SURFACING OPTIONS FOR LOW VOLUME ROADS IN MOZAMBIQUE

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Abstract
Mozambique has a classified road network of about 30 000 km, of which only 20% is paved. Most of the unpaved roads are rural with low volumes of traffic and cannot justify the conventional pavement design and material usage standards. The scarcity of conventional road construction materials in some areas of the country is also a major challenge.

Two low volume roads in Inhambane and Zambezia provinces have been constructed using locally available materials not complying with traditional standards as base course. Four different surfacing options were used on these roads: gravel, penetration macadam, Otta seal and sand seal (armoured base). The roads were built between 2009 and 2013.

Monitoring sections have been established on these roads and are being regularly assessed in terms of the Mozambique standard Monitoring Protocols. After up to 7 years the sections are generally performing well. Localized defects are attributed to poor construction quality and inadequate supervision on site.

The performance of the three surfacing solutions was analyzed and compared with the performance of the gravel section.

The paper summarizes the findings of the investigations and concludes that all the surfacing options are technically viable. However, each situation needs to be assessed in terms of its economic viability, particularly on roads carrying low traffic (less than 100 vpd) or where the necessary construction materials must be hauled over long distances.

Keywords— gravel, penetration macadam, Otta seal and sand seal (armoured base)

I. Introduction

Mozambique has a classified road network of about 30 000 km, of which only 20% is paved. Most of the unpaved roads are rural with low volumes of traffic and cannot justify the conventional pavement design and material usage standards. The scarcity of conventional road construction materials in some areas of the country is also a challenge.

Numerous experimental sections were constructed in Mozambique (in all provinces) between 2009 and 2013 as part of a broader programme of Targeted Interventions for Low Volume Roads. Two of these low volume roads were constructed in Inhambane and Zambezia provinces.

The Inhambane road (R903) links Cumbana to Chacane, which is on the N1 highway about 30 km south of Maxixe City. The Zambezia road (R650) links the village of Zero on the N1 highway about 140km south of Quelimane with the town of Mopeia. In both cases the design traffic load was almost 86 500 E80s: roads lightly trafficked, carrying mainly cars and 4x4s. The current cumulative traffic count is almost 10 200 E80s.

On the Inhambane experimental section, three different surfacing options were constructed: i) gravel wearing course, ii) penetration macadam and iii) sand seal on an armoured sand base.

The Zambezia experimental section has an Otta seal surfacing. In all cases the road base and sub base pavement was constructed with locally available materials not complying with conventional standards. The research project is being carried out by the Road Research Centre (RRC) of the Mozambique National Road Administration (ANE). Technical assistance is being provided to the RRC under the Africa Community Access Partnership (AfCAP), funded by UK Aid.

The main purpose of the investigation is to evaluate the performance of different surfacing solutions (gravel, penetration macadam, Otta seal and sand seal) on pavements that do not comply with traditional standards for base and sub base courses, in low volume roads.

An assessment of the economic feasibility of each surfacing solution is also carried out for a period of 20 years, being an element of evaluation complementary to the technical evaluation.

According to the results, all of the surfacing options are technically viable. In order to choose the best solution other aspects must be considered, in particular the life cycle costs. The cost of construction of the paved road sections is higher than the gravel road but the annual routine maintenance costs are much higher for the gravel road.

II. Methodology

A monitoring programme was established on each surfacing solution to evaluate the performance over time. Routine measurements and tests were carried out in accordance with the standard protocol for monitoring of experimental road sites developed for Mozambique [1] following the strategy below.

- Review of the existing data;
- Selection of the representative monitoring sections
- Marking of the sections; and
- Evaluation of the pavement condition (Test Pits for laboratory and field analysis, density and moisture content of the pavement layers, visual condition assessment, rut depth measurements, roughness measurements, etc)

The performance of the three surfacing solutions was analyzed and compared with the performance of the gravel section.

Monitoring visits were carried out in October 2017 (end of dry season) and March 2018 (end of rain season).

A. Review of existing data

The existing information used for the analysis included the project specifications, laboratory results, bills of quantities, and the as built report from the construction of the experimental sections. A preliminary site visit was carried out to assess the overall condition of the roads and to identify the sections to be used for the monitoring purposes.

B. Selection of representative monitoring

The sections of 250m length were identified and marked as indicated in Figure 1. for long term monitoring. The panels A, B and C 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.

The following factors were taken into account for the identification of the monitoring sections:

- Goals and aims of the study: it was necessary to choose sections that included each of the surfacing solutions under investigation;
- Representativeness of the section: it should reflect the characteristics of each surfacing option to the maximum extent;
- Safety: avoiding locations with poor visibility for motorists; and
- Section condition: avoiding sections with significant damage.

The paved road monitoring sections were 250 meters long and 6 meters wide. The sections include the full width of the road and are divided into 13 panels as shown in Figure 1. Panels A and C are 20m long and Panel B is 10m long. Panels 1 to 10 are each 20m long.

Destructive tests were performed in panels A, B and C and non-destructive tests in panels 1 to 10.

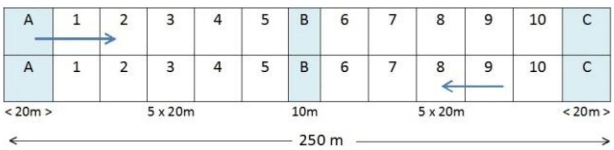

Fig. 1 Layout of the paved road monitoring sections

The gravel road section is 300 m long and 6 meters wide. The section is divided into two panels, one which is 50 m long and the other which is 250 m long (Figure 2).

Measurements of gravel loss are carried out on the 50 m panel through a level survey.

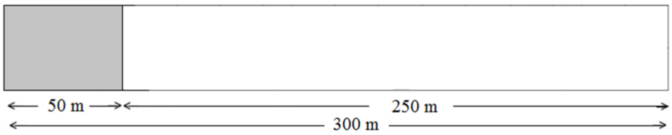

Fig. 2 Layout of the gravel monitoring section

C. Evaluation of pavement condition on all four sections

The evaluation of pavement condition was carried out in two ways:

- Functional properties – evaluation of the level of service, that is the quality of travel, comfort and safety for the road user; and
- Structural proprieties – evaluation of the pavement as a load bearing structure.

Functional proprieties

The functional analysis consisted of a visual assessment and roughness measurements.

Visual assessment

The visual assessment was carried out in accordance with the Mozambique monitoring protocol [2] and is evaluated in terms of the Visual Condition Index (VCI). This index provides information on the road service level and also indicates any need for maintenance, rehabilitation or upgrading.

On the paved road sections the visual assessment included a surface assessment (surface failures, patching, cracks, bleeding, deformation, potholes and patching), a structural assessment (block cracking, transverse, longitudinal and crocodile cracks, pumping, rutting) and a functional assessment (roughness, skid resistance, surface drainage, shoulder and edge condition).

On the gravel road section the visual assessment included gravel proprieties (material type and quality, maximum size, grading, estimated PI, layer thickness, exposure of subgrade and subgrade quality), surface distress (potholes, corrugations, rutting, loose material, stoniness and erosion) and a functional assessment (roughness, trafficability, safety, drainage).

Assessment of roughness

The basis for analysis of the riding quality is the measurement of roughness in terms of the International Roughness Index (IRI).

The IRI was measured using a MERLIN (Machine for Evaluating Roughness using Low-cost Instrumentation). Two hundred measurements were taken at regular intervals and graphically marked on a chart. After excluding the outer 10 marks at each end of the scatter the parameter D is then determined in millimeters. The IRI was calculated using the following equation:

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

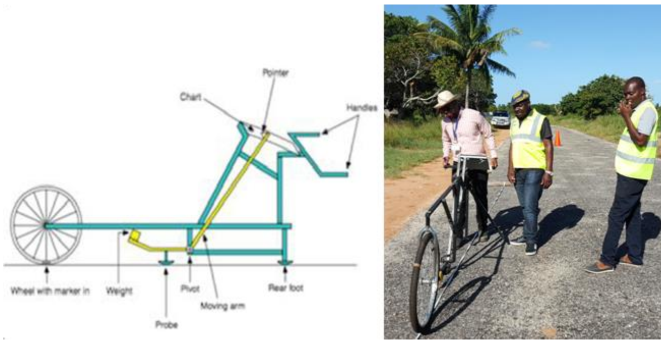

Fig. 3 Measurement of roughness

D. Structural proprieties

The structural analysis included rut depth measurement, gravel loss measurements, Dynamic Cone Penetrometer (DCP) tests and materials investigations using test pits.

Rutting

Rut depth measurements provide an indication of deformation or wear of the material in the pavement. Ruts on low volume sealed roads are indicative of problems such as shear failure in the road base or deformation of the subgrade.

The rut width is measured with a measuring tape, while the rut depth, which is the maximum measured perpendicular distance between the bottom surface of the straight edge and the contact area, is measured with a straight-edge and calibrated wedge.

Rut measurements were carried out using the methodology provided in the standard test method in ASTM [3].

Gravel loss

The leveling surveys were carried out on the gravel road section using a dumpy level. Levels were taken at each point in a pattern shown in Figure 4. The consecutive leveling surveys enable an estimation of the rate of gravel loss with time.

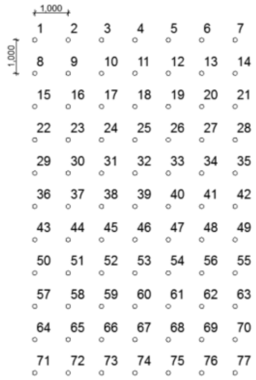

Fig. 4 Scheme used for leveling survey

Dynamic Cone Penetrometer (DCP) Test

DCP tests were used for the field determination of the in situ strength of the pavement layers, using the empirical method derived from pavement component analysis [4].

Materials investigations

The properties of the material in the pavement are the most important aspects to consider in the study of pavement performance. The behavior of the materials in different situations determines the performance of the pavement.

Test pits were excavated on each section, samples were removed and the following information was collected:

- Soil profile [5];
- In situ moisture content;
- Grading analysis;
- Atterberg limits;
- Maximum dry density and optimum moisture content; and
- CBR values.

III. Results and Discussion

A. Penetration Macadam

The pavement structure of the penetration macadam section comprises three layers: road bed, sub base and base.

In the road bed the existing track consisted of very loose sand, and this had to be removed to a firm foundation.

The sub base consists of a local red sand, with 150 mm, compacted to a minimum of 93% Mod. AASHTO Maximum Dry Density (MDD).

The base of the road section is untreated red sand, the same material as the sub base, with 150 mm, compacted to a minimum of 95% Mod. AASHTO MDD.

The surfacing is composed of two layers, the bottom one with crushed calcrete aggregate between 20 – 40 mm, and the top one with 10 – 13 mm calcrete aggregate. The binder used was SS60 emulsion with an application rate of 1.2 lt/m^2.

Fig. 5 Penetration macadam section

Soil profile

The description of the soil profile from the test pit on the penetration macadam section is included in Table 1.

TABLE I. PROFILE OF PENETRATION MACADAM

	Layer	Thickness	Moisture Content	Colour	Consistency	Structure	Soil Texture	Origin
	Surfacing	Penetration Macadam			Top layer - aggregates with 10 - 13 mm			
					Bottom layer - aggregates with 20 - 40 mm.			
	Base	150 mm	Medium wet	Red,	Medium dense	Granular	Medium sand	Sandy soil of mixed origin
	Sub-base	150 mm	Medium wet	Red,	Medium dense	Granular	Medium sand	Sandy soil of mixed origin
	Road bed	Infinite	Medium wet	Gray,	Medium dense	Granular	Medium sand	Sandy soil of mixed origin

According to the profile, the materials are medium wet, probably influenced by voids of the coating, and the test was done after rainy season.

Visual assessment

Based on the visual condition survey, the VCI was calculated and the results are shown in Table 2.

TABLE II. VCI SUMMARY RESULTS IN PENETRATION MACADAM SECTION

Item	Season	VCI	VCI (Variation)
1	October, 2017	91,3	0,2
2	March, 2018	91,1	

The VCI results on this section are 85% - 100% range, which means the road is in the very good condition according to this category description.

The variation of the section condition between the rainy and dry season is small. However, there is a slight reduction in the VCI value due to the appearance of potholes in the dry season, which were not repaired and increased in size in the rainy season.

The surface is slightly uneven, but there are no signs of cracks (crocodile, transverse and longitudinal) and settlements, just a few potholes, which mean that surface irregularities are due to construction defects.

Roughness

The results of IRI roughness done on each 250m long section in the outer wheel path in each lane are presented in Table 3.

TABLE III. IRI SUMMARY RESULTS IN PENETRATION MACADAM SECTION

Item	Season	IRI	VARIATION
1	October, 2017	7.8	-0.9
2	March, 2018	6.9	

The IRI value is high compared to the visual assessment of the condition of the road. The high roughness value is probably related to construction defects because visually, there are no cracks and settlements, only irregularities of the surface.

The negative variation after the rainy season is probably due to the accuracy of MERLIN (Machine to evaluate roughness using low cost instrumentation), as it does not allow the test to be carried out exactly in the same way.

Rutting

The rut depth results are presented in Figure 6. The data were taken from Panels 1 to 10, in March of 2018.

The greatest rut depth measured is 8 mm at km 17+290 in the right hand lane and in the inner wheel path and 8 mm at km 17+350 in the right lane and the outer wheel path.

However, there are no observed ruts in the road and the values found in fig.6, and probably in field, are related to the irregularities in the surface. These irregularities are probably a result of poor quality control (leveling of the surface) during construction, because there are no cracks and settlements.

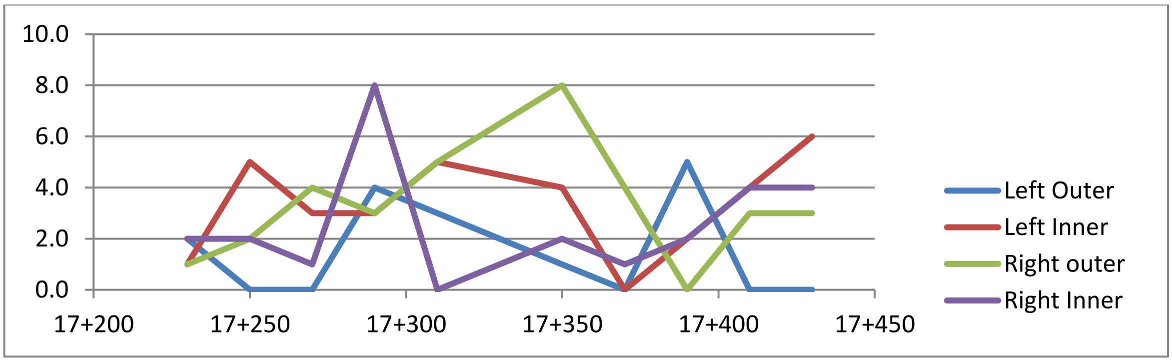

Fig. 6 Graphical representation of the rut depths

DCP Test

The in situ strength measured by the DCP was carried out at 3 points in panels A, B and C. The DCP tests were carried out in the wet season to understand the behavior of the material in its worst condition. The results are as shown in Table 4.

TABLE IV. DCP RESULTS PENETRATION MACADAM SECTION

Depth (mm)	Panel A		Panel B		Panel C	
	DN (mm/Blow)	CBR (%)	DN (mm/Blow)	CBR (%)	DN (mm/Blow)	CBR (%)
	Test1	Test1	Test1	Test1	Test1	Test1
0 – 150	6,58	39	6,29	40	9,23	24
151 – 300	4,23	59	6,62	37	10,25	21
301 – 800	8,25	45	3,19	94	5,6	46

The DCP results were analyzed using the AfCAP DCP computer program developed by the Council for Scientific and Industrial Research (CSIR) in South Africa. According to the analysis, the pavement in each panel is categorized as follows:

- Panel A – Category VI – Poorly Balanced Deep Structure (PBD);
- Panel B – Category VIII – Averagely Balanced Inverted Structure (ABI); and
- Panel C – Category IX – Poorly Balanced Inverted Structure (PBI).

In nearly all cases, the in situ strength of the base and subbase material shows that it does not meet the conventional standards for road pavement layers in high volume roads.

In panels B and C the DCP results indicates that the pavement has an inverted structure, which means that the compaction of the base layer was probably deficient.

In panel C, the field CBR is very low, that means that the compactions was probably deficient and the drainage is inadequated, because there is no side drain and the level of the road are down than the shoulders.

Classification of material

The classification of the pavement material, from borrow pits near of the road, below were done according to the TRH 14 [6] and is summarized in Table V.

TABLE V.CLASSIFICATION OF PAVEMENT MATERIALS – PENETRATION MACADAM SECTION

Layer	Description of the test	Results		Classification
Base	California Bearing Ratio (CBR)	CBR (%) @ 98% soaked	14	G7
		CBR (%) @ 95% soaked	13	
		CBR (%) @ 93% soaked	13	
	Atterberg limits	Plasticity Index (%)	7	
		Liquid limit (%)	23	
		Plastic limit (%)	17	
		Shrinkage limit (%)	2.1	
	Grading	Grading Modulus (GM)	1.3	
Sub Base	California Bearing Ratio (CBR)	CBR (%) @ 98% soaked	10	G7
		CBR (%) @ 95% soaked	9	
		CBR (%) @ 93% soaked	8	
	Atterberg limits	Plasticity Index (%)	6	
		Liquid limit (%)	24	
		Plastic limit (%)	18	
		Shrinkage limit (%)	2.0	
	Grading	Grading Modulus (GM)	1.4	
Sub grade	California Bearing Ratio (CBR)	CBR (%) @ 98% soaked	4	G8
		CBR (%) @ 95% soaked	4	
		CBR (%) @ 93% soaked	3	
	Atterberg limits	Plasticity Index (%)	NP	
		Liquid limit (%)	NP	
		Plastic limit (%)	NP	
		Shrinkage limit (%)	NP	
	Grading	Grading Modulus (GM)	1.5	

According to Table 5, all of the materials used in the pavement layers (base and sub base) would normally be considered are out of the specifications for high volume road.

The soaked CBR of those materials are lower than minimum recommended for G7 in sealed Low Volume Roads

(LVR), and the approximate field CBR is only adequate in panel A.

B. Sand seal armoured base

The sand seal on the armoured base section is composed of three layers: road bed, sub base and base.

In the road bed the existing track consisted of very loose sand, and this was removed to a firm foundation.

The sub base is a local red sand, 150mm layer, compacted to a minimum of 93% Mod. AASHTO MDD.

The base of the road section is the same red sand as the subbase, 100mm layer, compacted to a minimum of 95% Mod. AASHTO MDD, and an armoured, 50 mm layer, nominal size crushed calcrete aggregate.

The single sand seal surfacing used a coarse sand passing 4.75mm, and an SS60 bitumen emulsion binder with an application rate of 1.2 l/m^2.

Fig. 7 Sand seal on armoured base section

Soil profile

The description of the soil profile from the test pit on the sand seal section is included in Table 6.

TABLE VI. PROFILE OF SAND SEAL ON ARMOURED SAND BASE

<table>
<tr><th></th><th>Layer</th><th>Thickness</th><th>Moisture Content</th><th>Colour</th><th>Consistency</th><th>Structure</th><th>Soil Texture</th><th>Origin</th></tr>
<tr><td></td><td>Surfacing</td><td colspan="7">Sand Seal</td></tr>
<tr><td></td><td rowspan="2">Base</td><td>50 mm</td><td colspan="6">Armouring with Calcrete Aggregates</td></tr>
<tr><td></td><td>100 mm</td><td>Dry</td><td>Red</td><td>Medium dense</td><td>Granular</td><td>Medium sand</td><td>Sandy soil of mixed origin</td></tr>
<tr><td></td><td>Sub-base</td><td>150 mm</td><td>Dry</td><td>Red</td><td>Medium dense</td><td>Granular</td><td>Medium sand</td><td>Sandy soil of mixed origin</td></tr>
<tr><td></td><td>Road bed</td><td>Infinite</td><td>Medium wet</td><td>Gray</td><td>Medium dense</td><td>Granular</td><td>Medium sand</td><td>Sandy soil of mixed origin</td></tr>
</table>

Visual assessment

Based on the visual condition survey, the VCI was calculated and the results are shown in Table 7.

TABLE VII. VCI SUMMARY RESULTS IN SAND SEAL ON ARMOURED SAND BASE

Item	Season	VCI	VCI (Variation)
1	October, 2017	92.0	0.6
2	March, 2018	91.4	

The VCI results on this section are 85% - 100% range, which means the road is in the very good condition according to this category description.

The variation of the road condition does not vary significantly between the wet and dry seasons. However, there is a slight reduction in the VCI value due to the appearance of potholes, which were not repaired and have increased in size.

There are some isolated cracks (crocodile and longitudinal), settlement and potholes, all generally in slight degree. Most of these defects are in panel C, including edge breaks.

Roughness

The results of IRI roughness done on each 250m long section in the outer wheel path in each lane are presented in Table 8.

TABLE VIII. IRI SUMMARY RESULTS IN SAND SEAL ON ARMOURED SAND BASE

Item	Season	IRI (mm/km)	VARIATION
1	October, 2017	6.5	-1.3
2	March, 2018	5.2	

The sand seal on the armoured base is smoother than the penetration macadam section but the IRI values are still high for a sealed road.

The negative variation after the rainy season is probably due to the accuracy of MERLIN (Machine to evaluate roughness using low cost instrumentation), as it does not allow the test to be carried out exactly in the same way.

Rutting

The rut depth results are presented in Figure 8. The data were taken from panels 1 to 10.

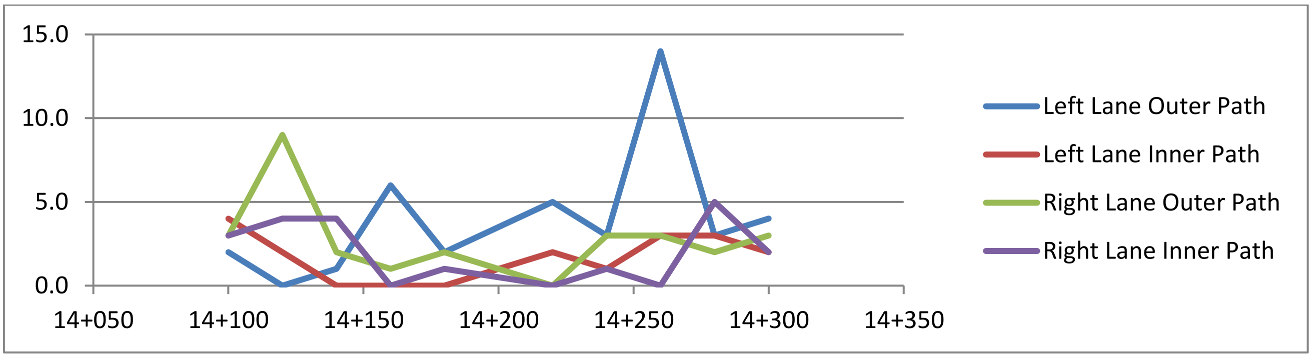

Fig. 8 Graphical representation of the rut depths

The highest rut depth is 14 mm at km 14+260 in the left lane outer wheel path. There is a settlement in this point.

DCP Test

The in situ strength measured by the DCP was carried out at 2 points at panels A and C. The tests were carried out in the wet season to understand the behavior of the material in its expected worst condition. The results are shown in Table 9.

At Panel B the DCP could not reach the depth of 800 mm of penetration due to the hardness of the in situ material. This test was repeated three times and it refused in the first layer.

TABLE IX. DCP RESULTS IN SAND SEAL ON ARMOURED SAND BASE

Panel A			Panel C		
Depth (mm)	DN (mm/Blow)	CBR (%)	Depth (mm)	DN (mm/Blow)	CBR (%)
0 – 150	2,15	153	0 - 200	7,13	40
150 - 300	3,45	90	200 - 400	4,73	97
301 - 450	2,02	114	400 - 600	2,1	160
451 - 600	2,99	151	600 - 800	6,13	42
600 - 800	5,02	56			

The depths in panel C are different because in the test pit was found pavement profile with 200 mm layers.

The DCP results were analyzed using the AfCAP DCP computer program. According to the analysis, the pavement in each panel is categorized as follows:

- Panel A – Category V – Averagely Balanced Deep Structure (ABD);
- Panel C – Category IX – Poorly Balanced Inverted Structure (PBI).

The DCP results indicates that in panel C the pavement has an inverted structure, which means that the compaction of the base layer was probably deficient.

There is a large difference in strength of the base course between the two panels, probably indicative of impeded drainage in the area of Panel C. In this panel, there are some edge breaks, longitudinal and transverse cracks.

Classification of material

The classification of the material was done according to the TRH 14.

From the results included in Table 10, the base material would not normally be recommended for use in accordance with conventional standards, but it can be used in LVR, because for G6 material the soaked CBR and approximate field CBR is only adequated for panel A. The sub-base material complies with conventional specifications for both situations.

TABLE X. CLASSIFICATION OF PAVEMENT MATERIALS IN SAND SEAL ON ARMOURED SAND BASE

Layer	Description of the test	Results		Classification
Base	Califórnia Bearing Ratio (CBR)	CBR (%) @ 98% soaked	41	G6
		CBR (%) @ 95% soaked	38	
		CBR (%) @ 93% soaked	36	
	Atterberg limits	Plasticity Index (%)	NP	
		Liquid limit (%)	NP	
		Plastic limit (%)	NP	
		Shrinkage limit (%)	NP	
	Grading	Grading Modulus (GM)		
Sub Base	Califórnia Bearing Ratio (CBR)	CBR (%) @ 98% soaked	37	G6
		CBR (%) @ 95% soaked	30	
		CBR (%) @ 93% soaked	28	
	Atterberg limits	Plasticity Index (%)	NP	
		Liquid limit (%)	NP	
		Plastic limit (%)	NP	
		Shrinkage limit (%)	NP	
	Grading	Grading Modulus (GM)		
Sub Grade	Califórnia Bearing Ratio (CBR)	CBR (%) @ 98% soaked	12	G8
		CBR (%) @ 95% soaked	11	
		CBR (%) @ 93% soaked	10	
	Atterberg limits	Plasticity Index (%)	NP	
		Liquid limit (%)	NP	
		Plastic limit (%)	NP	
		Shrinkage limit (%)	NP	
	Grading	Grading Modulus (GM)		

C. Otta seal

The pavement structure of the Otta seal section is similar to the previous two sections.

However, in the road bed, some earthworks were carried out during phase 1 of the project that included formation and graveling. The existing road was leveled and smoothed by scarifying to a depth of 15 – 20 mm and the camber was reshaped.

The sub base is quartzitic, compacted to a minimum of 93% Mod. AASHTO MDD, in a 150 mm layer.

The base of the road section is the same material as sub base compacted to a minimum of 95% Mod. AASHTO MDD, in 150 mm layer.

The Otta seal used aggregate with a maximum size of 13mm, and had a binder application rate of 1.2 – 2.0 l/m^2- MC 3000.

Fig. 9 Otta seal section

Soil profile

The description of the soil profile from the test pit on the Otta seal section is included in Table 11.

TABLE XI. PROFILE IN OTTA SEAL

	Layer	Thickness	Moisture Content	Colour	Consistency	Structure	Soil Texture	Origin
	Surfacing	Otta Seal						
	Base	150 mm	Medium wet	Brown, Stained	Medium Dense	Granular	Coarse gravel	Residual quartzite gravel
	Sub-base	150 mm	Medium wet	Dark Brown, Stained	Medium Dense	Granular	Coarse gravel	Residual quartzite gravel
	Road bed	Infinite	Medium wet	Dark Brown, Stained	Medium Dense	Granular	Medium sand	Sandy soil of mixed origin

Visual assessment

Based on the visual condition survey, the VCI was calculated and the results are shown in the table below.

TABLE XII. VCI SUMMARY RESULTS IN OTTA SEAL

Item	Season	VCI	VCI (Variation)
1	November, 2017	92.0	1.0
2	March, 2018	91.0	

The VCI results on this section are 85% - 100% range, which means the road is in the very good condition according to this category description.

The road condition does not vary significantly between the wet and dry seasons. However, there is a reduction in the VCI value due to the appearance of isolated potholes in slight degree, which were not repaired and have increased in size.

The road has some isolated longitudinal cracks in slight degree.

Roughness

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

TABLE XIII. IRI SUMMARY RESULTS IN OTTA SEAL

Item	Season	IRI	VARIATION
1	November, 2017	4,1	-0,6
2	March, 2018	3,5	

Rutting

The rut depth results are presented in Figure 10. The data were taken from panels 1 to 10.

The highest rut depth is 11 mm at km 2+675 in the right lane inner wheel path. There is a settlement in this point.

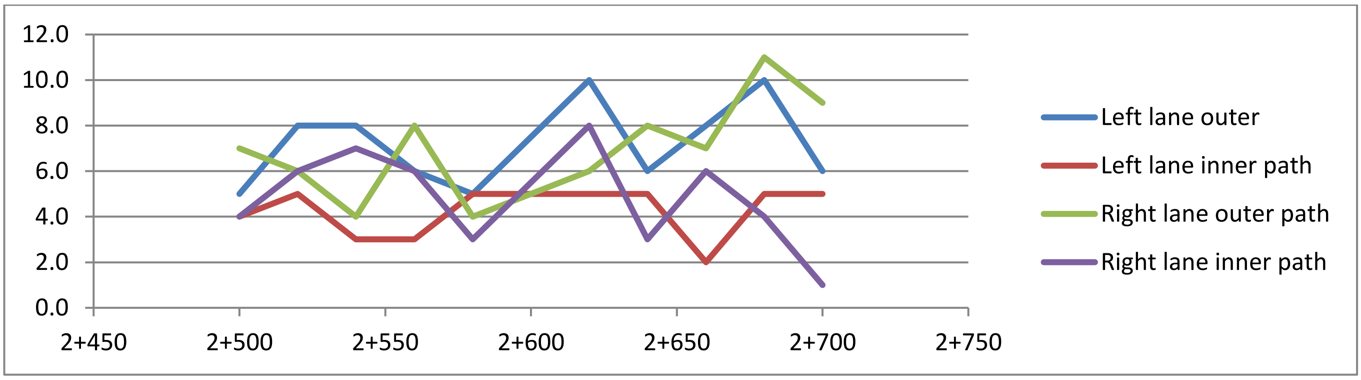

Fig. 10 Graphical representation of the rut depths

DCP Test

The in situ strength measured by the DCP was carried out at 2 points at panels A and C, all after the wet season to understand the behavior of the material in its worst condition. The results are shown in Table 14.

TABLE XIV. DCP RESULTS IN OTTA SEAL

Depth (mm)	Painel A		Painel C	
	DN (mm/Blow)	CBR (%)	DN (mm/Blow)	CBR (%)
0 – 270	5,73	48	6,23	36
271 – 630	11,93	26	10,5	21
631 – 800	4,58	57	5,62	45

The depths presented were defined according to the variation of the penetration in each layer, found by the results of the DCP.

The DCP results were analyzed using the AfCAP DCP computer program. According to the analysis, the pavement in each panel is categorized as follows:

- Panel A –Category V – Averagely Balanced Deep Structure (ABD);
- Panel C – Category V – Averagely Balanced Deep Structure (ABD).

The DN value of the second layer is probably high because of the bad compaction, since the materials has same characteristics.

Classification of material

The classification of the material below was done according to the TRH 14 and is presented in Table 15.

TABLE XV. CLASSIFICATION OF PAVEMENT MATERIALS IN OTTA SEAL

Layer	Description of the test	Results		Classification
Base	Califórnia Bearing Ratio (CBR)	CBR (%) @ 98% soaked	75	G5
		CBR (%) @ 95% soaked	60	
		CBR (%) @ 93% soaked	50	
	Atterberg limits	Plasticity Index (%)	6	
		Liquid limit (%)	24	
		Plastic limit (%)	19	
		Shrinkage limit (%)	2.5	
	Grading	Grading Modulus (GM)	2.2	
Subbase	Califórnia Bearing Ratio (CBR)	CBR (%) @ 98% soaked	50	G5
		CBR (%) @ 95% soaked	47	
		CBR (%) @ 93% soaked	35	
	Atterberg limits	Plasticity Index (%)	10	
		Liquid limit (%)	29	
		Plastic limit (%)	18	
		Shrinkage limit (%)	5.0	
	Grading	Grading Modulus (GM)	1.7	
Subgrade	Califórnia Bearing Ratio (CBR)	CBR (%) @ 98% soaked	29	G6
		CBR (%) @ 95% soaked	21	
		CBR (%) @ 93% soaked	19	
	Atterberg limits	Plasticity Index (%)	9	
		Liquid limit (%)	27	
		Plastic limit (%)	18	
		Shrinkage limit (%)	3.9	
	Grading	Grading Modulus (GM)	1.2	

From the results included in Table 15, the base material would not normally be recommended for use in accordance with conventional standards, but it can be used in LVR, because for G5 material the soaked CBR is adequated.

The approximate field CBR is low for LVR.. The sub-base material complies with conventional specifications for both situations.

D. *Gravel Road*

The Gravel section is composed of three layers: road bed, base and wearing course.

In the road bed the existing track consisted of very loose sand, and this had to be removed to a firm foundation.

The sub base is local red sand, compacted to a minimum of 95% Mod. AASHTO MDD in 150 mm layer.

The base of the road section is a red sand blended 1:1 with calcrete in a 150 mm layer compacted to a minimum of 95% Mod. AASHTO MDD. This layer is same as wearing course.

Fig. 11 Gravel Section

Soil profile

The description of the soil profile from the test pit on the gravel road sections is included in Table 16.

TABLE XVI. PROFILE IN GRAVEL ROAD

Layer	Thickness	Moisture Content	Colour	Consistency	Structure	Soil Texture	Origin
Wearing course	150 mm	Dry	Light gray, Blotched	Dense	Compacted	Coarse gravelly sand	Calcrete and sand of mixed origin
Sub-base	150 mm	Medium wet	Red, Speckled	Medium dense	Pinholed	Medium sand	Sandy soil of mixed origin
Road bed	Infinite	Medium wet	Very dark brown, Stained	Medium dense	Pinholed	Medium sand	Sandy soil of mixed origin

Visual assessment

Based on the visual condition survey, the VCI was calculated and the results are shown in Table 17.

TABLE XVII. VCI SUMMARY RESULTS IN GRAVEL ROAD

GRAVEL SECTION		
Season	VCI	VCI (Variation)
October, 2017	83	-21
March, 2018	62	

According to the VCI values the condition of the road during the rainy season is fair, and in the dry season it is good.

Roughness

Because of the varying surface condition of the unpaved road and the effect of individual storms, traffic and maintenance, the one-off roughness at any specific time is essentially meaningless and was therefore not taken.

Rutting

The rut depth results are presented in Figure 12 The measurements were taken at 20m intervals, in March, 2018.

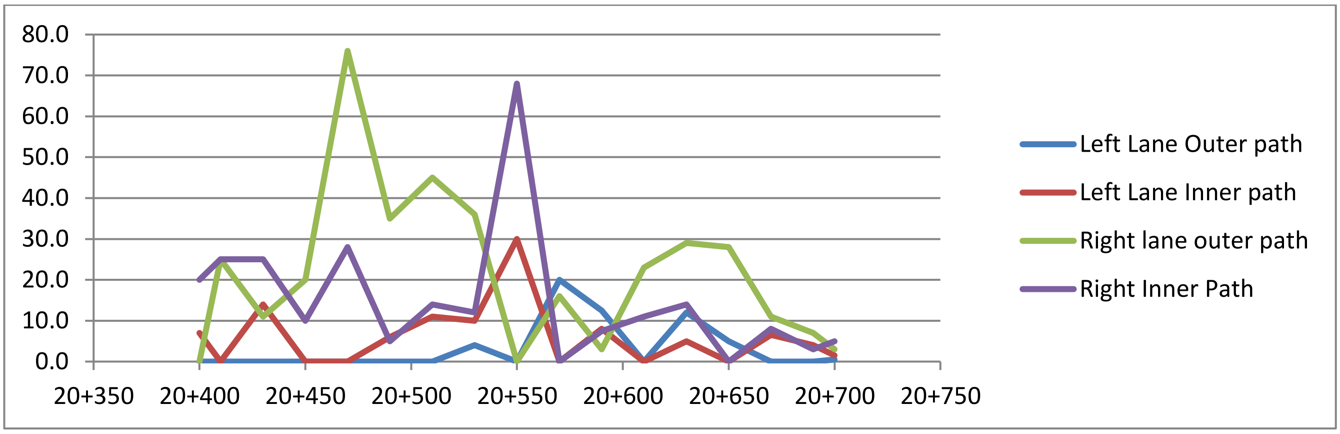

Fig. 12 Graphical representation of the rut depths

The greatest rut depth is 76 mm at km 20+470 at right lane in outer path. However, in the points with big rut like at km 20+500, 20+550, there are potholes.

Those values will vary with traffic movements and maintenance.

DCP Test

The in situ strength was measured using the DCP at 2 points. The tests were carried out after the wet season to understand the behavior of the material in its worst condition. The results are shown in Table 18.

TABLE XVIII. DCP RESULTS IN GRAVEL ROAD

Depth (mm)	Pit 1		Pit 2	
	DN (mm/Blow)	CBR (%)	DN (mm/Blow)	CBR (%)
0 – 150	7,54	32	8,61	27
151 – 300	5,25	50	5,18	51
301 – 800	7,19	33	4,24	65

Classification of material

The classification of the material below was done according to the TRH 14. The results are given in Table 19.

TABLE XIX. CLASSIFICATION OF PAVEMENT MATERIALS IN GRAVEL ROAD

GRAVEL SECTION				
Layer	Description of the test	Results		Classification of material
Base	Atterberg limits	Plasticity Index (%)	13	G7
		Linear shrinkage (%)	2.7	
		Shrinkage Product (Sp)	179	
	Grading	Grading Modulus (GM)	1.8	
		Grading Coeficient (Gc)	22.4	
	Califórnia Bearing Ratio	CBR (%) @ 98% soaked	24	
		CBR (%) @ 95% soaked	22	
		CBR (%) @ 93% soaked	21	
Classification acccording to TRH 20				E
Sub Base	Atterberg limits	Plasticity Index (%)	6	G7
		Linear shrinked (%)	2	
		Shrinkage Product (Sp)	142	
	Grading	Grading Modulus (GM)	1,2	
		Grading Coeficient (Gc)	1.4	
	Califórnia Bearing Ratio	CBR (%) @ 98% soaked	24	
		CBR (%) @ 95% soaked	21	
		CBR (%) @ 93% soaked	20	
Sub Grade	Atterberg limits	Plasticity Index (%)	NP	G8
		Linear shrinked (%)	NP	
		Shrinkage Product (Sp)	0	
	Grading	Grading Module (GM)	1.2	
		Grading Coeficient (Gc)		
	Califórnia Bearing Ratio	CBR (%) @ 98% soaked	9	
		CBR (%) @ 95% soaked	9	
		CBR (%) @ 93% soaked	8	

According to the results in Table 21, the base and sub base materials are suitable for these layers in a gravel road.

Gravel Loss

Insufficient data is currently available to assess the gravel loss of the section.

IV. Cost Analyses

For the analysis of costs, the following aspects were considered:

- The cost of construction of the experimental sections;
- The approximate maintenance costs for the road sections under consideration (it was not possible to obtain accurate maintenance costs);
- The analysis was done in US dollars, at the prevailing exchange rates, in order to minimize the effect of local currency oscillations;
- The analysis is based on total costs for a 1 km section of road, with a width of 6 meters.
- Drainage works were not considered.

The costs of the road section are shown in Table 20 and illustrated in Figure 13.

TABLE XX. RELATION OF THE COSTS IN DIFFERENT SURFACING OPTION

Surface	Cost	Construction cost (USD/km)	Annual costs (USD/km)			
			2014	2015	2016	2017
Penetration macadam	Maintenance cost (USD/km)	0	540	580	682	610
	Cumulative cost (USD/km)	138,950	139,490	140,070	140,751	141,361
Sand seal on armoured base	Maintenance cost (USD/km)	0	540	580	682	610
	Cumulative cost (USD/km)	134,087	134,626	135,207	135,888	136,498
Otta seal	Maintenance cost (USD/km)	0	450	432,00	483	435
	Cumulative cost (USD/km)	81,418	81,868	82,300	82,783	83,218
Gravel	Maintenance cost (USD/km)	0	14,245	9,738	8,691	7,353
	Cumulative cost (USD/km)	53,949	68,194	77,932	86,623	93,976

Taking into account the cost of maintenance of the four sections until 2017, the cost of the roads over 20 years was estimated. This included the cost of resealing the paved road sections after 8 years, and the cost of re-gravelling the unpaved road every 5 years.

Since in the sections chosen the platform of the road are in reasonable conditions the maintenance occurred consisted of grass cutting, cleaning of the drainage devices, and reloading of berms.

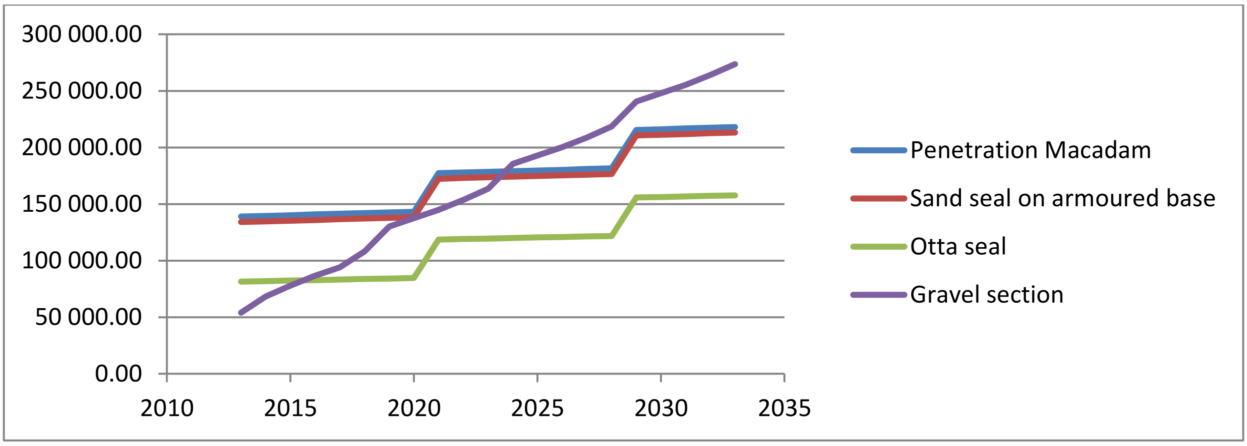

Fig. 13 Cost analysis for 20 years

Although the initial costs of construction of the paved sections are higher than the gravel road, the life-cycle costs of the gravel road become much higher than the paved sections over time, as can be seen in Figure 13.

After 3 years the gravel roads becomes more costly than the Otta sealed road and after 12 years (2024) the cost of the gravel road section becomes higher than the penetration macadam and sand sealed paved sections.

The cost of construction of the sealed roads that were built in Inhambane is probably higher than the cost of the Otta seal section in Zambezia because of the distance of the Borrow pit. According to the final reports of the Targeted Interventions project on low volume roads in Mozambique, Phase 2 [7], the free haul distance during construction of the Zero to Mopeia Road in Zambezia was 10 km, while the haul distance to construct the Cumbana to Chacane Road in Inhambane was almost 26 km.

Generally, the cost of construction of the paved road sections is higher than the gravel road, but the annual routine maintenance costs are much higher for the gravel road.

Furthermore, the sealing of a low volume road protects the base course material from degradation and erosion caused by the action of the environment (rain and wind) and the action of traffic. This has significant environmental and sustainability benefits in the long term.

However, according to the results found in fig. 13 over the long term the costs of the gravel road are higher than paved section.

V. CONCLUSIONS

Generally, all of the road sections that are under this monitoring programme are performing well, considering their age. Some localized potholes and cracks are appearing, and some areas in the wearing course layer of the gravel section are reducing in thickness.

Other defects detected in the monitoring sections are attributed to poor construction quality like deficient compaction of the layers and irregularities of the surface.

According to the results all of the surfacing options are technically viable. In order to choose the best solution other aspects must be considered, in particular the life cycle costs and the distance of the distance where the necessary materials must be hauled.

Those two aspects can be observed taking account the difference of general costs of the surfacing options in Zambézia and Inhambane, because of the distance of the necessary materials, and the difference of the costs in long term between sealed surfacing and gravel options.

VI. REFERENCES

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