ALTERNATIVE SURFACING FOR LOW VOLUME RURAL ROADS

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ABSTRACT

The overall objective of this project is to build district level capacity to undertake durable and cost effective improvement to District Roads using local resource based solutions. The methodology behind this project is to provide alternative pavements on a spot improvement/environmentally optimized design basis and thereby dramatically reduce the demand for gravel, provide a smoother running surface to reduce vehicle operating costs, provide basic all weather access and reduce travel times and dust pollution.

1. INTRODUCTION

Recent road engineering research has shown that, in general, most earth and gravel roads are uneconomical and practically unsustainable. The largely earth and gravel based rural networks in Africa are imposing huge maintenance burdens on poorly resourced authorities and governments. This is particularly true in Tanzania, which has a large earth and gravel road network. The resultant maintenance demand is high, threatening the future sustainability of the entire network. Gravel is becoming increasingly scarce or available only at long haulage distances, thus further increasing the cost of gravelling and regravelling.

This AFCAP project based in Tanzania aims to improve sustainable access to economic and social opportunities for poor rural communities. A further aim of the project is to provide all weather access to district roads using environmentally optimised design. Environmentally optimised design involves applying robust pavements at specific problematic locations along the road and applying less expensive and less wasteful designs in areas which are perfectly satisfactory all year round. The problematic sections along the roads will provide the locations of different trial sections using different sustainable solutions.

It is anticipated that these pavements will dramatically reduce the demand for gravel, provide a smoother running surface to reduce vehicle operating costs, reduce travel times and dust pollution. The project focuses on demonstrating different low cost solutions that once demonstrated, can be repeated across Tanzania and indeed, Africa.

Two pilot roads were selected for the project. One road is located in the coastal region in the Bagamoyo District, which shares with many roads in the area the typical problems of the coastal regions such as sandy subgrades and flat marshy areas containing black cotton soil. The second road is located on the slopes of Kilimanjaro in the Siha District, which is very steep and winding with clayey subgrades.

The project is also focused on using locally available materials. Substantial effort was made to use the local knowledge of the District Engineers and the communities in order to locate suitable gravel material. A number of borrow pits were located in the vicinity of each of the pilot roads.

The construction period for the road projects is eight months and the roads will be monitored thereafter for a further 2 years. The project in Bagamoyo started in August 2010 and the project in Siha will be tendered soon. Monitoring beacons will be constructed as reference points along the trial sections. The monitoring beacons will act as control points from which positions and levels can be taken throughout the monitoring phase of the pavements. The monitoring phase will include dipped levels and rut measurement, surface roughness, surface texture and traffic counts. After the completion of the project, we will have the knowledge to be able to select viable surface options and recommend design guidelines and specifications for each of the individual solutions that have performed well over the monitoring period. Furthermore, a whole life cost analysis will highlight the benefits of each of the different options and help in the selection of appropriate solutions.

2. SELECTION OF THE RURAL ACCESS ROADS

2.1 General Criteria for Selection

The demonstration sites for district road improvements were selected under the following categories:

1) Suitability for our demonstration sites;
2) Accessibility to the sites or proximity to proper utilities;
3) How difficult it will be to link these roads to other road networks;
4) The traffic count on the roads, and;
5) Access to local materials.

Based on requirements set out by the Prime Minister's Office Regional Administration and Local Government (PMO-RALG), that a single road be considered in each region, the list shown in Table 1 was compiled. The list contains the highest rated road based on the aforementioned criteria in each of the regions.

Table 1 Selection of Road for Demonstration Trials

Regional Rating Order	Region (Regional Centre)/ District	Road Name	Road Length (km)
1	Pwani (Kibaha)/ Bagamoyo	Talawanda to Bago	20.48
2	Kilimanjaro (Moshi)/ Siha	Lawate to Kibongoto	13.48
3	Tanga (Tanga)/ Muheza	Mamboleo to Bwembwera to Kwabastola	15.80
4	Dodoma (Dodoma)/ Konda	Ntunda to Hurui	43.00
5	Morogoro (Morogoro)/ Morogoro Rural	Mikese to Msonvizi	24.00
6	Iringa (Iringa)/ Iringa Rural	Makongati to Igangidungu	7.28

It was recommended, and accepted by the PMO-RALG, that the first two of these roads be chosen for implementation during this project as they fulfil the range of requirements. The locations of the roads are shown in Figure 1 and Figure 2.

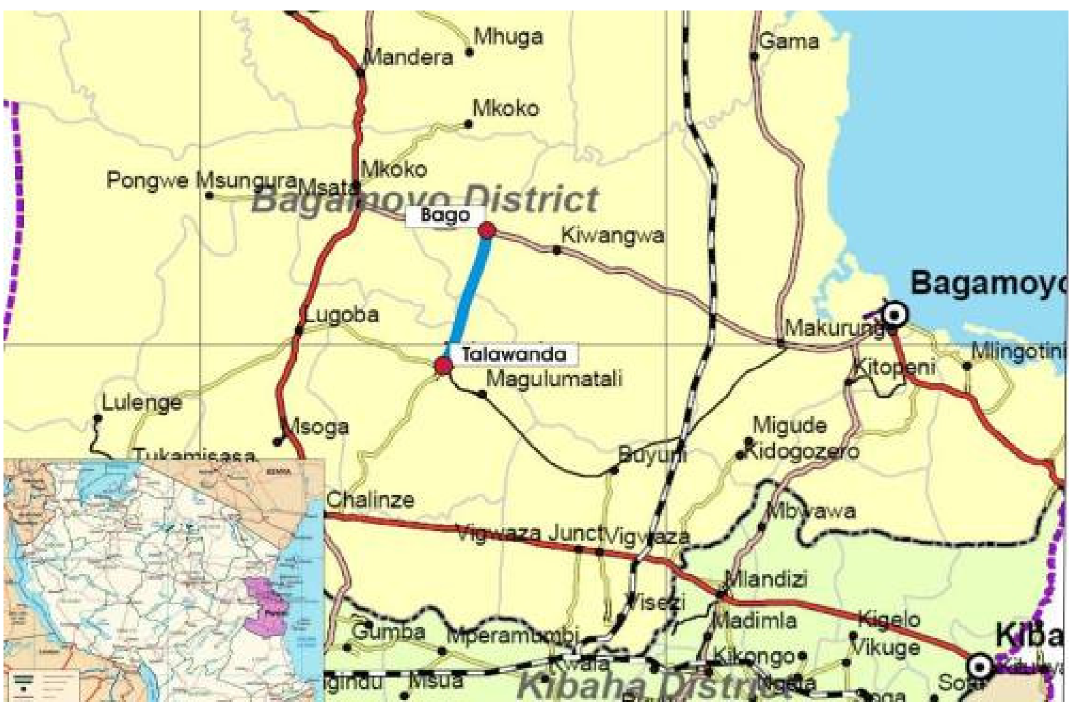

Figure 1 Location of the Bagamoyo Road

Figure 2 Location of the Siha Road

3. ENVIRONMENTALLY OPTIMISED DESIGN/ SPOT IMPROVEMENT DESIGN

The different pavement structures being used for this project are significantly more expensive than a standard gravel pavement. As a result, the pavement types are best used under an Environmentally Optimised Design (EOD)/ Spot Improvement Design (SID) approach.

EOD has been defined as a system of road design that considers the variation of different road environments along the length of the road such as steep gradients, wet and marshy areas as well as passage over easy terrain. The SID methodology is applied to EOD and concentrates on ensuring that each section of a road is provided with the most suitable pavement type for the specific circumstances to provide basic access along the road (James and Gillett, 2009).

4. PAVEMENT STRUCTURES

Various pavements were considered for use on the project roads. Several of these pavement types follow on from a similar project in Laos PDR, under the South East Asia Community Access Programme (SEACAP). The different pavement types being trialled in Tanzania include:

1) Double Sand Seal
2) Single Otta Seal with a Sand Seal
3) Double Otta Seal
4) Slurry Seal
5) Double Surface Dressing
6) Bitumen Penetration Macadam
7) Unreinforced Concrete Slabs
8) Lightly Reinforced Concrete Slabs
9) Concrete Geocells
10) Concrete Strips
11) Hand Packed Stone

5. INVESTIGATIONS

5.1 Introduction

This section discusses the different investigations taken by the Consultant and the District Engineer during the design process. It was very important for experienced engineer's to spend time in the field investigating the different problems along the roads and how they perform during the wet and dry seasons. They had the capability to identify the worst, most problematic sections along the road, and assess where basic access is being lost.

5.2 Traffic

For this project, the number of vehicles travelling along the road in both directions was estimated by the field team based on their experience of spending significant time on the project roads during the design phase of the project and being aware of a realistic traffic flow along the roads.

Whenever a major road project is undertaken an axle load survey will provide details for traffic loading estimates. However, it is impractical to do an axle load survey for a low volume rural road project and as a result, axle loads were estimated. But an axle load survey was available to the Consultant for another road project in Tanzania. This gave a good, realistic indication of the axle loads for each of the different vehicle classes.

5.3 Climate of the Project Areas

For the purpose of pavement design, Tanzania is divided into three climatic zones:

1) A dry zone in the interior
2) A large moderate zone
3) Several wet zones, mainly at high altitudes

The climatic zones are demarcated on the basis of the number of months in a year with surplus rainfall over potential evaporation. It was found that both roads were located in a moderate climate zone.

5.4 Subgrade

The subgrade for each of the roads was divided into different alignment material types in order to simplify the design and testing of each of the roads. Alignment trial pits were carried out for each material type to determine the subgrade bearing capacity. The different alignment material types for Bagamoyo and Siha are shown in Table 2 and Table 3, respectively.

Table **2** Alignment Material Types in Bagamoyo

Alignment Material Type	Soil Type and Material Description
Plastic Soils	
1	Grey/Black Plastic Soil
2	Grey Plastic Soil
3	Light Grey Plastic Soil
Sandy Soils	
4	Red Soil
5	Light Red Soil

Table 3 Alignment Material Types in Siha

Alignment Material Type	Soil Type and Material Description
Plastic Soils	
1	Brown Clayey Silt
2	Red Clay
3	Light Brown Clay

5.5 Drainage

An initial drainage system for the roads was designed by means of a hand written strip map. By driving along the road and visually assessing where low points and water crossings were, the field team recorded the chainage of probable locations for drainage structures on a hand written strip map and by taking Global Positioning System (GPS) co-ordinates of these locations. Photographs of these sites were also taken.

5.6 Gradient

The gradient of the roads was assessed using a handheld GPS. The gradient was used as a good indication of the difficult sections along the roads. The gradient was split into different categories to define the terrain type by gradient as shown in Table 4.

Table 4 Terrain Type as Defined by Gradient

Vertical Gradient	
0% to 3%	Flat
3% to 5%	Slight
5% to 10%	Moderate
10% to 15%	Steep
15% to 50%	Very Steep

5.7 Visually Assessed Poor Sections

A visual assessment of the most problematic sections along the roads was done. These sections were targeted as the most urgent sections along the roads and in need of immediate attention. These poor sections may contain defects/conditions such as:

1) Steep gradients
2) Sharp bends
3) Muddy tracks
4) Erosion channels
5) Slippery surface
6) Loose Sand
7) Soft wet areas (TRL, 2006)

This investigation required spending time along the road during the wet season and identifying the poor sections and recording these locations using a handheld GPS and by taking photographs of each of the defects.

5.8 Conclusions

The foregoing investigations were the basis for the design of the pavements and the selection of the different trial sections. The traffic, climate and subgrade investigations determined the layer thickness for the different pavements. While the subgrade, visual assessment and the gradient were all key in determining the different trial sections.

6. DESIGN ISSUES

6.1 Introduction

The pavements were designed using the Tanzanian Pavement Design Manual (TPDM). The design philosophy of the project is to 'use what you have', with regards to local materials, so the specification for the construction materials may be relaxed during the construction phase in order to incorporate locally sourced materials.

6.2 Local Construction Materials

A number of gravel sources were located in the proximity of each of the two roads with the intent of using natural gravel in the pavement layers, as opposed to crushed rock, when constructing the trial sections. In Siha, a number of volcanic gravels were located. In Bagamoyo, the local materials found include quarzitic river gravel and decomposed granite gravel. In Bagamoyo, the area has reasonable quantities of Gneiss stone which is very suitable for construction purposes and efforts were been made to include this stone into the design. This stone is to be used in the hand packed stone pavement, as well as the construction of the culvert headwalls, wingwalls, lined drains and scour checks. The location of the borrow pits are shown in Table 5 and Table 6.

Table 5 Location of Gravel Sources in Bagamoyo

Chainage(km)	Offset(km)	Description
2.72	1.25	Red Quarzitic Gravel
15.56	1.62	Grey Decomposed Granite Gravel

Table 6 Location of Gravel Sources in Siha

Chainage(km)	Offset(km)	Description
0.00	11.48	Volcanic Tuff
0.00	11.48	Volcanic Tuff
0.00	20.60	Volcanic Tuff

6.3 Subgrade Bearing Capacity

The pavement design method requires the design subgrade bearing capacity (CBR) to be defined for a road section. The subgrade bearing capacity was determined based on test results for alignment trial pits along each of the roads. A summary of the subgrade bearing capacity for each of the two roads is shown in Table 7.

Table 7 Design Subgrade Bearing Capacity

Subgrade Classes	Range Wet/Moderate CBR (%)	Length			
		Talawanda to Bago		Lawate to Kibongoto	
		(%)	(km)	(%)	(km)
Low Strength	< 3	18.8	3.8	0	0
S3	3 – 6	57.5	11.8	81.7	11.0
S7	7 – 14	23.7	4.9	18.3	2.5
S15	Min 15	0	0	0	0

6.4 Poor Subgrade (Black Cotton Soil)

Along the road in Bagamoyo, there is a significant length of low strength (CBR < 3%), expansive soils. The standard method for dealing with such soils is to excavate the subgrade to a depth of at least 600 mm and replace the soils with a non-expansive, non-plastic fill. This method was considered inappropriate and too costly for minor roads and it was decided to provide a surfacing which can accommodate some movement in the subgrade and can be easily maintained such as hand packed stone, geocells and concrete strips. The performance of each of these pavements will be monitored closely to gauge their durability and performance over the design life of the road.

6.5 Pavement Design

The pavement design predominately follows the TPDM for a design traffic loading of less than 0.2 million equivalent standard axles. Some minor changes from the TPDM were considered appropriate for this project considering low volume rural roads. Since a large number of the total traffic on these access roads consists of heavy vehicles, it was considered appropriate to change the specification set out in the TPDM for a bitumen pavement of 150 mm subbase with CBR requirement of 25% to 100 mm subbase with a CBR requirement of 45%.

The TPDM does not cover the design of concrete pavements. The design of the different concrete pavements in this project follows the basic design method set out in the TPDM, of bringing the subgrade bearing capacity up to a CBR of 15% by means of one or more improved subgrade layers. The designs for the concrete pavements are considered appropriate for low volume rural roads because they are suitable for labour based construction and have a relatively low whole life cost and can be used in conjunction with the TPDM to design concrete pavements for low volume rural roads in Tanzania. The final pavement design is shown below, in Table 8, assuming a subgrade CBR between 3% and 6%.

7. STRIP MAPS

7.1 Introduction

It was the aim of the Consultant not to carry out a detailed topographic survey of the road. Instead the Consultant produced a strip map using data from a handheld GPS and combining a number of different investigations. This strip map was used successfully to tender the projects.

7.2 Implementation of Strip Map

The data from the investigations was combined and put into a strip map using Microsoft Excel and used to assess which sections were suitable as trial sections. The strip map produced for this project combines the different profiles from the GPS data with a drainage system for each of the roads and provides the following information to the designer:

1) Vertical Gradients
2) Subgrade Type
3) Alignment Trial Pits
4) Subgrade Bearing Capacity
5) Road Condition Sections Based on Speed
6) Features and Observations including Drainage System
7) Trial Sections
8) Pavement Layers
9) Visually Assessed Poor Sections
10) Photographs

Once the above information was placed into the strip map the following factors were used to indicate the poor sections along the road:

1) The gradient of the road
2) The in-situ subgrade
3) Visual Assessment

When all three factors were lined up in the strip map with a corresponding chainage it made it much easier to select the final trial sections along the road.

7.3 Conclusions

In conclusion, the strip maps were very successful. The strip map was a low cost alternative to doing a detailed road survey and was successfully used for tendering purposes. The strip map was done entirely on Microsoft Excel 2003. The strip map was easily understood by the contractors once a brief explanation was given to them at the pre-tender meeting. The location of drainage structures is clearly shown at the correct chainage, the direction of the water flow, high points, low points and possible locations for the mitre drains. This allows the reader to easily and comprehensively understand the drainage system for the roads. This combined with the gradient, the location of the different pavements, the pavement structure, the subgrade bearing capacity and selected photographs along all sections of the roads, allows the reader to implement a detailed EOD/ SID suitable for low volume rural roads.

Table 8 Trial Pavement Construction Details

Pavement Types		Bitumen Pavement	Unreinforced Concrete	Reinforced Concrete	Concrete Paving Blocks	Concrete Strips	Geocells	Hand Packed Stone
Surface Layer	Type	Bitumen Surface	Concrete	Concrete	Blocks	Concrete	Concrete	Stone
	Thickness	Varies	75	75	65	100	75	200
Bedding Sand	Thickness	0	0	0	15	0	0	15
Base	Type	Natural Gravel CBR > 60%	-	-	-	-	-	-
	Thickness	150	-	-	-	-	-	-
Subbase	Type	Natural Gravel CBR > 45%	Natural Gravel CBR > 60%	Natural Gravel CBR > 60%	Natural Gravel CBR > 45%	Natural Gravel CBR > 45%	Natural Gravel CBR > 45%	Natural Gravel CBR > 45%
	Thickness	100	100	100	150	150	150	150
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%
	Thickness	150	150	150	150	100	100	100
Improved Subgrade	Type	Natural Gravel CBR > 7%	Natural Gravel CBR > 7%	Natural Gravel CBR > 7%	Natural Gravel CBR > 7%	Natural Gravel CBR > 7%	Natural Gravel CBR > 7%	Natural Gravel CBR > 7%
	Thickness	150	150	150	150	150	150	150
Subgrade	Type	CBR < 7%	CBR < 7%	CBR < 7%	CBR < 7%	CBR < 7%	CBR < 7%	CBR < 7%

8. TRIAL SECTIONS

The main factors considered when selecting the different pavement types included the following:

1) The cost of the pavement type/ available funding
2) Relative durability/sustainability of options
3) Severity of defect
4) The availability of materials of a suitable quality
5) Dust pollution
6) Traffic volume

Some of the pavement types are more appropriate in certain circumstances than others. A guideline showing the probable advantages and disadvantages is shown in Table 9. It was found that when more than one pavement was suitable for a particular problem location, the cost and the availability of local materials was the deciding factor in selecting a particular pavement. At this point in the project it is considered premature to come up with a definitive methodology for selecting a particular pavement for a particular circumstance before the long term performance of the different pavements has been assessed.

Table 9 Pavement Types Assessed Against some Key Markers

Pavement Type	Local Materials	Flat terrain	Steep Terrain	Populated Areas	Marshy Areas	Low Strength Subgrades	Small Contractor Suitability	Likely Cost Advantage	Maintenance Reduction
Gravel Pavement	+	+	-	-	-	+	+	+	-
Unreinforced Concrete	-	+	+	+	+	-	+	+	+
Reinforced Concrete	-	+	+	+	+	-	+	+	+
Concrete Geocells	-	+	+	+	+	+	+	+	+
Concrete Strips	-	+	+	+	+	+	+	+	+
Concrete Paving Blocks	-	+	+	+	+	-	+	-	+
Hand Packed Stone	+	+	+	-	+	+	+	+	-
Single Otta Seal with a Sand Seal	-	+	-	+	+	-	+	-	+
Double Otta Seal	-	+	+	+	+	-	+	-	+
Double Sand Seal	-	+	-	+	-	-	+	-	+
Slurry Seal	-	+	-	+	+	-	+	-	-
Double Surface Dressing	-	+	+	+	+	-	+	-	+
Bitumen Penetration Macadam	-	+	+	+	+	-	+	-	+
Engineered Natural Surface	+	+	-	-	-	-	+	+	-

Note: + indicates a positive advantage, - indicates a probable disadvantage

8.1 Trial Sections in Bagamoyo

A summary of the different trial sections in Bagamoyo and Siha are shown in

Table 10 and Table 11. This summary shows the existing problems that warrant a durable pavement structure and the various solutions that will be implemented during the project.

Table 10 Problematic Sections in Bagamoyo

Trial Section	Chainage (km)		Length (km)	Problem	Solution
1	0.02	0.22	0.20	Dust Pollution/ High Traffic Volume	Single Otta Seal with a Sand Seal
2	5.39	5.59	0.20	Marshy Area	Hand Packed Stone
3	5.59	6.11	0.52	Poor Subgrade	Concrete Strips
4	6.11	7.77	1.66	Poor Subgrade/Deep Erosion of the Carriageway	Concrete Geocells
	8.14	8.34	0.20	Moderate Gradient	Double Surface Dressing
	8.34	8.84	0.50	Erosion	Concrete Geocells
7	10.17	10.86	0.69	Steep Gradient/ Erosion Channels	Concrete Strips
8	11.31	11.51	0.20	Dust Pollution	Double Sand Seal
9	16.11	16.89	0.78	Poor Subgrade/ Erosion Channels	Concrete Strips
10	18.61	19.12	0.51	Poor Subgrade	Concrete Strips
	20.24	20.48	0.24	Dust Pollution	Slurry Seal
Total Length			5.70	28% of the Road	

Table 11 Problematic Sections in Siha

Trial Section	Chainage (km)		Length (km)	Problem	Solution
1	0	0.23	0.23	Dust Pollution/ High Traffic Volume	Double Otta Seal
2	1.35	1.48	0.13	Sharp Bend	Unreinforced Concrete Slab
3	1.96	2.54	0.58	Steep Gradient	Concrete Geocells
4	2.72	3.62	0.90	Steep Gradient	Concrete Geocells
5	4.30	4.99	0.69	Steep Gradient/ Sharp Bends	Concrete Paving Blocks
6	4.99	5.95	0.96	Moderate Gradient/ Sharp Bends	Double Surface Dressing
7	6.42	6.64	0.22	Short Steep Section	Unreinforced Concrete Slab
8	6.84	7.01	0.17	Short Steep Section	Unreinforced Concrete Slab
9	7.22	7.37	0.15	Short Steep Section	Unreinforced Concrete Slab
10	7.7	8.3	0.60	Steep Gradient	Concrete Strips
11	8.7	8.8	0.10	Short Steep Section	Unreinforced Concrete Slab
12	9.71	9.95	0.24	Steep Gradient	Unreinforced Concrete Slab
13	10.13	11.23	1.10	Steep Gradient	Concrete Geocells
14	11.23	11.71	0.48	Moderate Gradient/ Sharp Bends/ Dust	Bituminous Penetration Macadam
15	11.71	12.56	0.85	Steep Gradient/ Sharp Bends	Lightly Reinforced Concrete Slabs
16	12.70	13.06	0.36	Steep Gradient	Concrete Geocells
Total Length			7.76	57% of the road	

8.2 Discussion and Conclusions

In the case where a number of different pavement types are suitable for a particular section, the cost is the main factor in deciding which pavement to use over another suitable pavement. The project in Bagamoyo began in August 2010, however at the time of this paper the project in Siha had not been tendered and as a result it was decided not to publish the costs of the different pavements.

Since the aim of this project is not only to provide all weather access, but also to demonstrate the performance of different pavement options available, the Consultant tried to incorporate as many different pavement options as possible. Where the situation warranted, the cheapest pavement option may not have been used and a more expensive option may have been used, even if it was only for a short 200m section. This is the case with the bitumen pavements going through the villages. In most cases, the bitumen pavements are more expensive than the concrete pavements, which conflicts with the SEACAP conclusions in Laos PDR. Experience in Laos PDR showed that the concrete pavement options were more expensive than the bitumen options, while also concluding that the concrete options are more suitable for labour based construction and have superior durability. The Consultant put the expensive cost of bitumen pavements in Tanzania down to a lack of experience of small contractors working with bitumen. The contractor was taking on more risk when working with bitumen than with concrete. Based on these facts, the Consultant felt that it was important to demonstrate the different bitumen options because it is expected that once smaller contractors become more familiar across Tanzania with the various different seals, the price of the bitumen pavements will be significantly reduced.

9. CONCLUSIONS

Only limited conclusions can be made at this early stage of the project. The roads will be monitored for deterioration after construction. As a result of the medium to long term nature of the project, only preliminary conclusions can be drawn now as to the suitability of the pavements.

The following are the preliminary conclusions for the project so far:

1) During the selection process of the different pavement trials, if more than one option is considered suitable for a particular section then other than the cost and the availability of local materials, there isn't a defined methodology for using a particular pavement.
2) Any benefits from the durability and long term performance of a particular pavement will be assessed after the monitoring phase of the project.
3) It is important for skilled engineers to spend significant time in the field, particularly during the rain season, to clearly identify the problematic areas along the road and assess where basic access is being lost. This is an important requirement for the EOD philosophy.
4) It is important to incorporate local materials as much as possible in the design and selection of the different pavement structures. This is critical for cost-effective and sustainable solutions for low volume rural roads. This is an important requirement for the EOD philosophy.
5) The strip map is a low cost alternative to a detailed topographic survey and efforts should be made to incorporate this method for District Roads.
6) The costs of the bitumen pavements are expected to reduce once small contractors become more familiar with them.
7) It is clear that small contractors need to be better informed about the different pavement types and would benefit from training in understanding exactly what is required in the tender documents.

10. REFERENCES

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