) values are lower than expected from the soaked CBR, due to water ingress and high plasticity of the blended materials and possibly low compaction. On both panels, the pavement structure is poorly balanced.

TABLE XIV. : RESULTS OF DCP ON PANEL A

Layer (mm)	Weighted Average DN value (mm/blow)		Equivalent CBR (%)	
	1	2	1	2
0 - 150	8.38	3.32	28	89
151 - 300	6.35	2.3	39	143
301 - 800	7.9	6.1	30	41

TABLE XV. : RESULTS OF DCP ON PANEL E

Layer (mm)	Weighted Average DN* value (mm/blow)		Equivalent CBR (%)	
	1	2	1	2
0 - 150	3.52	5.31	83	49
151 - 300	3.87	3.14	74	96
301 - 800	8.48	4.61	27	59

5) Rutting

The rut depth results are taken from all 20m panels (numbered 1 to 20). The greatest rut depth is 11 mm at kmKM 4+190. However, it is less than 20mm (terminal condition), and can be attributed to the base deformations as results of poor compaction and high moisture in the base layer.

6) Visual Condition Index (VCI)

The average of VCI on the blended base is 85.5 showing that the road is in a good to moderate condition [12]. However, as the sections are under routine maintenance (periodically patched) the VCI value does not reflect the true structural condition of the pavement.

7) Roughness

The results of the roughness measurements reported as IRI are given in Table XVII.

During routine maintenance of the blended base section there has been a lot of patching to rectify potholes, cracks and deformation occurring along sections of the road. The value of the IRI increased between the first and second measurements. Overall the condition of the road is similar to a well-maintained unpaved road since there are recorded surface imperfections and frequent minor depressions.

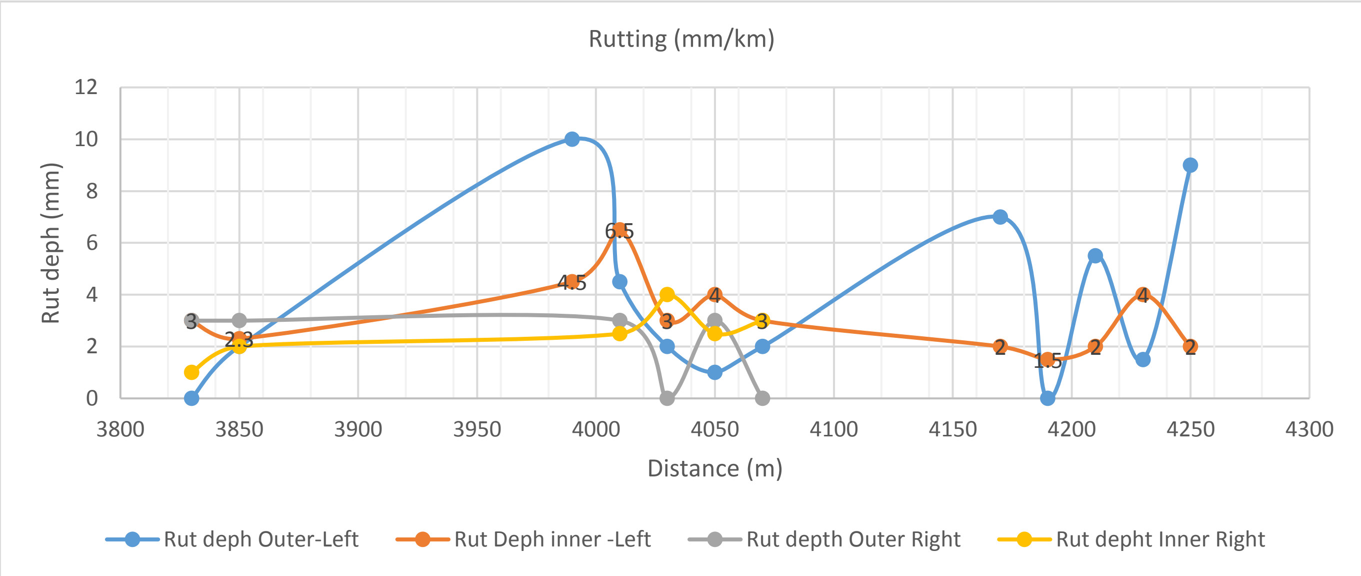

Fig. 13. Graphical representation of the rut depths

TABLE XVI. : RESULTS OF IRI

From	To	Measured Side	Length (m)	IRI (mm/km)	
				1	2
3+800	4+050	left	250	7.13	8.54
4+050	4+300	left	250	4.89	6.72
4+300	4+050	right	250	5.58	5.54
4+050	3+800	right	250	4.99	7.89

8) Effect of kerbing

Based on in situ moisture results presented on Table X and XI, it seems that the part of the road protect by kerbs has lower moisture contents, probably due to the high fill and kerb protections.

V. CONCLUSIONS

Based on traffic, it is concluded that the actual traffic load is lower than equivalent traffic design load.

In general, the section with the armoured base is performing better than the blended base section. The distress on the armoured base sections are surface failure.

From TABLE IV, the compaction of the base and subbase layer is good, and the moisture in the base and subbase layer in different seasons are on drier side of OMC, which make the layer stable and stiff.

The performance of the blended base sections is poor as most of the distress is structural due to high in situ moisture and high PI of the blended materials, and low compaction of the base layer.

The potholes are attributed to the higher moisture content in the base.

The research project has shown that the local sandy materials can be mechanically stabilized to provide an adequate base course without the high cost of conventional stabilization. Attention must be given to keeping the upper pavement layers dry by raising the road embankment and providing effective drainage. The performance of the blended base could be improved by reducing the fines included in the calcrete component.

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12. Draft TRH 9 Pavement conditions and evaluations, Pretoria, South Africa 1997