TAN008

Design, Construction and Monitoring of Demonstration Sites for District Road Improvement in Tanzania to the Prime Minister's Office – Regional Administration and Local Government (PMO-RALG) under the African Community Access Programme (AFCAP)

Bagamoyo Final Monitoring Report

June 2013

This project was funded by the Africa Community Access Programme (AFCAP) which promotes safe and sustainable access to markets, healthcare, education, employment and social and political networks for rural communities in Africa.

Launched in June 2008 and managed by Crown Agents, the five year-long, UK government (DFID) funded project, supports research and knowledge sharing between participating countries to enhance the uptake of low cost, proven solutions for rural access that maximise the use of local resources.

The programme is currently active in Ethiopia, Kenya, Ghana, Malawi, Mozambique, Tanzania, Zambia, South Africa, Democratic Republic of Congo and South Sudan and is developing relationships with a number of other countries and regional organisations across Africa.

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DESIGN, CONSTRUCTION AND MONITORING OF DEMONSTRATION SITES FOR DISTRICT ROAD IMPROVEMENT IN TANZANIA TO THE PRIME MINISTER'S OFFICE – REGIONAL ADMINISTRATION AND LOCAL GOVERNMENT (PMO-RALG) UNDER THE AFRICAN COMMUNITY ACCESS PROGRAMME (AFCAP)
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1 EXECUTIVE SUMMARY

The Prime Minister's Office of Regional Administration and Local Government (PMO-RALG) has set up the Local Government Transport Programme (LGTP), with the aim of supporting rural development and poverty alleviation. The Africa Community Access Programme (AFCAP) has subsequently been asked by PMO-RALG to assist with the implementation of demonstration sites in selected districts in Tanzania. The goal of AFCAP is to promote low cost, sustainable solutions for rural access. Improving the sustainability and affordability of rural access will lead to improved access to economic opportunities and health and education services; thereby creating opportunities for pro-poor growth and poverty alleviation.

Construction of the demonstration sections in Bagamoyo was completed in September 2011 and includes concrete strip sections, concrete geocells, hand packed stone, double surface dressing, an Otta seal with sand cover seal, double sand seal, slurry seal and gravel wearing course. Following completion of construction works in Bagamoyo in September 2011, baseline monitoring data was collected for comparison with data collected in subsequent monitoring periods in order to assess the performance and suitability of the various surfacing options. The final monitoring stage has now been completed. It was observed during the monitoring stage that most of the sections have performed well, particularly the double surface dressing, the Otta seal and concrete geocell. The slurry seal, double sand seal and hand packed stone sections have deteriorated rapidly and are not expected to have a long service life.

This report details the findings from the data collection during monitoring, interpretation of the data, conclusions drawn and subsequent recommendations. Now that monitoring with the assistance of the Consultant is complete, the monitoring will be carried out annually by the District Engineers for a period of eight years.

2 INTRODUCTION

2.1 Project Background

The Africa Community Access Programme (AFCAP) has been asked by PMO-RALG to assist with the implementation of demonstration sites in selected districts in Tanzania. The aim of this AFCAP project is to improve sustainable access to economic and social opportunities for poor rural communities in Tanzania. A further aim of the project is to provide all weather access on district roads using Environmentally Optimised Design (EOD).

A number of demonstration sections were constructed at Bagamoyo including gravel sections, hand packed stone, concrete strips, double surface dressing, Otta seal with sand cover seal, double sand seal and slurry seal. These pavements will improve problematic sections of the road so that all weather access is provided, dramatically reduce the demand for gravel, provide a smoother running surface to reduce vehicle operating costs, reduce travel times and reduce dust pollution.

The construction of the demonstration sections at Bagamoyo was completed in September 2011 and monitoring data has been collected in September and October 2011, April 2012, September 2012 and finally in April 2013, in order to make an assessment on the performance of the sections.

2.2 Objectives of the Monitoring

The objectives of the monitoring phases are as follows:

- Visually assess which of the demonstration sections have performed well and which have deteriorated rapidly, and assess the suitability of the sections.
- Assess the performance of the sections using a variety of methods including roughness measurements using the MERLIN device, DCP testing, rut depth measurements and surface profile measurements.
- Make recommendations regarding which sections are best suited for the Bago-Talawanda road.
- The monitoring phase of this project is crucial for identifying the performance of the various demonstration sections, their cost effectiveness and suitability for use on other projects. It is therefore apparent that sufficient data collection and interpretation is fundamental in achieving the long term goals of the AFCAP project, which is to provide safe, reliable and sustainable access to vital services for communities in rural Africa.

2.3 Project Site

The road is located in the coastal region of the Bagamoyo District of Tanzania and illustrates typical problems of coastal regions such as sandy subgrades and flat marshy areas of black cotton soils. The road is 20.24 km long and connects the small villages of Bago and Talawanda, passing through a number of other small settlements. All sections, except the concrete geocells, were completed by September 2011. The map in Figure 1 shows the location of the road.

Figure 1 Location of Bago-Talawanda Road

2.4 Purpose of this Report

The purpose of this report is as follows:

- To describe the monitoring methods used in order to collect the data.
- The present the findings of the monitoring and interpretation of the data collected.
- To draw conclusions on the performance of the sections and make recommendations.

3 DESIGN OF THE SECTIONS

3.1 Pavement Design

The pavement designs in Bagamoyo are shown in Table 1, the chainages at which these pavements were constructed is shown in Table 2. The pavement design for Bagamoyo was carried out using the modified TPMDM method, in order to achieve pavement designs that are economical and appropriate for the low volume rural roads.

In Bagamoyo a number of different bituminous sections were selected and it was necessary to include an improved subgrade layer due to the expansive black cotton soil found at the site, and the requirement of the TPMDM that all subgrade must have a minimum CBR of 15%. Further details of the pavement design are given in the Design Report.

3.2 Geometric Design

A camber of 6% was used for gravel sections 4% for the paved sections in Bagamoyo. Due to budget restraints the selected pavement width was 3.0 m, with 1 m gravel shoulders and passing bays constructed at regular intervals.

3.3 Drainage

Many existing drainage structures including culverts and drifts were present at Bagamoyo. Substantial improvement to the side drains was carried out including establishment of unlined drains as well as construction of masonry lined drains where necessary, as adequate drainage is critical to the performance of the pavements.

Table 1: Pavement Designs for the Bagamoyo Site

Pavement Types		Single Otta + Sand Seal	Double Sand Seal	Double Surface Dressing	Slurry Seal	Concrete Strips Unreinf'd	Concrete Strips Reinf'd	Geocells	Hand Packed Stone
Surface Layer	Type	Bitumen	Bitumen	Bitumen	Bitumen	Concrete	Concrete	Concrete	Stone
	Thickness	26 mm	20 mm	20 mm	8 mm	100 mm	100 mm	75 mm	150 mm
Bedding Sand	Thickness	0	0	0	0	0	0	0	50 mm
Base	Type	Natural Gravel CBR ≥ 60%	Natural Gravel CBR ≥ 60%	Natural Gravel CBR ≥ 60%	Natural Gravel CBR ≥ 60%				
	Thickness	150 mm	150 mm	150 mm	150 mm				
Subbase	Type			Natural Gravel CBR ≥ 45%		Natural Gravel CBR ≥ 45%	Natural Gravel CBR ≥ 45%	Natural Gravel CBR ≥ 45%	Natural Gravel CBR ≥ 45%
	Thickness			150 mm		150 mm	150 mm	150 mm	150 mm
Improved Subgrade	Type	Natural Gravel CBR ≥ 15%	Natural Gravel CBR ≥ 15%	Natural Gravel CBR ≥ 15%	Natural Gravel CBR ≥ 15%	Natural Gravel CBR ≥ 15%	Natural Gravel CBR ≥ 15%	Natural Gravel CBR ≥ 15%	Natural Gravel CBR ≥ 15%
	Thickness	150 mm	150 mm	150 mm	150 mm	100 mm	100 mm	100 mm	100 mm
Improved Subgrade	Type			Natural Gravel CBR ≥ 7%			Natural Gravel CBR ≥ 7%	Natural Gravel CBR ≥ 7%	Natural Gravel CBR ≥ 7%
	Thickness			150 mm			150 mm	150 mm	150 mm
Subgrade	Type	CBR = 3%	CBR = 9%	CBR ≤ 2%*	CBR = 3%	CBR = 9%	CBR ≤ 2%*	CBR ≤ 2%*	CBR ≤ 2%*

*Indicates expansive clay subgrade

The pavements types selected for the demonstration sections in Bagamoyo are shown in Table 2

Table 2: Demonstration Sections in Bagamoyo

Section	Chainage (km)		Length (km)	Surfacing Type
	Start	End		
1	0.030	0.230	0.200	Single Otta seal with a sand seal (26 mm)
2	5.340	5.520	0.180	Hand Packed Stone (150 mm)
3	5.560	6.080	0.520	Concrete Strips (100 mm - Reinforced)
4	6.080	6.740	0.660	Geocells (75 mm)
5	8.000	8.240	0.240	Double Surface Dressing (20 mm)
6	9.980	10.670	0.690	Concrete Strips (100 mm - Unreinforced)
7	11.200	11.400	0.200	Double Sand Seal (20 mm)
8	12.200	12.580	0.380	Gravel Wearing Course
9	16.240	17.100	0.860	Concrete Strips (100 mm - Reinforced)
10	18.480	18.740	0.260	Concrete Strips (100 mm - Reinforced)
11	19.000	19.200	0.200	Gravel Wearing Course
12	20.040	20.260	0.220	Slurry Seal (8 mm)
	Total Length		**4.610**	

4 MONITORING METHODS

4.1 Overview

Base line data was collected following construction completion on the Bagamoyo project site. Further sets of data were then collected at six month intervals in order to facilitate comparison and analysis, enabling conclusions on the pavement performance over time and suitability of the sections to be drawn. The pavement performance is assessed by comparing the six monthly monitoring results with the base line data.

In order to monitor the demonstration sections, monitoring beacons are required at regular intervals along the implemented pavement options. The spacing of the monitoring beacons is dependent on the length of the demonstration section; on sections less than 200 m in length the monitoring beacons are installed at 10 m intervals and on sections over 200 m in length the beacons are installed at 20 m intervals. The monitoring beacons serve the following purposes:

To divide up the demonstration section into manageable segments to allow easy identification of the various areas, and;

To provide a consistent and easy identification of the monitoring test points during the long term monitoring framework.

The following monitoring methods are used:

- Visual inspection;
- Photographic logging;
- Surface profile measurement between beacons;
- Surface rut measurement using a standard straight edge;
- Surface roughness using a MERLIN apparatus;
- Surface texture measurement using sand patch testing;
- Dynamic Cone Penetrometer (DCP) testing;
- Classified traffic counts, and;
- GPS Survey.

4.2 Visual Inspection

A visual inspection foot survey is carried out along all sections. The inspection allows for the location of various modes of surface distress and deformation to be recorded, thus creating a historical reference of the deterioration of the demonstration section surfaces in each survey. Modes of surface distress recorded include cracking, pot holing, corrugations, edge wear, erosion and drainage defects.

4.3 Photographic Logging

Photographic logging is carried out on all demonstration sections and provides a visual record of the deterioration identified in the visual inspection. Photographs are taken at each monitoring beacon along all of the demonstration sections in order to provide a visual record of any changes in the appearance of the road over the monitoring period. Each trial section is photographed from the centreline of the road at each beacon location, ensuring the photograph is taken at head height with the road surface in the centre of the photograph. This ensures that each section is photographed from approximately the same position throughout all monitoring periods. The photos for all sections for each monitoring phase can be found on the Bagamoyo monitoring CD.

4.4 Surface Profile Measurement

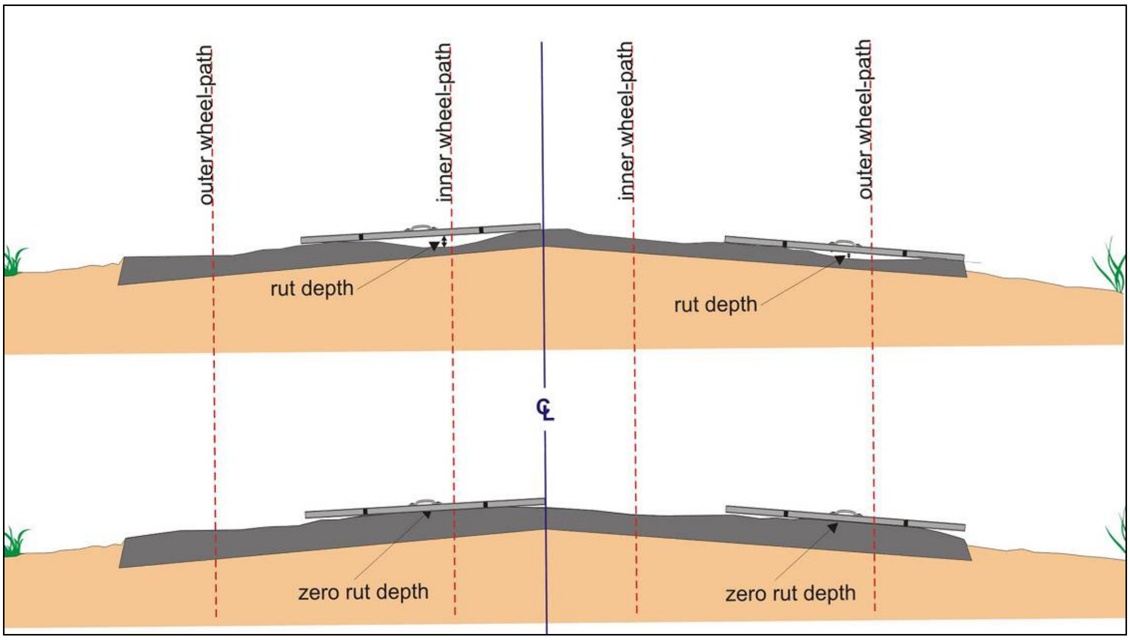
A staff and dumpy level are used to take surface profile measurements at each beacon location, so that any changes in the surface profile between each monitoring phase can be measured. Levels are taken at regular intervals across the cross-section, so that the surface profile levels can be determined. This method of measuring the surface profile is shown in Figure 2.

Figure 2: Surface Profile Measurement

4.5 Surface Rut Measurement

Rut depth measurement is carried out using a 2 m straight edge and a wedge. The wedge is marked at 1 mm increments of its depth so that when pushed under the straight edge, the depth of the rut will be indicated. Measurements are carried out across each wheel path of the carriageway as shown in Figure 3. For a single lane carriageway rut depth measurement should be taken either side of the centreline and not from the carriageway edge.

Figure 3: Rut Depth Measurement



4.6 Surface Roughness Measurement

Surface roughness measurement should be carried out using MERLIN apparatus, which records the longitudinal unevenness of a road surface by taking numerous readings along the wheel path. Taking two hundred readings along the wheel path of a road section will produce a histogram, from which a value of the International Roughness Index (IRI) can be calculated. A full, detailed user guide on the MERLIN roughness machine is given in TRL Report 229[1]. It is to be noted that there is an inherent standard error in the IRI value calculated using the MERLIN apparatus. This error is given to be up to 10%. The MERLIN apparatus is shown in Figure 4.

[1] ***The MERLIN road roughness machine: User Guide TRL Report 229,*** *M A Cundill, Transport Research Laboratory, Berkshire, 1996.*

Figure 4: MERLIN Apparatus

4.7 Surface Texture Measurement

The sand patch method is used on bituminous sections to measure surface texture, and takes place at each set of monitoring beacons in order to provide consistency in future monitoring phases. During the test procedure a measuring cylinder is filled with a measured quantity of sand, which is then poured onto the surface and spread into a circular patch. The diameter of the sand patch is measured at four diameters and the mean diameter is calculated; the mean diameter is then used to calculate surface texture. This method is illustrated in Figure 5.

Figure 5: Sand Patch Testing

4.8 Dynamic Cone Penetrometer Testing

The Dynamic Cone Penetrometer (DCP) is an instrument designed for the rapid in-situ measurement of the structural properties of existing road pavements or existing subgrade. Where pavement layers have different strengths the boundaries can be identified and the thickness of the layers determined. With a team of three operators, the instrument provides a quick and efficient method of obtaining information and tests are carried out at each set of monitoring beacons on all bituminous and gravel demonstration sections. The DCP device consists of an 8 kg weight dropping through a height of 575 mm, delivering a blow onto a penetration cone. The depth of penetration below the road surface is recorded every five blows; continuous measurements are taken until the penetration reaches a depth of 800 mm. The DCP method is shown in Figure 6.

Figure 6: DCP Testing

4.9 Classified Traffic Counts

Manual traffic counts are carried out at an observation point on the side of the road. Each passing vehicle is recorded on a survey form according to the vehicle type and the hour in which the vehicle was observed, traffic is counted in both directions for the duration of the counts. Due to the six month intervals of the monitoring periods, an assessment on seasonal variation of the traffic flows can be made.

4.10 GPS Survey

A GPS survey consists of a drive through along the project road at a target constant speed using a handheld GPS device, which will then record a GPS track and the speed along the road during the drive through. If this is carried out at each monitoring phase, the variation in actual travel speed over time can be assessed. Areas where the actual speed is significantly lower in the target speed can indicate the location of difficult spots along the road.

5 PERFORMANCE OF THE DEMONSTRATION SECTIONS

5.1 Monitoring programme

A set of base line data was collected on the Bagamoyo site between September and October 2011, with subsequent monitoring visits carried out in April 2012, September 2012 and April 2013.

During the monitoring phases at the Bagamoyo site it was noted that most sections are performing well with little visible deterioration. Some sections did however exhibit deterioration, as described in this section. Some general items noted include silting of drains causing water to flow across the road surface, silting of drifts, and erosion of side drains.

The overall performance of the sections has been visually recorded in the photographic logging. A representative photograph of each section is given in the Monitoring CD. The photographic logging from each monitoring stage is included in the CD in Appendix A. The monitoring data is also included on the CD. Further details of the monitoring phases are given in the Quarterly Reports during the Monitoring Phase.

5.2 Concrete Strips

The concrete strip sections in Bagamoyo have performed fairly well and have been successful in providing all weather access at these locations. The strips are in good condition in all demonstration sections that we applied them in. The concrete strips are notably smoother in Bagamoyo than in Siha.

5.3 Geocells

The geocell section at the Bagamoyo site is performing reasonably well. From chainage 6+200 there is inadequate gravel on the shoulder, causing a drop between the surface and the shoulder. There is some minor breaking away of concrete along the lines of the geocell matt. The cells have a few small cracks forming on the Geocell surface.

5.4 Hand Packed Stone

The hand packed stone section at the Bagamoyo site is in fair condition at the start, the surface is very rough. In April 2012 and September 2012 it was noted that there was flooding of the drift structure on the Hand Packed Stone Section, due to heavy rainfall. This caused substantial damage with large stones becoming dislodged, causing vehicles to divert from the road. However since this section has been redone the road is still useable. The District Engineer Kalesi decided to raise this section so this was done and a slight camber added to help in the drainage of this section. The recent measurement of the surface roughness was recorded for this section and measured at 13.40m/km which is very rough. The measurement for surface roughness taken at six months after construction was measured at 9.448m/km. This value is high due to the nature of the stone used. The surface is naturally rough and the size and shape of the stone is critical when choosing which stones to use. However this is expected due to the nature of the rocks used.

5.5 Bituminous Sections

5.5.1 Surface Dressing

The double surface dressing at the Bagamoyo site is in good condition and has performed well throughout the monitoring period. There is some minor polishing of the aggregate in the wheel paths as expected, and a longitudinal edge crack on the left hand side at chainage 8+100 km.

5.5.2 Otta Seal

The Otta seal section at the Bagamoyo site consists of a single Otta seal plus a sand cover seal. This section is performing well and is in good condition, with no cracking or bleeding visible. There are some slight tyre depressions visible in the surface, caused by heavy vehicles in hot weather and the softness of the bitumen. The surface exhibits a low IRI value relative to the other sections and has become smoother during the monitoring period, due to polishing of the aggregate. The masonry side drains are in good condition.

5.5.3 Slurry Seal

The slurry seal at the Bagamoyo site has not performed as well as other sections during the monitoring phase and extensive deterioration has occurred, including erosion of the surface and exposure of sub base material. There is also slight longitudinal cracking at the edges on both the left and the right hand side. There is vegetation growth in the side drains. Two different types of construction material, namely lime and cement slurry were used in different lanes. With Lime performing considerably worse than cement. Both sides have experienced severe cracking and there is loose aggregate visible on the surface.

5.5.4 Double Sand Seal

The double sand seal at the Bagamoyo site is generally in good condition at the 18 month monitoring stage with no visible cracks occurring. A small number of depressions were noted, and have led to disturbance of the seal in some locations and exposure of the subbase material. This has been caused by the bitumen becoming soft during hot weather. Local villagers have attempted to construct speed humps from stone and mortar, using farm tools which have failed under traffic loading. The drainage is in good condition. It should be noted that this type of surfacing is usually expected to last for around two to three years if no maintenance is carried out.

5.5.5 Rut Depths

A summary of the average rut depth at base line, 6 month and 12 month monitoring stages for each of the bituminous sections at Bagamoyo is given in Table 3. It can be seen that average rut depths have significantly increased since construction, The Double Sand seal and Slurry Seal have increased the most since construction. These sections are visibly uneven today as you walk on them. It was noted that the slurry seal has excessive over sized stones in the gravel base course layer. The surface had failed and these stones were visible on the surface. When a straight edge was put on the road and rutting measured there was a rut of 7mm. It was suggested that the Double Sand seal was uneven due to the heat softening the road surface and causing ruts to form over time.

Table 3: Average Rut Depth on Bagamoyo Sections

Surface Type	Average Rut Depth (mm)			
	Base Line	6 Months	12 Months	18 Months
Single Otta Seal with Sand Seal	1.48	2.13	1.26	5.61
Double Surface Dressing	1.80	2.28	1.74	5.96
Double Sand Seal	2.58	2.88	2.48	7.10
Slurry Seal	1.83	2.74	2.74	7.00

5.5.6 Texture Depth

Surface texture measurement using the sand patch method was carried out as part of the baseline data collection on all bituminous surface options at the Bagamoyo site. The baseline data was collected in February 2012, rather than September and October 2011 as with the other monitoring activities. A data set was not collected during the April 2012 monitoring visit as there was not significant elapsed time since the baseline data collection.Table 4 shows the average texture depth for each section from the baseline, the 12 month and the 18 month monitoring phases at the Bagamoyo site. A slight increase can be seen in the surface texture depth of the Otta Seal and the Double Sand Seal between the baseline and 12 month surveys, suggesting that the sections have become slightly rougher. This effect is most notable in the Double Sand Seal due to some traffic erosion of the surface material; the Double Sand Seal is expected to deteriorate more rapidly than the other surfaces. The texture depth of the Double Surface Dressing has decreased suggesting that the surface has become smoother, due to the polishing effect of traffic on the aggregate.

Table 4: Texture Depth Results at Bagamoyo

Section	Surface Type	Surface Texture Depth (mm)		
		Base Line	12 Month	18 month
1	Single Otta Seal with Sand Seal	0.63	0.66	0.224
5	Double Surface Dressing	2.23	1.96	1.372
8	Double Sand Seal	0.49	0.62	0.264
12	Slurry Seal	0.81	0.89	1.238

5.6 Gravel Sections

The gravel wearing course sections at Bagamoyo have generally performed well, retaining good road shape. There has been some gravel loss in places as expected, leading to exposure of rocks underneath the surface and many loose stones. The gravel wearing course sections, have steadily increased in roughness since the first monitoring stage demonstration section 8 more so than section 11. The gravel wearing course at 8 has doubled in roughness since the baseline monitoring data was taken. Both sections need to be re-gravelled as the sections are barely noticeable and all gravel has been washed away.

5.7 Surface Profile Measurement

Surface profile measurements were taken on all sections at the Bagamoyo site during the baseline monitoring, during the monitoring in April 2012, September 2012 and April 2013, in order to determine any subsidence, gravel loss or any other changes in the surface profiles. Only slight changes in the surface profile levels have been observed in most locations during the monitoring stages, caused by the light wearing of the running surface and low levels of gravel loss that are visually apparent along the road. The Hand Packed Stone section exhibits larger changes in surface profile due to the depressions and erosions evident along the section.

On some sections at Bagamoyo the surface profiles at the 12 month monitoring stage are found to be higher than the higher reduced levels taken at the baseline stage. Three possible points of error have been identified for this discrepancy; human error in staff readings, un-calibrated equipment or settlement and displacement of monitoring beacons, which are used as benchmarks when taking levels. A number of monitoring beacons became dislodged due to ground movement or vehicle damage. This raises issues with the method being used for surface profile measurements, and alternative methods to provide more accurate and reliable results should be explored for use after handover of the monitoring.

5.8 Surface Roughness

The MERLIN apparatus was used to measure surface roughness and calculate an IRI value for all demonstration sections. A summary of the IRI values calculated at the Bagamoyo site for base line, 6 month, 12 and 18 month monitoring stages are indicated in Table 5.

Table 5: IRI Values on the Bagamoyo Site

Section	Surface Type	IRI (m/km)			
		Base Line	6 Month	12 Month	18 Month
1	Single Otta Seal with Sand Seal	4.238	4.065	4.389	4.83
2	Hand Packed Stone	9.658	9.838	N/A	13.40
3	Concrete Strips	5.508	5.296	5.528	6.06
4	Concrete Geocells	7.269	N/A	7.995	7.89
5	Double Surface Dressing	6.040	6.205	5.992	6.72
6	Concrete Strips	5.672	5.720	5.929	6.86
7	Double Sand Seal	5.160	4.630	5.254	7.14
8	Gravel Wearing Course	6.593	6.790	7.046	11.85
9	Concrete Strips	5.569	5.478	5.950	7.14
10	Concrete Strips	6.491	6.487	6.688	6.99
11	Gravel Wearing Course	5.958	6.245	6.350	6.67
12	Slurry Seal	5.631	5.761	5.676	6.86

As expected there was a slight increase in the IRI values for most of the demonstration sections between the baseline and the 6 month surveys. There was a slight increase in all sections between the baseline and the 12 month survey, with the exception of the Double Surface Dressing. This is likely to be due to the polishing effect of traffic on the aggregate in the Double Surface Dressing, giving a slightly smoother surface. The roughness of the hand packed stone section is considerably higher than other sections, mainly due to the nature of the construction of this section giving a relatively uneven surface. It is evident that the Otta seal option has given the smoothest finish among the sections. It is expected that the IRI values will continue to gradually increase over time. The roughness of the gravel sections should increase at a higher rate than the bituminous sections, concrete strip sections should exhibit the smallest change in IRI over time. The 18 month data shows a significant increase in the gravel wearing course since the last time it was monitored. From 7.046 to 11.85 the gravel has been mainly washed away and on the surface large pieces of aggregate are visible protruding through the surface. This is why the values for the IRI as measured with the Merlin are so high.

5.9 Dynamic Cone Penetrometer Testing

The Dynamic Cone Penetrometer (DCP) is a field tool for determining the strength profile through the pavement at the existing conditions of moisture and density. A 60˚ cone with an outside diameter of 20 mm is attached to a steel rod, 16 mm in diameter, and is driven into the pavement by repeated blows with an 8 kg hammer dropping 800 mm. The penetration of the cone can be measured after each hammer blow but it is normal to wait for several blows before making the measurement. For this study the penetration was measured after groups of 5 blows. The penetration per blow is related to the in-situ CBR of the material.

DCP testing was carried out at the Bagamoyo site during the first monitoring phase in April 2012 and the follow up monitoring in September 2012. DCP testing was not carried out during the baseline data collection in September and October 2011. The DCP testing was carried out in order to explore the perceived self-cementing properties of the marly limestone used in construction, by assessing the increase in strength over time. An increase in pavement strength suggests that a degree of self-cementing has occurred in the marly limestone.

Table 6: DCP Testing Results at Bagamoyo

Material	4 Day Soaked CBR (BS 95% Heavy)	PI	OMC	April 2012		September 2012		April 2013	
				DN, mm/ blow	CBR, %	DN, mm/ blow	CBR, %	DN, mm/ blow	CBR, %
Red Quartzitic Gravel BP2	20	26	6.8	6.87	39	7.11	38	4.75	57
Marly Limestone BP3	25	14	8.5	4.49	62	3.62	78	4.53	60
Marly Limestone BP4	46	14	11.5	4.45	62	4.41	63	4.77	56

The DCP results are displayed according to the materials used in construction and the borrow pits that each material was sourced from. The red quartzitic gravel from Borrow Pit (BP) 2 was used as an improved subgrade layer of G7 material. Marly limestone from BP 3 was used as G15 sub base material and as a gravel wearing course material. Marly limestone from BP 4 was used as G45 and G60 sub base material.

There is no significant change in the pavement strength according to the CBR values between April and September 2012 in the Red Quartzitic Gravel or the Marly Limestone from Borrow Pit (BP) 4. However there is a clear increase in strength in the Marly Limestone from BP3, suggesting that a degree of self cementing may have occurred. The increase in strength may also be caused by the compacting effect of traffic loading. All material has increased in strength relative to the 4 day soaked CBR values though it should be noted that the season in which DCP testing is carried out can also affect the DCP results; when testing is carried out during the dry season, the material is expected to be nearer to Optimum Moisture Content (OMC).

The results from the most recent monitoring stage done in April 2013 show an increase in the CBR strength of the Red Quartzitic Gravel sections. In September 2012 it was 38% 7 months later it had increased to 57% an increase of 19%. This may be due to an increase in the in situ density due to Traffic compaction over time. The results from Borrow pit 3 have not changed much with only a 2% difference in the CBR over the 7 months. The Marly Limestone from Borrow Pit 3 however has a slightly higher difference in the CBR strength. This could be due to the difference in the moisture content at the different times of the year. In BP3 and 4 in April 2012 and 2013 the values for the CBR were lower than in September 2012.In April it is the rainy season in Tanzania whereas September is in the dry season. Therefore the Moisture content in the soil is higher in April as opposed to September and the soil is more saturated making it easier for the DCP to penetrate.

5.10 Classified Traffic Counts

Traffic counts were carried out on the Bagamoyo site at the beginning and at the end of the construction phase. The baseline traffic counts were carried out in both directions for seven days consecutively before and after construction. 12 hour traffic counts were carried out over the first 5 days and 24 hour traffic counts over the last 2 days. Two count stations were established; the first at Bago village (chainage 0+640) and the second at Ludiga village (chainage 11+040).

These two count stations were used for the 6 month, 12 month and 18 month monitoring stages. Due to difficulty in arranging suitable staff to carry out 24 hour counts, it was only possible to carry out 12 hour counts. These values were then extrapolated using data from previous counts to obtain values for a further two 24 hour counts. The average daily traffic results of all counts are summarised in Table 7 and Table 8.

Table 7: Average Daily Traffic Count Data Bago Village

Traffic Counting Data (Bago village; Ch. 0+640)								
Date	Classification							Total
	Pedestrian	Bicycle	Motorcycle	Saloon Car	Pick up/ 4WD	2-axle truck/ bus	3-axle truck	
Sep 10	408	356	238	2	9	12	0	1,025
Aug 11	180	282	226	5	15	0	0	708
Apr 12	417	423	441	32	14	19	0	1,351
Sep 12	926	491	576	14	15	19	0	2,039
Apr 13	335	188	337	11	11	14	0	896

Table 8: Average Daily Traffic Count Data Ludiga Village

Traffic Counting Data (Ludiga village; Ch. 11+040)								
Date	Classification							Total
	Pedestrian	Bicycle	Motorcycle	Saloon Car	Pick up/ 4WD	2-axle truck/ bus	3-axle truck	
Sep 10	212	197	44	1	5	0	0	460
Aug 11	172	211	159	2	5	0	0	549
Apr 12	328	228	235	14	16	14	0	835
Sep 12	628	293	247	2	5	2	0	1,179
Apr 13	459	193	243	7	10	5	1	918

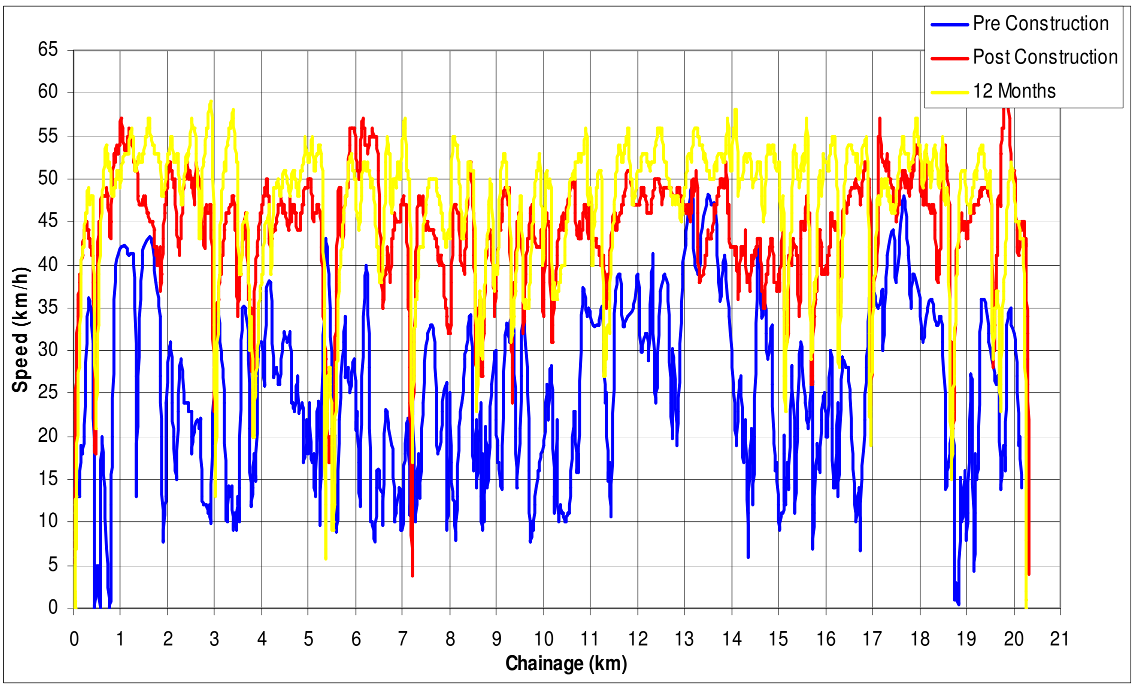
There was an expected small decrease in traffic during the construction period. Following construction there is clearly a significant overall increase in traffic during the remainder of the monitoring period, with the extra traffic mostly consisting of pedestrians, bicycles and motorcycles. Motorcycles are by far the most common motorised mode of transport used on the road. It can therefore be seen that axial loading on the road is currently very small, however traffic could increase significantly over the next five to ten years with a higher proportion of motorised vehicles. In both directions it can be seen that September 2012 had the most traffic count throughout the monitoring period. The reason for the varying counts could be to do with the season. In Bagamoyo during April rainfall is at its peak due to it being the rainy season therefore people are not travelling as much and there are less BodaBoda journeys being done. Whereas in September it is coming into the dry season so the weather is hot and people are able to commute more readily.

5.11 GPS Monitoring

A drive through survey using a GPS device was undertaken along the road at Bagamoyo prior to and directly after completion of construction, and during the monitoring in September 2012. The method utilises the output of the GPS device, after driving along the road at a target constant speed. The target speed is maintained as closely as possible, but it is not practical to adhere strictly to it. The GPS data can then indicate problematic sections on the road that caused the vehicle to drop significantly below the target speed.

When assessing the GPS data the time of year in which the survey was carried out must be taken into account. Readings taken during or immediately after the wet season will show the road to be rougher than readings taken during the dry season. Figure 7 shows the results from the GPS survey carried immediately before and after construction and the survey in September 2012; a target speed of 40 km per hour was achievable along most of the road. It is clear that there is a substantial improvement from the pre construction condition to the condition during the 12 month monitoring period, as the vehicle speed is generally higher throughout the length of the road.

Figure 7: GPS Drive Through Data



6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

It is concluded that many of the sections constructed at the Bagamoyo site have performed well and will successfully provide all weather access, using the principles of EOD. Considering the condition of the road prior to construction, which can be seen from the comparison between post and pre-construction photographs in the Bagamoyo Construction Report, it is clear that massive improvements have been made to the road and to the provision of access. There are also areas that can be improved on, such as the performance of the slurry seal. More detailed conclusions are as follows:

- The Otta seal with sand cover seal and double surface dressing sections have proven to be viable surfacing options for low volume roads, provided that materials of adequate quality are available at an affordable cost and adequate quality control measures are in place during construction. Where suitable aggregate for double surface dressing is not available, the Otta seal is a highly effective alternative.
- The double sand seal has also proven to be an effective surfacing option that is less costly than a double surface dressing, though the typical life span of this surfacing type is lower.
- The slurry seal has not performed well and has deteriorated significantly during the monitoring phase. If this surfacing option is to be used in future, further investigation into an effective mix design that is appropriate for local conditions must be carried out.
- Concrete strips are concluded to be a suitable pavement option in flat or rolling areas, and can be constructed using local labour. This option makes much more efficient use of the concrete.
- A significant amount of contractor training will be required in order to bring geocells into regular practice in Tanzania, however this can be a highly effective option once local practitioners have a good understanding of the construction technique.
- Flooding of the drift on the hand packed stone section has caused significant damage along most of the length of the section and many stones have become dislodged. This pavement option also gives a very rough surface, and is not a preferable option for roads carrying a significant number of motorised vehicles.
- It was observed during the monitoring that the Engineered Natural Surface sections on the Bagamoyo site are most at risk of becoming impassable during the rains. No new pavement was constructed in these locations due to the favourable geometry and in situ material.

6.2 Recommendations

6.2.1 Applicability of the Pavement Options

Based on the performance of the demonstration sections throughout the monitoring stage, the following recommendations are made:

- Gravel sections can be used on sections where geometry and in situ materials are favourable, and risk of excessive deterioration is at a minimum. Gravel sections are not recommended for use on steep slopes or in areas prone to flooding.
- The bituminous sections have proven to be effective surfacing options and should continue to be used on rural access roads, on sections where a gravel road would be particularly vulnerable to erosion and excessive deterioration. Further experimentation should be undertaken to determine a better slurry mix that will work well in local conditions; it is thought that the mix used at Bagamoyo contained excess water, which was added to achieve the required workability. Cement should be used in the mixtures rather than lime.
- Hand packed stone is not recommended for rural roads that carry cars or motorbikes as this section type is vulnerable to rapid deterioration. This section type could however be used to provide pedestrian access.
- The use of concrete geocells is recommended as this option has considerable benefits, as previously discussed in this report. As this is a relatively specialized area that is new in Tanzania, some practitioner training will be required if geocells are used on future projects.

6.2.2 Ongoing Maintenance

- It is recommended that appropriate maintenance is continually carried out over the next 4 years on the project roads at Bagamoyo, in order to maximise the service life of the sections and prevent undue deterioration.
- The bituminous sections will require some maintenance during their service life, such as pothole and crack repair. An assessment of the required maintenance should be made each year during the annual monitoring that will take place under the district engineers, so that any required works can be carried out.
- Suitable maintenance should be carried out on the gravel sections in order to ensure that the road shape retains an adequate camber for draining water from the surface. This is especially important during the rainy season.
- Other general maintenance items that should be carried out include the clearing of side drains and culverts, as well as the maintenance of the monitoring beacons. This will

include ensuring that the beacons do not become obscured by bush, and replacing any damaged or missing beacons.

6.2.3 Monitoring Beacons

- During the monitoring phase in April 2013 it was apparent that a large number of the monitoring beacons at Bagamoyo could not be located or were heavily damaged. It is highly recommended that the monitoring beacons are maintained, as this is vitally important for the success of continued monitoring by District Engineer.

Appendix A Monitoring Results CD