Training on the Use of the DCP Pavement Design Method for Low Volume Sealed Roads in Malawi

Training Report

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April 2014
CONTRACT REF NO. AFCAP/MAL/134/A

BEIA 13 WINNER

British Expertise International Awards 2013: **Outstanding International Collaboration**

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This material has been funded by UKaid from the Department for International Development, however the views expressed do not necessarily reflect the department's or the managing agent's official policies.

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Report Summary

Malawi is at the forefront in Africa in the adoption of the DCP Design Method for upgrading of gravel and earth roads to a Low Volume Sealed Roads (LVSR) standard and is one of the first countries in the southern African region to have formally recognized the method as an alternative to the traditional CBR based design method.

The Malawi DCP Design Manual was completed in 2013, but the local consulting industry needs to be trained to apply the design method as documented in the manual. To this end a one week course was commissioned through AFCAP to train Roads Authority staff and project staff from a locally based consulting firm, Royal Associates, which has been awarded a design contract for five Low Volume Sealed Roads totaling 40 km under the World Bank-funded ASWap Project.

The training course was conducted with 17 participants from 1st – 3rd April 2014 at Livingstonia Lodge in Senga Bay, and on 4th April at the Central Materials Laboratory in Lilongwe for demonstration of the Laboratory DN test to determine the suitability of imported material as the new road base.

The participants were trained in the background and principles of the DCP Design Method as well as in other important aspects for cost effective design of LVSR. At the end of the course they are deemed to have achieved an intermediate competency level.

The DCP Design Method introduces several techniques that engineers take time and practice to become fully familiar and conversant with. More training and guidance is therefore needed before they are able to undertake a full DCP design on their own.

Training courses must also be arranged for Technicians and Laboratory staff since the success of the design method hinges on these staff categories being able to collect DCP data and perform laboratory tests in a reliable manner in accordance with the set procedures and test standards.

DCP data from T357 Lifuwu Road in Salima District was used for the pavement design exercise. However, it was observed the the major problem on this road is the design and construction of the drainage system which was outside the remit of the trainers. On the basis of data supplied by the design consultant only general recommendations regarding drainage and road standard could be made. Further investigations and testing are required for the final design decision.

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List of Abbreviations

AFCAP	African Community Access Programme
ASWap	Agriculture Sector Wide Approach
CBR	California Bearing Ratio
CSIR	Council for Scientific and Industrial Research
CUSUM	Cumulative Sum
DCP	Dynamic Cone Penetrometer
DFID	Department for International Development
DN	DCP Number - Rate of DCP penetration in mm/blow
EOD	Environmentally Optimized design
EDD	Extended Design Domain
GPS	Global Positioning System
Km	Kilometre
LVR	Low Volume Road
LVSR	Low Volume Sealed Road
MDD	Maximum Dry Density
MESA	Million Equivalent Standard Axles
OMC	Optimum Moisture Content
FMC	Field Moisture Content
ToR	Terms of Reference
UK	United Kingdom

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1 INTRODUCTION

The Africa Community Access Programme (AFCAP) is a programme of research and knowledge dissemination funded by the UK government though the Department for International Development (DFID). AFCAP is promoting safe and sustainable rural access in Africa through research and knowledge sharing between participating countries and the wider community. The first phase of AFCAP commenced in June 2008 and will end in June 2014. The management of AFCAP 1 was contracted by DFID to Crown Agents Limited.

The adoption of the regional research-based pavement design method using the portable Dynamic Cone Penetrometer (DCP) provides the potential for cost-effectively upgrading unpaved roads to a paved standard in a manner not possible with more traditional approaches. The DCP method lends itself to evaluating in situ road conditions and, by integrating the design strength profile optimally with the in situ strength profile, to designing light road pavement structures in a highly cost-effective manner. This approach allows maximum use to be made of the natural gravels in the unpaved road. As a result, construction costs can be reduced significantly thereby enabling the sealing of gravel roads to be economically justified in terms of life cycle costs often at traffic levels of less than 100 vehicles per day (vpd).

AFCAP activities in Malawi have resulted in the preparation of a new pavement design manual for low volume sealed roads (LVSR) which is based on the DCP design method. The manual was developed through a highly collaborative approach in-country and an international peer review process. The manual has now been published as an official Malawi government document and is available in hard and soft copy. It will be used for the design of 80km of low volume sealed roads under the ASWap, which is being coordinated by the World Bank. A contract has been signed by the Road Authority with a locally-based consulting firm to undertake the design of these roads, which are located in different parts of the country. The firm has no previous experience with the use of the DCP design method for upgrading gravel roads.

Despite Malawi being at the forefront in Africa in the adoption of the DCP Design Method, much training is needed of government officials and the local construction industry before the DCP Design Method can be applied on a broad scale.

As part of the dissemination of the Malawi DCP manual and ensuring its use in local industry, AFCAP commissioned a one-week training course which was conducted from 31st March to 4th April 2014. The training event was attended by 17 participants from the Roads Authority and the consulting firm Royal Associates, which has been awarded the contract for design of the 8.6 km T357 Lifuwu Road near Salima. This road has been selected for upgrading under ASWap.

2 ASSIGNMENT SCHEDULE

The assignment schedule shown in Table 1 below.

Table 1: Mission Schedule and Training Programme

Date	Activity
25.03	Arrival Jon Hongve, introduction to Roads Authority
26.03	Field trip to T357
27.03	Meeting with Royal Associates. Collection of project data, follow-up on materials sampling and preparations for Lab DN testing
28.03	Follow-up on materials sampling and preparations for Lab DN testing
29.03	DCP Data entry and preparation of training files
30.03	DCP Data entry and preparation of training files. Arrival of Estime Mukandila
31.03	Preparations, arrival of Mike Pinard, inspection of project road, travel to course venue
01.04	Field and Classroom Training
02.04	Classroom Training
03.04	Classroom Training
04.04	Demonstration of Laboratory DN test. Departure M. Pinard
05.04	Reporting. Departure of E. Mukandila
07.04	Demonstration of Laboratory DN test continued.
08.04	Follow-up on materials classification tests. Departure J. Hongve

The original training programme included the demonstration of the Laboratory DN test on Monday 31st March, 2014. However, due to unexpected delays with the materials sampling and preparation of samples for testing, the demonstration was rescheduled to take place on Friday 4th April, 2014 after return from the training workshop at Senga Bay.

3 OBJECTIVE

The objective of the training course, as stated in the Terms of reference (ToR) was:

- To conduct a training course in the use of the Malawi DCP Manual for the design of low volume sealed roads. The output of the training course will include draft geometric and pavement design recommendations for the upgrading of the identified road in Salima District.

4 TRAINING

4.1 Trainee categories and numbers

The staff categories and number of staff attending the course are shown in Table 2 below. The trainees comprised a mix of Senior Management from Roads Authority and Engineers/Practitioners from Roads Authority and Royal Associates. No Technicians were included in the course.

Table 2: Trainee attendance

Trainee attendance				Classroom training			Lab
No	Name	Title	Organisation	01.04	02.04	03.04	04.04
1	Joseph Kasambara	Project Engineer	Roads Authority	V	V	V	V
2	Fletcher Mkandawire	Project Engineer	Roads Authority	V	V	V	V
3	Aamon Mukasera	Project Engineer	Roads Authority	V	V	V	V
4	Macleod Phiri	Senior Maintenance Engineer	Roads Authority	V	V	V	V
5	Patrick C Kamanga	Construction Engineer	Roads Authority	V	V	V	V
6	Wainright Chihana	Construction Engineer	Roads Authority	V	V	V	V
7	Joseph J Ngure	Team Leader	Royal Associates	V	V	V	V
8	Grill Moses	Engineer	Royal Associates	V	V	V	V
9	Tapona Neba	Engineer	Royal Associates	V	V	V	V
10	Samuel Ndikuno	Engineer	Royal Associates	V	V	V	V
11	Neddie Nansongile	Project Engineer	Roads Authority	V	V	V	V
12	Thokozani Kaluwa	Project Engineer	Roads Authority	V	V	V	V
13	Jarrison Chilongu	Highway Planning Engineer	Roads Authority	V	V	V	V
14	Sharmey Banda	Senior Engineer – Planning	Roads Authority	V	V	V	V
15	Jeoffrey Mtope	Inspector	Royal Associates	V	V	V	V
16	Stanley Phiri	Engineer	Royal Associates	X	V	V	V
17	David Geilinger	Rural Roads Adviser	Roads Authority	V	V	V	V
				16	17	17	17

4.2 Training Methodology

An application-oriented training approach was adopted with clearly defined topics, objectives and learning outcomes that are relevant to the substantive jobs held by the staff. This approach allowed the trainees to actually undertake DCP data collection in the field and to subsequently use this data in the classroom to design a LVR pavement based on the DCP methodology. The trainees were also able to assess the suitability of borrow pit materials for incorporation in the road pavement by undertaking or witnessing, as appropriate, laboratory DCP-DN measurements. Thus, the training methodology was devised in such a manner that the field, classroom and laboratory training were complementary to each other in a mutually reinforcing way.

The DCP data had been collected by Royal Associates at 100 m intervals for the whole length of the road prior to the training course. The practical exercise on the use of the DCP was thus limited to re-doing DCP tests at or around potential problem spots and assessing the likely cause of the problems at these spots.

4.3 Training Materials and Modules

The Malawi DCP Design Manual provided the necessary reference materials for each training session. This manual provides an in-depth explanation of the underlying development of the DCP design method, as well as a fully illustrated step-by-step guide to the design of LVR pavements based on this method.

For the use of the WinDCP software and Excel for data analysis and pavement design, a step-by-step PowerPoint presentation was prepared to guide the trainees during the practical exercises.

The presentations and other material used during the training are attached in Annex 1.

4.4 Execution of training

4.4.1 Training programme

The training was carried out at Livingstonia Hotel in Senga Bay and on the project road T357 Lifuwu Road from 1st – 3rd April. The demonstration of the Laboratory DN Test was carried out at the Central Materials Laboratory in Lilongwe 4th April.

Table 3: Training Programme

	Original	Actual
Day 1	• Background to and principles of DCP Design Method highlighting differences with and shortcomings of traditional CBR based design, environmentally optimized design (EOD), Extended Design Domain for LVSR	• Field exercise in use of DCP • Intro to WinDCP software, exercise on opening files, defining DCP desing curve, data entry, basic analysis, transfer data to Excel, Cusum analysis
Day 2	• Field exercise in use of DCP • Intro to WinDCP software, exercise on opening files, defining DCP desing curve, data entry, basic analysis, transfer data to Excel, Cusum analysis	• Background to and principles of DCP Design Method highlighting differences with and shortcomings of traditional CBR based design, environmentally optimized design (EOD), Extended Design Domain for LVSR
Day 3	• Pavement Design exercise using DCP data from project road, Travel to Lilongwe	• Pavement Design exercise using DCP data from project road, Travel to Lilongwe
Day 4	• Laboratory DN test demonstration	• Laboratory DN test demonstration

The change of the programme as shown in Table 3 became necessary due to the temporary indisposition of one of the trainers. As it turned out, the trainees gave a positive feedback on the sequence of the training, since they had time to digest the technicalities of the WinDCP software and the basic data analysis, before this was used for the design exercise.

4.4.2 Training Attendance

As shown in Table 2 above, all 17 trainees were present during the three days of classroom training as well as the Laboratory Demonstration apart from one Engineer from Royal Associates who reported on the second day of the classroom training.

4.4.3 Classroom training

The objective of the classroom training was to impart knowledge of the various aspects involved in the DCP Design Method to an intermediate level of competence. During the training each group was exposed to the theoretical and practical aspects of DCP design including:

- Background and development of DCP design
- Justification for sealing of Low Volume Roads
- Alternative empirical methods of design for Low Volume Sealed Roads
- DCP design principles
- Environmentally Optimised Design (EOD) of LVSRs
- Drainage and erosion control requirements

- Use of the Win DCP design software
- Data entry (using the data collected previously during the field training exercise)
- Data analysis
- Pavement design
- Surfacing options
- Materials selection based on laboratory determination of DN values.

Picture 1: Classroom training in session

4.4.4 Field Training

The objectives of the field training were to:

- Familiarize the trainees with the condition of the road and drainage system so that they could relate the DCP data to design decisions during the classroom training.
- Familiarize the trainees with the assembly and correct use of the DCP equipment.
- Practice correct procedures for carrying out the DCP survey and quality assurance in the collection DCP data.
- Collect DCP data to be used in the subsequent design exercise during the classroom sessions. The analysis of the DCP field data will determine whether and to what extent material must be imported for additional pavement layer(s).

The field work is necessary for the designers to familiarize themselves with the road environment to be able to relate the DCP data to the actual conditions along the road. Localized areas that may require special interventions can then be identified, and if necessary, further DCP measurements can be made to identify the extent of such sections. This was discussed during the classroom sessions.

Picture 2: Training in the use of the DCP

During the field work the designers should make note of:

- The time of the DCP survey in relation to the seasonal rainfall.
- The condition of the existing drainage system and the required improvements. A drainage system in bad condition will influence the DCP data in that the moisture in the existing pavement will most likely be higher than the anticipated moisture after the improvement of the road and drainage system.
- Traffic patterns along the road. This must be accompanied with traffic counts at key points along the route to determine the design traffic loading for the various sections.

Picture 1: Standing water in the side drain indicate soaked subgrade

Since Royal Associates had collected DCP data for the entire length of the road at 100 mm intervals beforehand, the practical exercise on the correct use of the DCP was limited to four points identified as potential problem spots from the DCP data set.

The general condition of the road and drainage system was observed and discussed, as well as the likely cause of the high DN values at the selected spots. It was evident from observations of the condition of the drainage system that the subgrade at the selected spots was in a soaked condition. Apart from one point at the start of the sandy section at km 7+100 where the subgrade consists of deep sand, there is no reason to suspect that the subgrade would be of a different nature at the selected spots. The subgrade generally consists of weathered granite and proved to be quite uniform and strong for the full length of the road.

5 MATERIALS

5.1 Alignment moisture samples

Royal Associates had taken two samples per km of the three upper 150 mm layers in the existing road at the time of the DCP testing. A summary of the results is shown in Table 4 below. The detailed results are shown in Annex 3.

Although the tests were taken towards the end of the rainy season, the in situ pavement was generally fairly dry, most likely due to good drainage in the weathered granite and sandy subgrade. For the design exercise it was therefore assumed that the in situ moisture was more or less at the anticipated long term in-service moisture content.

Table 4: Summary of Field Moisture Samples

Layer	FMC / OMC %	
	Min	Max
0-150 mm	42 %	72 %
150-300mm	35 %	76 %
300-450 mm	46 %	70 %

5.2 Location and sampling of borrow pit material

One existing borrow pit containing weathered granite is located approximately mid way along the road. It is assumed that this material has been used for the existing gravel wearing course on the road. However, the pit seems to be exhausted and will in any case need to be drained before it can be further exploited, perhaps for fill material.

Another borrow pit is located approx. 2 km from the start of the road along the road to Senga Bay. Substantial quantities of laterite can be won from this pit. Samples from this pit were collected for the Laboratory DN test, results of which are shown in Table 5 below. These results only provide an indication that the material may be used, neat or possibly mechanically stabilized. More representative samples must be taken and tests should be carried out in triplicate in strict adherence to the prescribed procedures to lend some reliability to the results.

Due to the uncertainty of the suitability of the laterite, Royal Associated should make further investigations into the location of alternative material sources. DCP tests and samples from the road leading to Raphatsa Lodge, which was constructed with material from the same borrow pit, will give useful information as to the suitability of this material for base.

5.3 Material test results

5.3.1 Laboratory DN Test

The laboratory staff at Central Materials Laboratory (CML) were not familiar with the requirements and procedures for preparation of samples for the Laboratory DN test. This caused a delay in the preparations forcing a re-scheduling of the demonstration from Monday 31st March to Friday 4th April.

On Friday 4th April samples were ready for testing at various moisture contents and compaction efforts. However, samples had not been dried back to 0.75 OMC as requested, so the test could only be demonstrated for samples after 4 days soaking and at OMC.

The remaining samples were then to be dried back to 0.75 OMC by the following Monday, but again there was a misunderstanding of the procedure for drying back. On Monday morning the dried back samples were at approximately 0.5 OMC or below.

The uncertainties experienced by the staff at CML with undertaking correct laboratory test procedures in strict adherence with the Malawi DCP Manual underlines the need for training of Technicians, since the success of the DCP Design Method relies on Technicians and Laboratory Staff being able to collect DCP data, operate the WinDCP software and perform materials sampling and laboratory tests in a reliable manner in accordance with the procedures set out in the Malawi DCP Design Manual.

The results of the Laboratory DN demonstration are shown in Table 5. As can be seen, the DCP was hardly able to penetrate the samples at 0.5 OMC and below. There may therefore be scope for using this laterite for base or sub-base, depending on the final estimation of the Design Traffic Loading.

Table 5: Results of Laboratory DN test demonstration

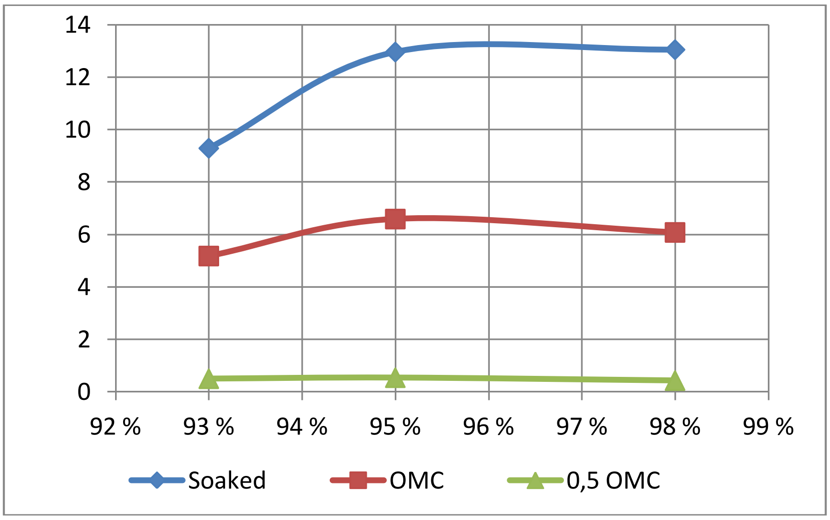
Region: Salima	Project: T357 Lifuwu Road	Quarry: Off main road to Senga Bay
Date:	Sample no:	Tested by:

4 days soaked											
98 %				95 %				93 %			
No of blows n	DCP Reading	DN per n blows	Avg. DN per blow	No of blows n	DCP Reading	DN per n blows	Avg. DN per blow	No of blows n	DCP Reading	DN per n blows	Avg. DN per blow
0	111			0	105			0	110		
2	147	36	18,00	1	130	25	25,00	2	132	22	11,00
2	169	22	11,00	1	140	10	10,00	2	159	27	13,50
2	186	17	8,50	2	161	21	10,50	2	174	15	7,50
2	205	19	9,50	2	179	18	9,00	2	190	16	8,00
2	232	27	13,50	2	195	16	8,00	2	204	14	7,00
				1	207	12	12,00	2	216	12	6,00
				1	211	4	4,00	2	230	14	7,00
				1	222	11	11,00				
Penetration depth		121				117				120	
Weighted Average DN			13,05				12,96				9,29

OMC											
98 %				95 %				93 %			
No of blows n	DCP Reading	DN per n blows	Avg. DN per blow	No of blows n	DCP Reading	DN per n blows	Avg. DN per blow	No of blows n	DCP Reading	DN per n blows	Avg. DN per blow
0	98			0	97			0	95		
2	114	16	8,00	4	134	37	9,25	2	109	14	7,00
2	130	16	8,00	2	144	10	5,00	2	120	11	5,50
2	143	13	6,50	2	157	13	6,50	2	130	10	5,00
2	155	12	6,00	2	168	11	5,50	2	141	11	5,50
3	172	17	5,67	2	178	10	5,00	2	152	11	5,50
3	187	15	5,00	2	187	9	4,50	2	160	8	4,00
3	199	12	4,00	2	196	9	4,50	2	169	9	4,50
2	206	7	3,50	2	206	10	5,00	3	179	10	3,33
Penetration depth		108				109				84	
Weighted Average DN			6,08				6,59				5,18
DN_{OMC}/DN_S =			47 %				51 %				56 %

Mould no 7 RMC 38%				Mould no 39 RMC 48%				Mould no 4 RMC 49%			
98 %				95 %				93 %			
No of blows n	DCP Reading	DN per n blows	Avg. DN per blow	No of blows n	DCP Reading	DN per n blows	Avg. DN per blow	No of blows n	DCP Reading	DN per n blows	Avg. DN per blow
0	109			0	102			0	110		
20	121	12	0,60	20	119	17	0,85	10	115	5	0,50
30	122	1	0,03	20	127	8	0,40	20	124	9	0,45
30	130	8	0,27	30	136	9	0,30	20	137	13	0,65
30	131	1	0,03	30	145	9	0,30	30	151	14	0,47
								30	163	12	0,40
Penetration depth		22				43				53	
Weighted Average DN			0,43				0,54				0,50

Figure 2: DN variation with compaction effort and moisture content



5.3.2 Material Classification

The laterite sampled for testing was fairly fine grained with some nodules, most of which could easily be broken down with the fingers. Naturally the material broke down significantly under compaction as shown in Picture 2 below.

Picture 2: Laterite before (left) and after compaction (right)

Normally one would assume that the breakdown under compaction would be the reason for the apparent decrease in strength (increasing DN value) when going from 93% to 95% and 98% compaction as shown in Table 5 and Figure 1 above. However, the back-analysis of the compacted samples for the Laboratory DN test shown in Table 7 below, shows no significant difference in grading between the samples compacted at the different compaction efforts. The variation in the DN values is therefore probably a result of inconsistent procedures and/or operator errors in the preparation of the samples. This is indicated by the unexpected variation in the Dry Density of the material in the moulds after compaction. However, the results are too few to draw any firm conclusions, but they do show the importance of materials sampling and testing being done in an appropriate and consistent manner in strict adherence to the testing standards.

Table 6 a & b: Material Classification and grading

LL	PI	BS Heavy MDD kg/m3	OMC %	Linear shrinkage %
26	11	2038	10.4	6.0
27	12	2038	10.4	6.4

Sample no	Percentage passing before compaction (sieve size in mm)										
	19	13.2	9.5	4.75	2.36	0.600	0.425	0.300	0.150	0.075	GM
Sample 1	100	98	90	67	58	51	49	43	30	25	1,68
Sample 2	100	99	93	75	67	60	57	51	35	29	1,47

Table 7 a & b : Back-analysis of samples for Lab DN test

Compaction	Average percentage passing after compaction (sieve size in mm)										
	19,00	13.2	9.5	4.75	2.36	0.600	0.425	0.300	0.150	0.075	GM
98% (2 samples)		100	98	85	74	65	61	54	38	31	1,34
95% (3 samples)		100	99	86	77	69	64	58	40	33	1,25
93% (1 sample)		100	98	86	74	68	65	54	40	33	1,28

Laterite MDD 2038 kg/m3, PI 11-12, OMC 10.4%				
Moisture level	Compaction	Dry Density kg/m3	OMC %	MC after test %
Soaked	98 %	2009	10.3	11.0
Soaked	95 %	2031	9.9	11.6
Soaked	93 %	2015	9.1	10.8
OMC	98 %	1995	10.3	9.1
OMC	95 %	2011	10.0	9.9
OMC	93 %	2005	9.1	9.0
0.75 OMC	98 %	1992	10.3	Not analysed
0.75 OMC	95 %	2035	10.2	
0.75 OMC	93 %	1975	9.1	

6 TRAFFIC

A summary of a 7-day traffic count carried out by Royal Associates is shown in Table 8 below. The detailed traffic count is shown in Annex 4.

Table 8: Traffic count summary (7 day count)

Traffic Count Summary	Car, Pickup, 4WD, Minibus	Light goods	Bus	Medium goods	Heavy goods	Tractor	Motor cycle	Bicycle	Animal carts	Total Motorised	Total Non Motorised
Outbound	169	60	0	28	3	1	31	1987	3	292	1990
Inbound	168	56	0	14	1	0	29	2104	5	268	2109
Total	337	116	0	42	4	1	60	4091	8	560	4099
ADT	**48**	**17**	**-**	**6**	**1**	**-**	**9**	**584**	**1**	**80**	**585**

The count was carried out at one station at the beginning of the road. To possibly distinguish between pavement and geometric design requirements on different sections rather than adopting a blanket design for the whole road, the counting should be carried out at a minimum of two stations, one at the beginning of the road and one at km 7+000 at the entry to Lifuwu village.

6.1 Design Traffic Loading

Based on the traffic count figures the Design Traffic Loading was provisionally estimated for the pavement design exercise using two different sets of Vehicle Equivalent Factors (VEF):

1. Standard VEF given by Roads Authority
2. Reduced VEF as suggested in the "Performance Review of Design Standards and Technical Specifications for Low Volume Roads in Malawi (Pinard 2011)

As can be seen from Table 9 below, the Light and Medium Trucks account for nearly all of the Design Traffic Loading and a slight variation in the actual VEF for these vehicle classes will have a huge impact on the actual traffic loading. An axle load survey of vehicles using the road is therefore recommended to guard against over- or underdesign of the pavement.

Seasonal variations must also be taken into account. The harvest from the rice project at the end of the road will be transported out on this road. One should therefore try to estimate the tonnage of rice to be brought out and get information on the typical type of vehicle used for this transport. In this way one can get a good idea of the additional traffic loading in the rice harvesting season.

In any case it seems unlikely that the Design Traffic Loading for a 10 year design period will exceed 100,000 ESA in the heaviest trafficked direction. The applicable Pavement Design Class would then be LE 0.1.

For a 15 year design period the appropriate Pavement Design Class would be LE 0.3 which was used for the pavement design exercise.

6.2 Capacity

While the motorized ADT is low, the large number of non-motorised traffic at the start of the road may require a wider cross section for improved road safety. A traffic count at Lifuwu village will reveal whether a wider cross section may also be required there.

Table 9: Provisional Estimate of Design Traffic Loading

Design traffic loading[1]	Inbound			Outbound		
Vehicle class	ADT (2014)	VEF[2]	DESA	ADT (2014)	VEF[2]	DESA
Light trucks	10	0,7	7	10	0,7	7
Buses	0	1,18	0	0	1,18	0
Medium goods vehicles	2	1,88	5	5	1,88	9
Heavy goods vehicles	1	4,22	5	1	4,22	2
Total DESA 2014			17			18

Design traffic loading[1]	Inbound			Outbound		
Vehicle class	ADT (2014)	VEF[3]	DESA	ADT (2013)	VEF[3]	DESA
Light trucks	10	0,7	7	10	0,7	7
Buses	0	0,75	0	0	0,75	0
Medium goods vehicles	2	1,75	4	5	1,75	8
Heavy goods vehicles	1	2,8	3	1	2,8	1
Total DESA 2014			14			16

1) Includes 20% generated traffic first year

Cumulative Equivalent Standard Axles: $CESA = 365\ T_b[(1+r)^n - 1]/r$

Tb = DESA 2014
r = annual growth rate 3 %
n = design period (years)

T357 Lifuwu Road	Inbound			Outbound		
Design period (years)	5	10	15	5	10	15
CESA (standard VEF)	26355	56907	92325	34881	75318	122195
CESA (reduced VEF)	21704	46864	76032	31005	66949	108618

7 Pavement Design

The details of the data analysis and pavement design are shown in Annex 5.

The Cusum Analysis showed three uniform sections that were designed separately:

Figure 3: Cusum diagram T357 Lifuwu Road

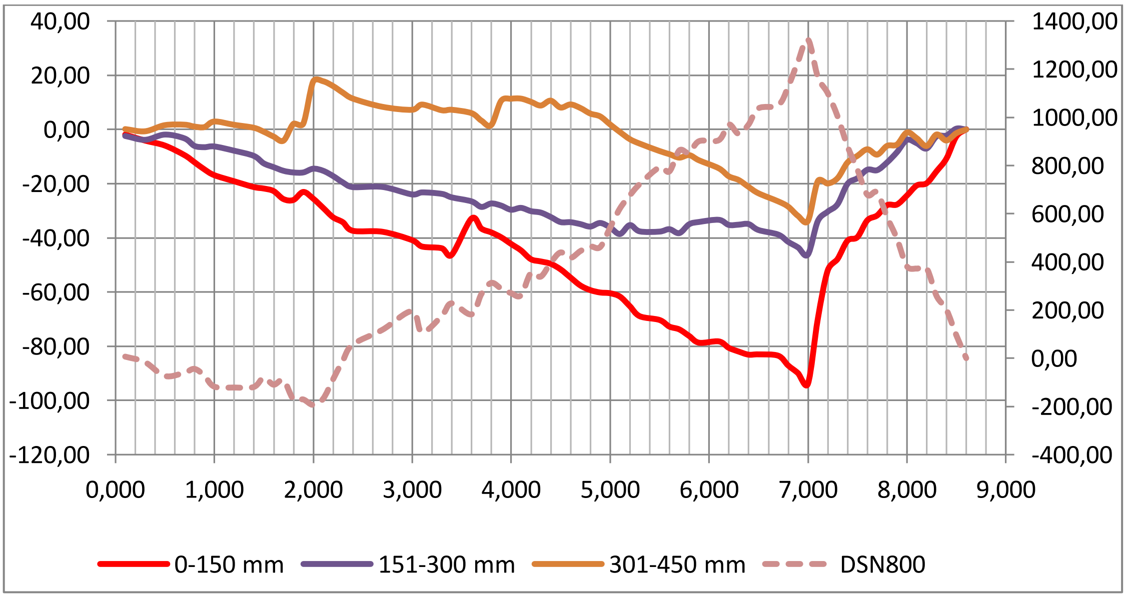


Table 10: Pavement Design Example T357 Lifuwu Road

Design class LE 0.1	Spec. DN/layer mm	Uniform Section 1 km 0+000 - 2+000	Uniform Section 2 km 2+000 - 7+000	Uniform Section 3 km 7+000 - 8+600
0-150 mm	3,2	4,34	4,36	11,34
151-300 mm	6	3,90	4,14	7,42
301-450 mm	12	6,78	4,74	7,47
451-600 mm	19	8,15	5,69	8,95
601-800 mm	25	7,66	6,25	11,35
DSN800	100	178	227	119

Marginal/can be improved	Outside spec.	Within spec.

Import of one layer with required DN value will ensure that all layers satisfy the design criteria

Design class LE 0.1	Spec. DN/layer mm	Uniform Section 1 km 0+000 - 2+000	Uniform Section 2 km 2+000 - 7+000	Uniform Section 3 km 7+000 - 8+600
0-150 mm	3,2	≤3.2	≤3.2	≤3.2
151-300 mm	6	4,34	4,36	≤6
301-450 mm	12	3,90	4,14	11,34
451-600 mm	19	6,78	4,74	7,42
601-800 mm	25	8,15	5,69	7,47
DSN800	100			

Imported layer within spec.

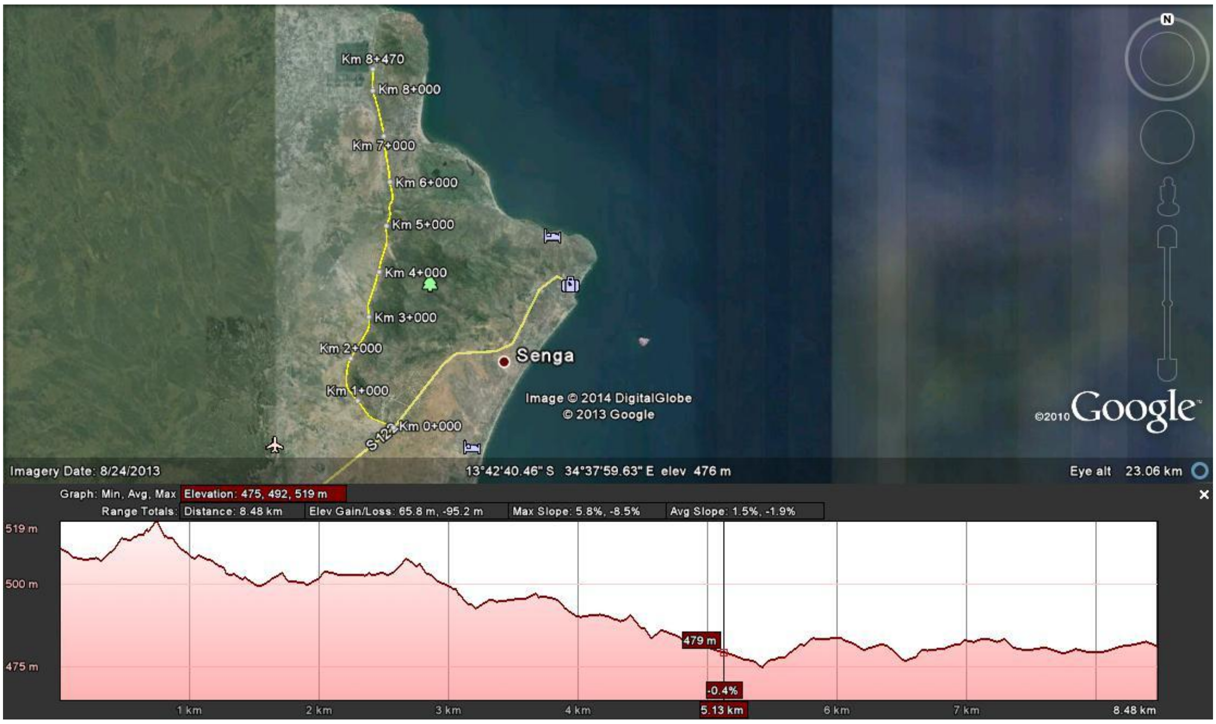
In the example, one additional layer is required for Sections 1 and 2 and two layers for Section 3.

If it is found that Traffic Class LE 0.1 is more appropriate for this road by using actual VEFs calculated on the basis of an axle load survey and/or reducing the design period to 10 years, the upper layer in Sections 1 and 2 may be brought to within specifications (DN ≤ 4 mm) by lightly scarifying and proof-rolling the layer.

8 Practical Design and Construction Considerations

8.1 Topography and drainage

Figure 4: Map and Longitudinal profile of T357



The road goes through gently rolling terrain gradually falling off towards the river at approx. km 5+300 where it flattens out up to Lifuwu village at approx. km 7+000.

Picture 3: Erosion gullies on the right hand side

From km 0+000 to about km 5+000 run-off from the hills on the right hand side drains towards the road. This has caused severe scouring and development of deep erosion gullies on most of this section.

Picture 4: Left hand side drain silted up

On the left hand side the terrain is generally lower making it possible to construct drain and culvert outlets into lower ground. The side drain on the left hand side is mostly silted up with materials from the gravel wearing course.

Picture 5: Flat section towards Lifuwu village

Beyond the bridge at km 5+300 the run-off from the hills is draining into the river. On this flatter section there is therefore not a severe drainage problem.

8.2 Alignment and levels

The horizontal and vertical alignment can generally be followed, but levels need to be adjusted to accommodate the drainage which is the major concern on this road.

The final levels will be dictated by the level of the outfall from culverts outlets and mitre drains. The invert of the right hand side drain must be determined by working back from this point at a minimum grade of 1-2% while at the same time maintaining a grade of min. 1% in the side drain.

The pavement needs to be lifted at least by one 150 mm layer on most sections, probably by 300 mm on flat sections from km 0+000 to km 5+300. Beyond the bridge there is less of a drainage problem, so probably one 150 layer will suffice provided satifactory outlets can be constructed.

The final levels must then be checked to ensure that H_{min} and D_{min} requirements as per the Malawi DCP Design Manual, Section 8.4, are met.

The approach to the bridge at km 5+300 occasionally gets overtopped, possibly as a result of severe overgrowth in the river bed which is restricting the flow under the bridge. The overgrowth must be cleared, but the approach should nevertheless be lifted to guard against future overtopping and potential wash-out.

8.3 Drainage design

Due to the amount of water in the right hand side drains, this drain must be lined nearly all the way from km 0+000 to the bridge at km 5+300. A trapezoidal drain with sufficient cross section and minimum grade of 1% must be achieved.

Lining is probably best done with burnt clay bricks unless nearby sources of suitable stones can be found.

Picture 6: Example of brick lined side drain

The left hand side drain will only receive run-off from the carriageway. Properly constructed scour checks should therefore be sufficient to prevent erosion in this drain.

8.4 Road width and traffic safety

At the current traffic level (ADT 80), there will be on average 9 minutes between passings of motorized vehicles, motorcycles included, at any point of the road if one assumes that all motorized traffic takes place during 12 hours of daylight. At this traffic level vehicles tend to use the middle of the road. A total sealed width of 6.5 m therefore seems to be an appropriate standard, which will provide adequate space for non-motorized traffic. Traffic safety must be further enhanced by judicious use of speed reducing measures.

8.5 Construction method

To save on haulage of fill and pavement materials, as much as possible of the consolidated pavement should be left undisturbed.

The current effective width is about 4.0 - 4.5 m. To accommodate a sealed width of 6.5 m, the formation up to the existing level must be widened to about 8.0 m depending on height of the lift from the current level. Widening on the left hand side wherever possible without disturbing the existing pavement appears to be the most efficient construction approach.

On sections where this is not possible, scarifying the existing pavement and using this as the first layer of the fill, may be the most rational construction method.

9 REVIEW AND EVALUATION OF TRAINING COURSE

9.1. Objectives and Outcomes

Based on the feedback and discussions during the course, the training objective has evidently been achieved. However, it must be emphasized that the trainees through this course will only have reached an intermediate level of competence. To be fully conversant with the method and its application for a complete project design, more training, guidance and experience will be needed.

The Course Evaluation by the trainees, which is summarised in Table 11 below, supports the above assessment. Copies of the trainees' Course Evaluation Forms are attached in Annex 6.

Based on the data provided to the trainers and the material samples collected for testing, only recommendations for further investigations and testing could be made. The pavement design exercise nevertheless gives a good foundation for the complete design.

The main concern in this project is proper drainage design and erosion control which requires detailed investigations and is outside the remit of the trainers.

A typical cross section with 6.50 m sealed width including shoulders seems to be an appropriate standard taking into account the required traffic capacity, accommodation of non-motorized traffic and road safety and the available construction budget.

Table 11: Course Evaluation Summary

1. OVERALL OBJECTIVE AND OUTCOMES

Item	Strongly Agree	Agree	Partially Agree	Disagree	Strongly disagree
The objectives of the workshop were achieved	12	4			
The outputs of the workshop were achieved	10	5	1		
The workshop has provided me with an adequate appreciation of the DCP design method	14	2			

2. FIELD TRIP AND PRESENTATIONS

Item	Strongly Agree	Agree	Partially Agree	Disagree	Strongly disagree
The field trip was beneficial to the classroom presentations	13	3			
The workshop presentations were well made	9	6	1		
The principles of the DCP design method were understood	11	5			
The analysis of DCP data was understood	7	6	3		

3. WORKSHOP VENUE AND ORGANIZATION

Item	Excellent	Very Good	Good	Poor	Very Poor
Workshop venue	6	9	1		
Workshop organization	5	5	5	1	
Workshop materials	5	3	8		
Workshop content	4	7	5		
Quality of food served	3	5	8		

Picture 7: Course participants and trainers

9.2 Challenging Aspects of DCP Design

The DCP Method of Design is such a significant departure from the traditional CBR-based design method and introduces a number of new concepts that are relatively difficult to grasp without continued training and practical exposure.

Aspects that the trainees found most challenging were dealt with in depth to engender a thorough understanding of these difficult issues, including:

- The adoption of an Environmentally Optimised Design (EOD) approach in which the final design should be "fit for purpose" and should be responsive to all factors in the road environment.
- The application of an Extended Design Domain (EDD) principle which allows the existing alignment to be followed with minimal changes or improvement whilst not imposing undue risks on road users. The EDD will allow for varying travelling speed and potential traffic hazards can be mitigated e.g. by local widening, road marking, speed humps etc.
- The adjustment of the DCP DN values by the judicious choice of an appropriate percentile applied to the data set to account for the in situ moisture content at the time of the DCP survey in relation to the anticipated long-term in-service moisture content in the pavement.
- The undertaking of a Cumulative Sum or CUSUM analysis of the weighted average DN values to determine uniform sections.
- Optimised use of local materials, i.e. making the specifications fit the available materials rather than making the materials fit the specifications, by modification or stabilization, and avoiding the adoption of non-material specific specifications that are applied in a blanket fashion and, by so doing, do not reflect the real needs or the local environment.

- Test standards. The participants were quite shocked by the revelation of the unreliability of the CBR test that they routinely carry out on their projects. The DCP test also has a margin of error, but this has been found to be more accurate and reliable than the CBR test. No matter which tests one is using, the importance of following the test procedures to the letter was emphasised.
- The significant difference in test procedures of various international testing standards for carrying out, for example, compaction and CBR testing (e.g. TMH1/AASHTO versus BS standards) which produce results which are very different and not comparable.

9.3 Need for further training

Only one of the trainees had been sensitised previously to the DCP Design Method through participation in the previous training in Malawi. He clearly benefitted the most from the training courses and expressed as much during the training.

It is the personal experience of the trainers, that in order to attain Advanced Competency further training is needed, including for those who may have had some previous exposure. This would entail, in outline, undertaking all the activities required for the upgrading of a typical rural road of about 10 km in length, including DCP measurements, data analysis, pavement design, materials selection, etc., as well as, of course, other attendant design issues such as drainage, road safety, etc. Such courses should be planned in the not so distant future to retain the momentum and be designed as individual projects under guidance and review by the trainers.

9.4 Attitudes to the adoption of the DCP Design Method

As with any new technology, and particularly a method that demands a paradigm shift in peoples' mind-set that brings them out of their comfort zone, the uptake and adoption is likely to be slow to start with. There will be a minority of those who actively oppose the new idea (inhibitors) and another minority who will be eager to adopt and promote the change (innovators). The vast majority will be somewhere in the middle and their tendency to change will be largely influenced by the persuasive ability of the inhibitors or innovators.

By a simple hands-up survey, most of the trainees seemed to be on the side of either following or wanting to adopt the change (innovators).

Only by continued training and application through demonstration projects will it be possible to build the required momentum to make the process of change in approach to pavement design for LVRs self-sustaining. Moreover, it is clear that the uptake of the DCP technology will only be facilitated after it is embedded in the national standards of the country.

9.5 Challenges to implementation

Malawi is in the forefront in Africa in the adoption of the DCP Design Method as a national standard as an alternative to the traditional design method and is so far the only country with a recognized DCP Design Manual that can be used by consultants for project design.

However, the application of the method for design of Low Volume Sealed Roads will not be taken up on a broad basis without extensive training of local consultants. It is therefore imperative that more training courses are held including Training of Trainers who can sustain the long term training.

9.6 Lessons Learned

A number of lessons were learnt by the trainers in organizing and undertaking the training course. These may be summarized as follows:

- The trainees should download the DCP software and should obtain the license key (provided by CSIR) well in advance of the course, so that they can familiarise themselves with its use, including reading of the User Manual. Despite ample notification period of the process to obtain the software and license code before the start of the course, some of the trainees had not got the software installed on their laptops and thus had to share a laptop with other trainees.
- Training needs to be provided for Technicians and Laboratory Staff in the collection of DCP data, basic operation of the WinDCP programme and materials sampling and testing. Well trained Technicians and Laboratory Staff are indispensable and the success of the DCP Design Method relies heavily on the work of these staff categories.
- Trainees should participate in both the fieldwork and classroom training in order to derive maximum benefit from the course.
- The choice of demonstration project used to collect the DCP field data should provide a variety of conditions (terrain, drainage conditions, material type, etc.) so as to bring out a range of discussion points during the classroom training.
- The trainees for future courses should be chosen well in advance of the start date of the course, say a minimum of about 4 weeks, so that they can plan and prepare themselves accordingly. The in-country organizers should ensure that all trainees download and install the WinDCP Software and obtain license key before coming to the course.
- Every effort should be made by the in-country organizers to ensure participation of as many senior managers as possible so as to engender at least an appreciation of the benefits of the introduction of any relatively new technology to their organizations, such as the DCP design method.
- Laboratory equipment to be used for the materials classification and preparation of samples for Laboratory DN testing and DCPs must be available in sufficient quantities and in good working order.

9.7 Next steps

In order to facilitate uptake of the DCP design method amongst stakeholders - Senior Management in the road sector, politicians and leaders at local and national level – the following should be considered as a basis for ultimately embedding the DCP Design Method choice for upgrading of gravel and earth roads to Low Volume Sealed Roads:

1. The training of trainers who will spearhead and sustain the continued development and application of the DCP technology in the country.
2. The involvement of training institutions, technical institutions and universities whereby the DCP technology is included in their curricula.
3. The production of well-illustrated, reader-friendly, promotional leaflets that illustrate homegrown success examples in which the technical, economic and social benefits are quantified.
4. Visits to demonstration projects by key stakeholders, including political and technical decision-makers in the country.