AFCAP

African Community Access Programme
Project MAL/016

Performance Review of Design Standards and Technical Specifications for Low Volume Sealed Roads in Malawi

Final Report

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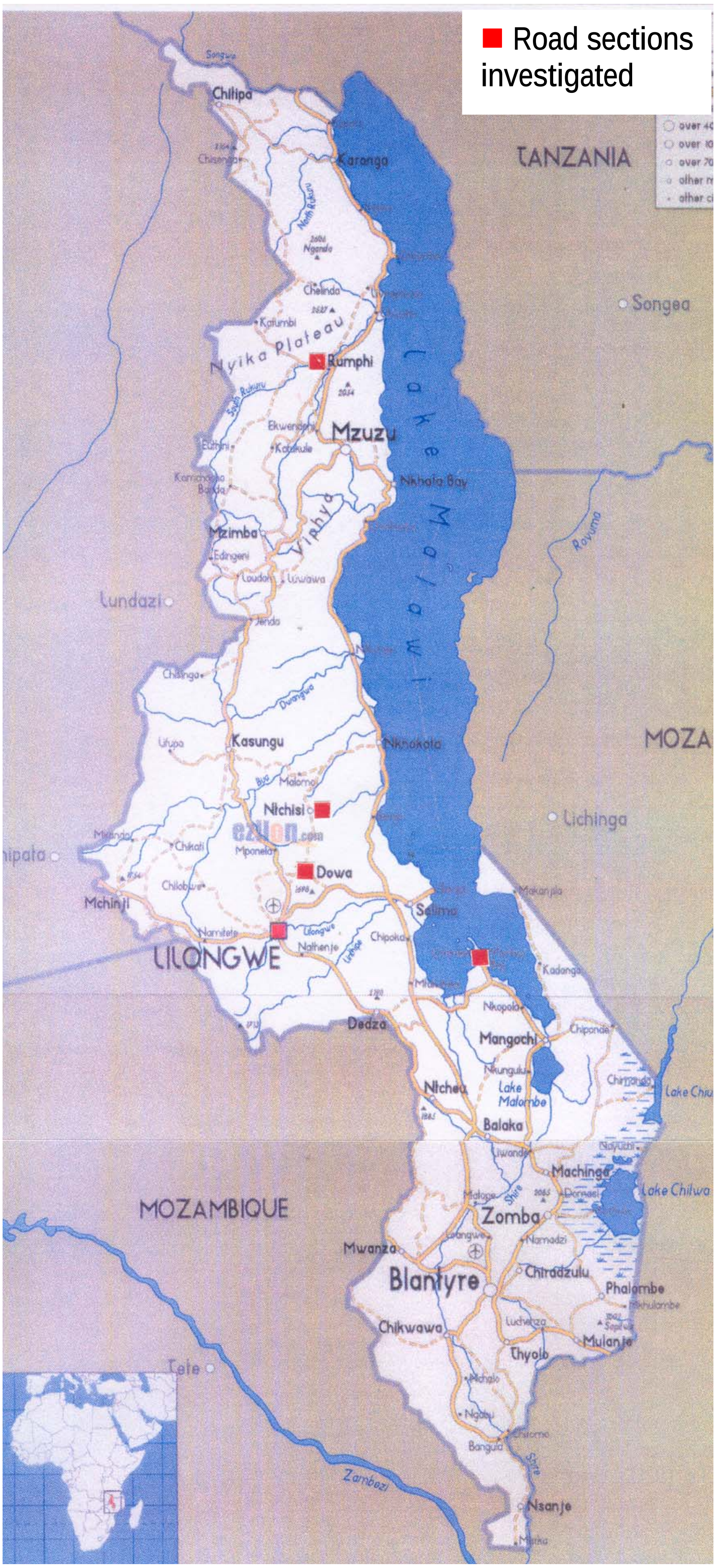
LIST OF ABBREVIATIONS

AADT	Average Annual Daily Traffic
AFCAP	African Community Access Programme
BS	British Standard
CBR	California Bearing Ratio
CML	Central Materials Laboratory
CSIR	Council for Scientific and Industrial Research
DCP	Dynamic Cone Penetrometer
DF	Drainage Factor
DN	The average penetration rate in mm/blow of the DCP in a pavement layer
DSN_{800}	The total number of blows required to penetrate the pavement to a total depth of 800mm
ESA	Equivalent Standard Axle
EMC	Equilibrium moisture content
HGV	Heavy goods vehicle
HV	Heavy vehicle
IDD	In situ dry density
IWP	Inner wheel path
LGV	Light goods vehicle
LHS	Left hand side
LL	Liquid Limit
LV	Low-volume
LVR	Low volume road
LVSR	Low volume sealed road
MC	Moisture content
MDD	Maximum dry density
MGV	Medium goods vehicle
MK	Malawi Kwacha
MESA	Million Equivalent Standard Axles
OMC	Optimum moisture content
ORN	Overseas Road Note
OWP	Outer Wheel Path
P075	Percentage material passing the 0.075mm sieve
PI	Plasticity Index
PM	Plastic Modulus
RA	Road Authority
RC	Relative compaction
RHS	Right hand side
SADC	Southern African Development Community
SB	Subbase
SG	Subgrade
ToR	Terms of Reference
TRL	Transport Research Laboratory
UK	United Kingdom
USD	United States dollar
VEF	Vehicle Equivalence Factor
vpd	Vehicles per day

Road Map of Malawi



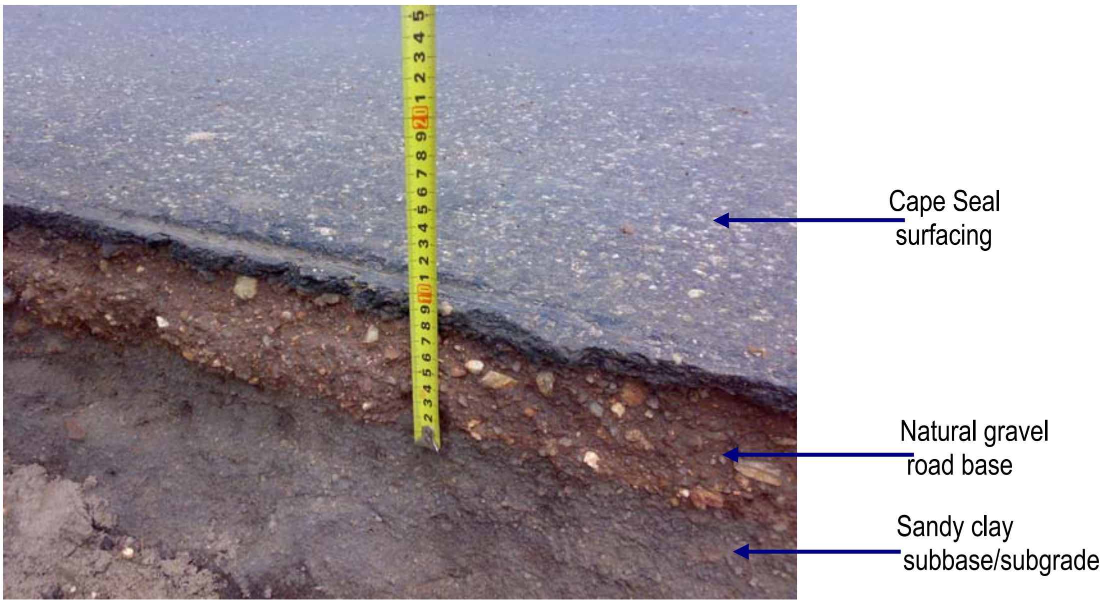
EXECUTIVE SUMMARY

Background

More than 70% of Malawi's public road network of just under 15,500 km is unpaved, including a large proportion of secondary (approx. 87%), and almost all the tertiary and district roads. The cost of maintaining this network to provide all year passability has proved to be a major challenge and the resulting unsustainable road conditions have impacted adversely on much of the population who live in rural areas.

Whilst there are significant life-cycle benefits to be achieved from upgrading these relatively lightly trafficked unpaved roads to a paved standard, including a reduction in the continuous exploitation of non-renewable gravel sources, environmental benefits due to reduced erosion and health benefits due to reduced dust, the cost of doing so following traditional standards and specifications is prohibitive.

Fortunately, there is a history of successful performance of roads in Malawi that have been constructed to less costly standards than dictated by current design manuals. The photograph below provides an example of such a road which was upgraded to a paved standard by the placement of a nominal 150mm layer of appropriate quality gravel on the proof-rolled and previously traffic consolidated subgrade. This road, like many other similarly constructed roads in the country, has performed exceptionally well for a period of over 20 years without exhibiting any signs of significant distress.



Example of typical low volume road pavement in Malawi: the 20 year old Lilongwe ABC road

More recently, the Roads Authority (RA) has embarked on the upgrading of a number of un-paved roads to a paved standard adopting both a simplified bidding documentation and construction approach based on the good performance of the older roads. These relatively lightly trafficked, low volume roads (LVSRs) are now 6-8 years old and have all performed extremely well at a construction cost significantly less than that of traditionally designed and constructed roads.

Unfortunately, despite the very good results derived from the use of the LVSR approach, its more widespread use has been constrained by a concern held in a number of quarters that the standards employed do not conform with traditional standards. As a result, such roads are sometimes considered to be a high risk undertaking. In order to allay these concerns, the Roads Authority requires performance-based standards and technical specifications that reflect historical experience in Malawi and in the region and are also acceptable to all stakeholders including political decision makers, local consultants and contractors.

The Low Volume Sealed Roads Project

At the request of the Roads Authority, the Africa Community Access Programme (AFCAP) has assisted the Authority in undertaking a project aimed at gaining official acceptance of appropriate low volume sealed roads (LVSR) standards to ensure their application on a wider scale.

The key objectives of the project were to:

(a) Undertake a review of performance of existing low volume sealed roads, existing design standards and specifications used for the construction of low volume sealed roads in Malawi;

(b) Establish an appropriate design methodology for LVSRs and provide recommendations for the development of manuals and other official documentation needed to facilitate the use of appropriate LVR standards by the road sector in Malawi;

(c) Estimate the costs that can be achieved through adopting more appropriate design standards for LVSRs.

Project Roads

The following LVSRs were selected for detailed investigation:

Region	Road Section	Date of Construction	Base Type
Central	Ntchisi (School) Ntchisi (Hospital) Ntchisi (Standard)*	2002 2002 2006	Laterite
Central	Dowa	2004	Weathered granite
Northern	Rumphi	2004	Weathered granite
Southern	Cape Maclear	1985	Quartzitic gravel
Central	Lilongwe ABC road	1985	Quartzitic gravel

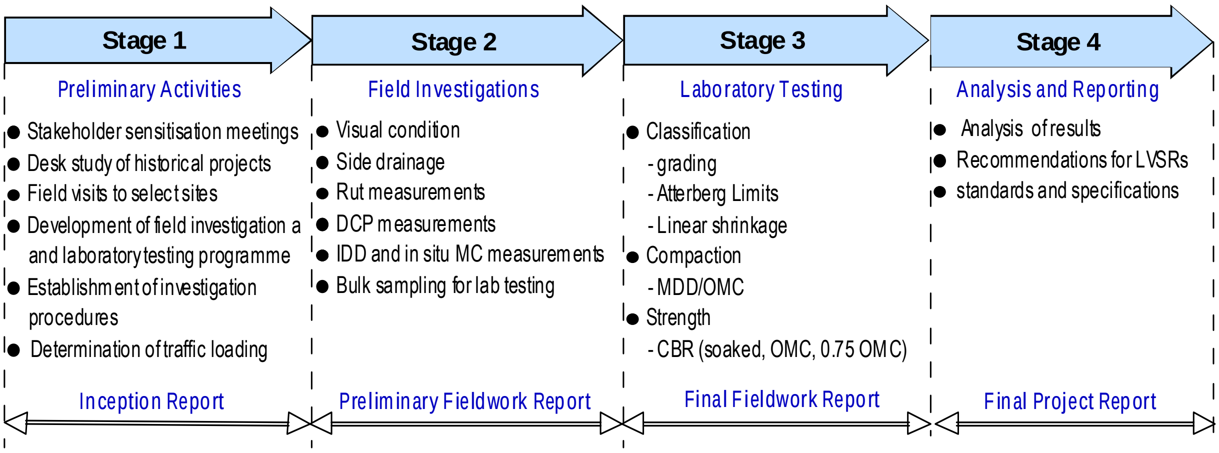
* This section was constructed in the traditional manner as a 3-layer pavement system using conventional design standards and specifications and is contiguous with the LVSR sections.

The project roads are located in climatic regions of the country where the annual rainfall ranges from 600-1200 mm, i.e. a relatively wet climate (Thornthwaite Moisture Index 0 to +20, Weinert N-Value 2-4)

General Approach and Methodology

A four-stage, sequential process was adopted for undertaking the project as follows:

- Stage 1 - Preliminary activities
- Stage 2 - Field investigations
- Stage 3 - Laboratory testing
- Stage 4 - Analysis and reporting



Main Findings and Conclusions

LVR performance

All the LVSRs investigated have performed extremely well in the prevailing service environment. These relatively lightly trafficked roads, which have all carried less than 0.25 million equivalent standard axles (MESA) since construction, remain structurally sound with no significant signs of distress. According to conventional pavement design standards, these roads should have already failed. This can be interpreted as indicating that traditional design standards and specifications are inappropriate for use with LVSRs – a conclusion that has also been reached from a number of similar investigations carried out in other countries in the region.

Photo: Ntchisi road (school) - constructed in 2002 Condition: Good/sound

Photo: Dowa road – constructed in 2004 Condition: Good/sound

The road safety aspects of the LVSRs will need to be carefully considered in future designs particularly at passing/overtaking sections and where sharp curves/bends occur. This may require the specification of additional road reserve clearing to cater for such situations.

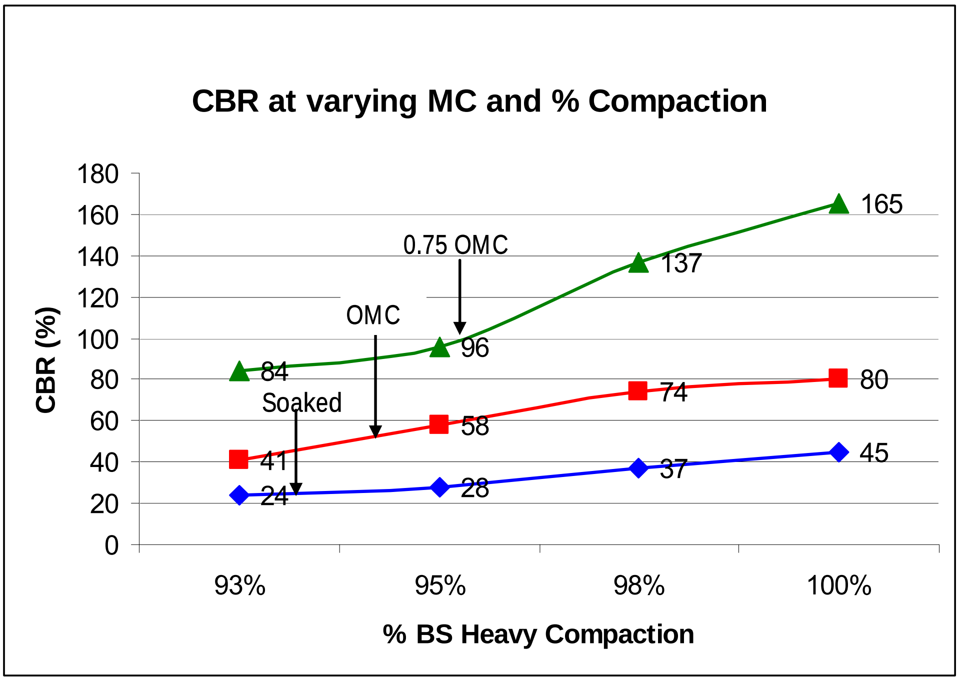
Traffic

The project roads can all be defined as “low volume” roads in that although their Annual Average Daily Traffic (AADT) in some cases exceeds 300 vpd, the traffic loading carried in service is less that 0.5 million ESAs. However, the current manner of classifying commercial vehicles for traffic estimation purposes (LGV, Buses, MGV and HGV) and the use of tabulated values representing average rather than road specific VEFs need to be refined in order to avoid the costly impact of over- or under-estimation of the traffic growth which can lead to unnecessarily conservative or risky road designs.

Materials

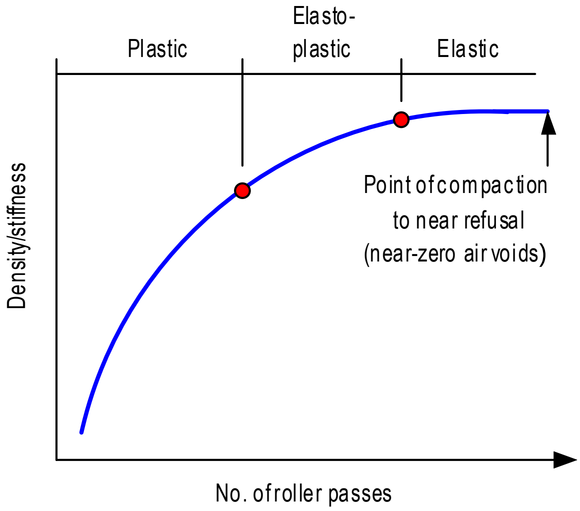
None of the materials used in the construction of the LVSRs comply fully with the traditional standards and specifications normally applied in Malawi in terms of the commonly specified plasticity, grading and strength requirements. Nonetheless, they are “fit for purpose” and should not be rejected for use in LVR pavements merely because of their non-compliance with traditional standards and specifications.

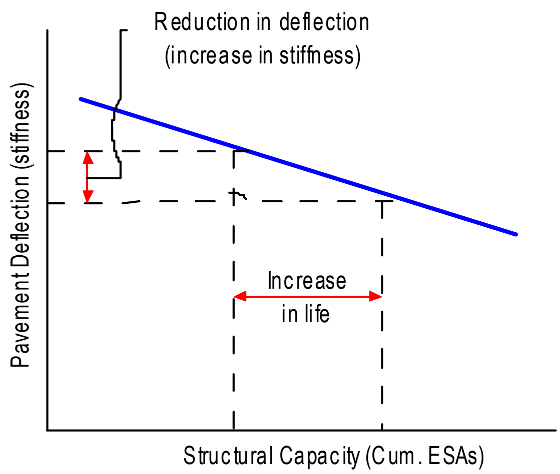
A knowledge of the inter-relationship between the moisture, density and strength of the materials used in the construction of LVSRs provides critical insight into their properties and likely behaviour in the prevailing road environment. A laboratory investigation of this inter-relationship is of paramount importance in deciding how best to use these materials in the construction of LVSRs for which a typical output is provided below.



Compaction

The investigation has shown that “compaction to refusal” (with the heaviest plant available) not only maximizes the strength potential of the construction materials, but also reduces their moisture susceptibility and, in so doing, contributes to improved pavement performance, i.e. longer life (refer to the following two graphs which illustrate these concepts). The required compaction techniques and supervision level will need to be emphasized in the new standard specification.





The Field Moisture Content to Optimum Moisture Content (FMC/OMC) ratio proved to be a significant factor related to the good performance of the LVSRs in that, even at the wettest time of the year, this ratio was generally below OMC, even in the relatively vulnerable outer wheel path of the of the project roads. It is important to ensure, through effective drainage, that the materials in the road pavement can be maintained at a moisture content that does not rise above OMC in the rainy season. By so doing, more extensive use can be made of local, relatively plastic materials that might otherwise not be suitable if they were to become soaked in service.

In the relatively warm climate areas of the country, with pronounced dry seasons, the road base and subbase/subgrade of the reasonably well constructed LVSRs remain relatively dry (< OMC) under the bituminous surface treatment. Under such conditions, quite high cohesive (suction) strengths are developed in the pavement layers under the combined actions of initial compaction, repeated wetting and drying cycles, and further compaction under traffic.

Drainage

The side drainage of the LVSRs was rated on the basis of their Drainage Factor (DF) - the product of the height of the crown of the road above the bottom of the ditch (h) and the horizontal distance from the centerline of the road to the bottom of the ditch (d) (see photo below). The distance d is dependent on the width of the carriageway and shoulders plus the horizontal distance of the side slope plus the half width of the drain whilst the height h is a minimum of 0.75m. The DF is also dependent on whether or not the drains are lined as well as on the longitudinal slope of the road.

Based on their DF's, the LVSRs were rated as either:

(a) moderate-good in those urban/peri-urban sections where the lined drains are on a longitudinal slope

(b) very poor to poor in those sections where there are no drains and the terrain is flat

.

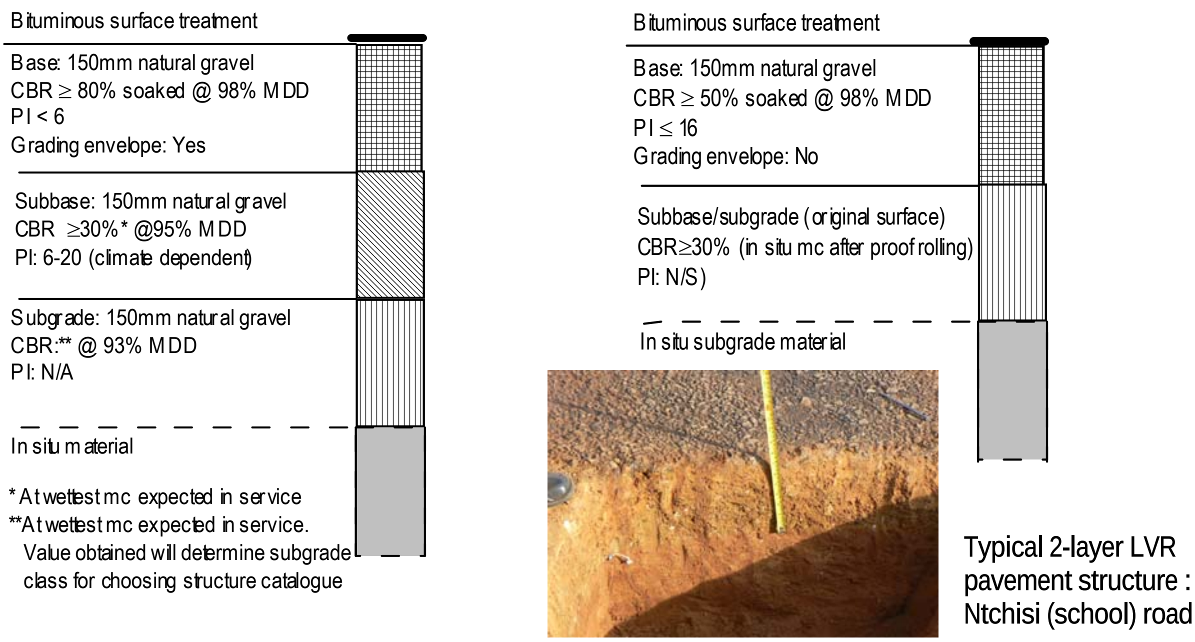
Example of a well-drained pavement (DF > 7.5) (unlined drain)

Bidding documentation

The use of simplified bidding documents using global work items, rather than conventional documents using numerous work items, has been found to be a significant contributory factor to the cost savings offered by the LVSR approach.

Construction

For the relatively low traffic carried, the performance of LVSRs constructed directly on the traffic-consolidated and proof-rolled subgrade, i.e the existing earth running surface (essentially a 2-layer pavement system) was just as good as the traditionally constructed roads having a subbase (essentially a 3-layer pavement system). Thus, the use of a single imported layer of appropriate quality base material on a proof rolled subgrade offers significant cost savings in the construction of LVSRs.



Typical traditional 3-layer pavement structure (left)
and 2-layer LVR structure (right)

A minimum level of quality assurance and control is required with respect to careful selection of natural gravels in borrow pits and attainment of minimum base layer thickness and maximum pavement layer densities. This will ensure that the assumptions on which the designs are based are actually realized during construction.

Costs

There are significant costs savings to be achieved in the construction of LVSRs using the standards and specifications applied on the project roads instead of the traditional standards and specifications embodied in national documents. Based on a comparison of the costs of constructing two adjacent sections of the same (Ntchisi) road constructed to traditional (Class II) and LVR standards respectively, the LVR standard offers the following savings.

Comparison of road costs - LVR versus traditional design standards

Road Design Standard	Typical Construction Cost/km (US$)*	Cost Difference (%)
LVR	150,000	-
Class II	400,000 - 500,000	166 - 233
Class I1	> 500,000	> 233

***** Excludes bridge costs

Standards and Specifications

The results of the investigations have shown clearly that the application of current, traditional standards and specifications to the design of LVSRs can be very conservative, unnecessarily costly and, in the final analysis, inappropriate for application in Malawi. This is manifested in no better way than by comparing two adjacent sections of the Ntchisi road, one of which was constructed to “traditional” standards (Ntchisi-Standard) and the other to “LVR” standards (Ntchisi-LVR) as shown in the photo below.

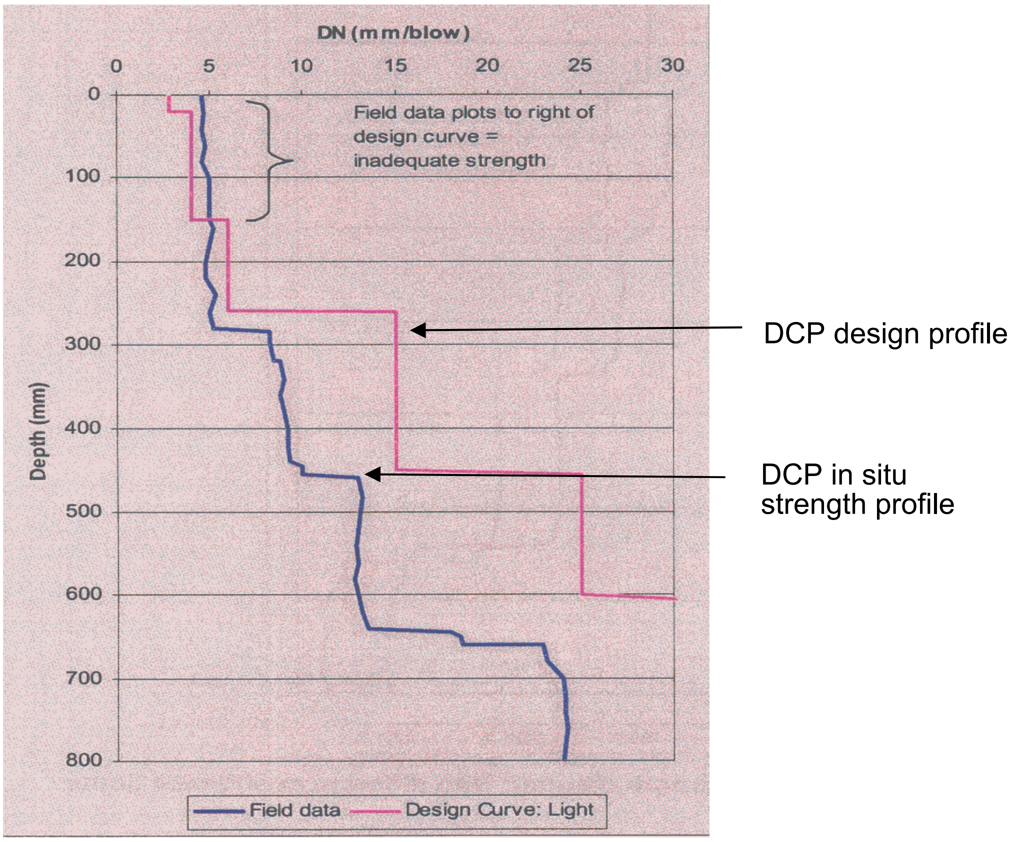
LVR construction

Standard construction

Standard construction (foreground),
LVSR construction (background) - Ntchisi road

As would be evident from the above Photo, in an identical road environment (moisture regime, traffic loading, topography, etc.), there is no discernible difference in structural or functional performance between the 5 years old Ntchisi-Standard and the 8 years old Ntchisi-LVR sections of road. However, there is one major significant difference – that of construction cost which is standard related – with the Ntchisi-Standard section costing more than twice that of the Ntchisi-LVR section.

The 2-layer pavement system adopted in Malawi for the construction of LVSRs should be embodied in a national design standard for LVSRs. The Dynamic Cone Penentrometer (DCP) design method which involves evaluating in situ conditions and integrating the design strength profile optimally with the in situ soil strength profile, is well suited for use in Malawi.



DCP layer strength diagram: Field data versus Master Design Curve

Risk

The adoption of appropriate design standards and specifications for LVSRs does not mean an increased risk of road failure, but, rather, requires a greater degree of pavement engineering knowledge, local experience and judgment which is supported by local investigation and research.

The primary requirements for mitigating against the risk of LVR failure in Malawi are to ensure that the pavements are well drained, construction quality is tightly controlled, high compaction standards are achieved, the road is timeously and effectively maintained and overloading is avoided, all coupled with careful application of the fundamental principles of pavement and material behaviour derived from local and regional research.

Recommendations

New standards and specifications

(1) A new manual for the design and specification of LVSRs in Malawi should be prepared based on the body of local research information that is available from this and previous investigations carried out in Malawi and other countries in the region.

DCP Design Catalogue

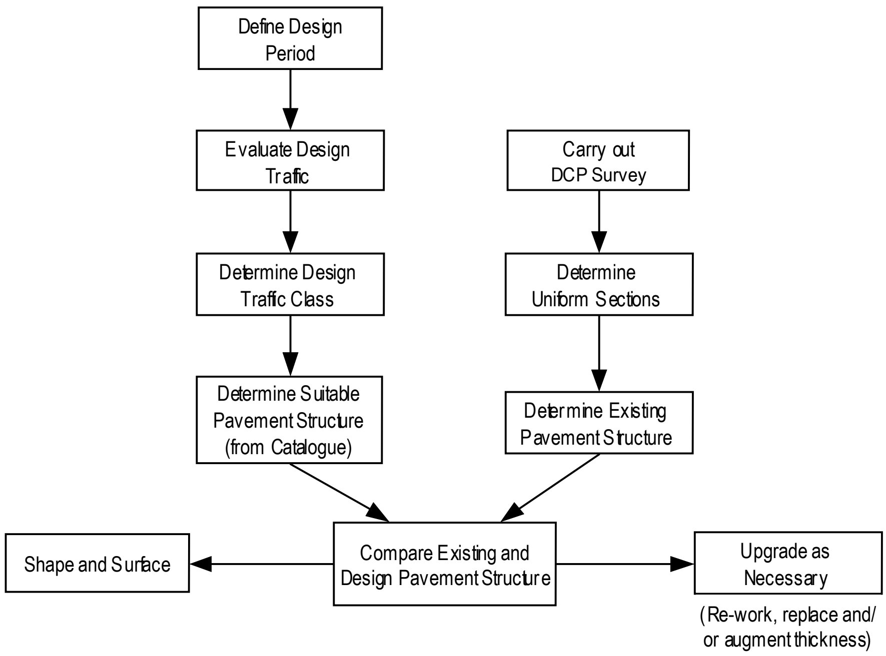
(2) The following DCP design catalogue is recommended for designing LVSRs in Malawi. It has been developed on the basis of investigations on LVSRs carried out in the region and has been calibrated by the results of the DCP measurements undertaken in Malawi.

Pavement design catalogue for different LVR categories

Pavement Class E80 x 10^6	LV 0.01 0.003 – 0.010	LV 0.03 0.010 – 0.030	LV 0.1 0.030 – 0.100	LV 0.3 0.100 – 0.300	LV 1.0 0.300 – 1.000
150mm Base ≥ 98% BSH	DN ≤ 8	DN ≤ 5	DN ≤ 4	DN ≤ 3.2	DN ≤ 2.5
150mm Subbase ≥ 95% BSH	DN ≤ 19	DN ≤ 14	DN ≤ 9	DN ≤ 6	DN ≤ 3.5
150mm subgrade 93% BSH	DN ≤ 33	DN ≤ 25	DN ≤ 19	DN ≤ 12	DN ≤ 6

DN = DCP penetration rate in mm/blow

The recommended DCP design process is illustrated in the flow diagram below. In essence, the design process needs to fit the pavement structure to the in situ conditions on each uniform section of the existing road determined from a DCP design survey. Where the in situ strength is less than the design strength, an imported base layer of appropriate quality and thickness would be required.



Flow diagram of DCP design process

Bidding documentation

(3) Simplified bidding documents with relatively few global work items should be developed that are appropriate for use by medium scale local contractors.

1. INTRODUCTION

1.1 Background Context

1.1.1 Local experience with low volume roads

Most unpaved roads in Malawi carry relatively low volumes of traffic, typically less than 300 vpd. During the past decade, the National Roads Authority has upgraded a number of these unpaved roads to paved standard, using the philosophy enunciated in the SADC Guideline on Low Volume Sealed Roads (SADC, 2003) and a simplified bidding documentation and construction procedure. In essence, these roads comprise a two-layer pavement system in which the existing running surface was proof-rolled and overlaid with a 150mm natural gravel base (soaked CBR of about 60%) compacted to 98% of BS Heavy MDD and surfaced with a bituminous Cape Seal (19mm aggregate and 10mm slurry seal). An example of a typical low volume road pavement is shown in Figure 1-1.

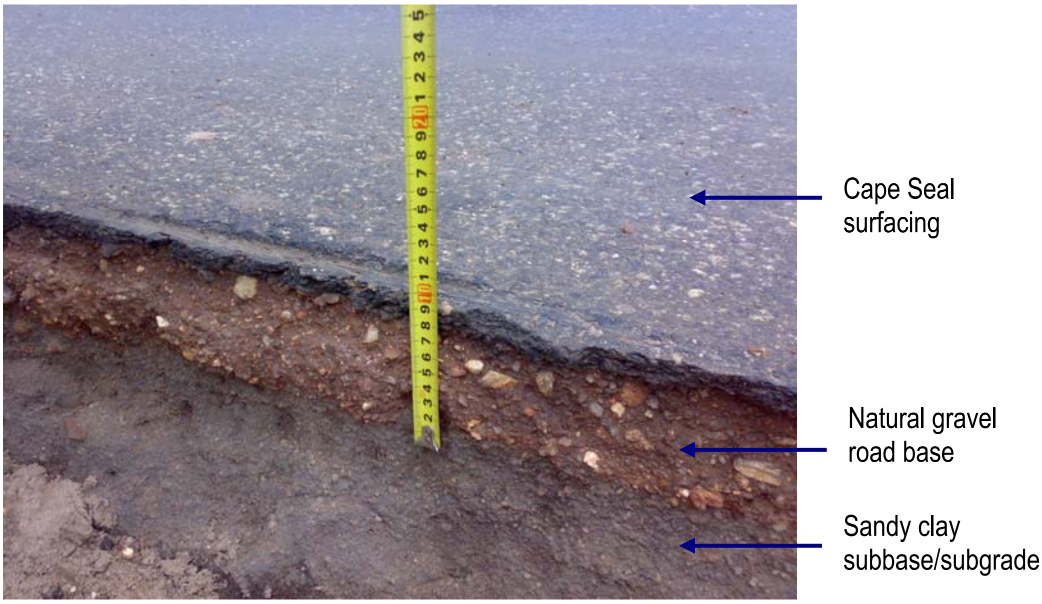


Figure 1-1: Example of typical low volume road pavement in Malawi

The low volume sealed roads (LVSR) in Malawi as described above have generally performed well despite their perceived "non-standard" nature. Moreover, the cost of their provision has been substantially less than similar roads constructed to traditional standards.

Unfortunately, the LVSRs have not been subjected to rigorous technical monitoring and investigations. However, some other "low-cost" roads have been subject to technical monitoring by organisations such as the UK Transport Research Laboratory (TRL), but the outcome of this research is not well known locally and has not been incorporated in national design standards for this class of road. In addition, political decision makers and local consultants are unaware of this body of knowledge, and tend to favour the traditional, and much more costly, design standards that are more appropriate for higher traffic roads.

[1] Low volume roads are defined as those roads which, over their design life, are required to carry an average of up to about 300 vpd and/or less than about 1.0 million equivalent standard axles (ESA) in one direction.

The good performance experienced with the construction of a number of LVSRs in various regions of the country provides a strong motivation for considering the application of this approach to the design of future low volume roads, possibly even for medium traffic volume roads. Most of the unpaved roads in Malawi fall within the low volume road category (less than about 200 vpd), and could be upgraded to a paved standard at significantly less costs than the traditionally designed roads. This approach would also reduce the substantial and costly burden incurred in providing adequate recurrent maintenance of these unpaved roads.

1.1.2 Regional experience with low volume roads

Regional experience in countries such as Botswana, Zimbabwe and South Africa provides additional evidence for a different approach to the provision of sealed, low volume rural roads in Malawi. This approach is encapsulated in the SADC Guideline for Low Volume Sealed Roads. The Guideline calls for a more comprehensive and holistic approach to the use of locally available materials for low volume road construction, as well as appropriate geometric design standards based on extensive research carried out in the region over the past 20 years. The major impacts of adopting such approaches include a reduction of life-cycle costs, a reduction in the continuous exploitation of non-renewable gravel sources, lower vehicle operating costs, environmental benefits due to reduced erosion, and health benefits due to reduced dust.

1.1.3 Need for revised standards and specifications

The Malawi Roads Authority (RA) is now receiving significant resources from development partners and the government for upgrading higher traffic earth and gravel roads to paved standard. Many of these roads have low traffic volumes, with less than 200 vehicles per day. The Malawi Roads Authority requires design standards and technical specifications that are appropriate to this class of road and traffic volumes. These standards and specifications should reflect historical experience in Malawi and the region and be acceptable to political decision makers and local consultants and contractors. The official acceptance of appropriate standards is necessary to ensure their application on a wider scale. The use of appropriate standards will lead to significant cost savings in the initial construction of paved roads, and longer term savings in the overall maintenance requirements of the road network.

1.1.4 Performance review of standards and specifications

The Roads Authority has requested the Africa Community Access Programme (AFCAP) to assist with a Performance Review of Design Standards and Technical Specifications used on existing Low Volume Sealed Roads in Malawi. The project is expected to contribute to greater awareness of the need for appropriate design standards for low volume roads and the benefits that these standards can provide for the local economy. The intention is to gain support amongst key decision makers and practitioners in the sector for a subsequent project which will develop an official design manual, standard specifications for the design and construction of low volume sealed roads and associated relevant standard bidding documents for Malawi.

1.2 Goal, Objectives and Outputs

1.2.1 Goal

The overall goal of the project is to reduce road transport costs in Malawi by promoting rational, appropriate and affordable design for low volume roads that comprise a substantial proportion of the road network in the country.

1.2.2 Objectives

In support of the above goal, the main objectives of the project are to:

(a) Undertake a review of performance of existing low volume sealed roads, existing design standards and specifications used for the construction of low volume sealed roads in Malawi;

(b) Establish an appropriate design methodology and provide recommendations for the development of manuals and other official documentation needed to facilitate the use of appropriate LVSR standards by the road sector in Malawi.

(c) Gain acceptance of the LVSR approach amongst decision makers using an evidence-based approach;

(d) Achieve capacity building and technology transfer amongst staff that have been assigned to the project from the National Roads Authority and the Central Materials Laboratory of the Ministry of Transport and Public Infrastructure.

1.2.3 Outputs

The main outputs of the project are:

(1) Recommended design methodology for LVSRs and recommendations for the development of national design standards and technical specifications for LVSRs in Malawi;

(2) An estimation of the cost savings that can be achieved through the adoption of more appropriate design standards for low volume roads;

(3) Dissemination the study findings through seminars and meetings with key stakeholders in the government, development partners and the private sector.

1.3 Structure of Report

This report is structured as follows:

Section 1: (this section): Provides the background to the project including local and regional experience with LVSRs, the motivation for adopting revised standards and specifications for LVSRs in Malawi and the goal, objectives and outputs of the project.

Section 2: Outlines the general approach that was followed in carrying out the project, the methodology that was adopted and the scope of activities that were undertaken in each of the four stages of work aimed at achieving the requirements of the Terms of Reference.

Section 3: Presents the results, findings and observations arising from the execution of the four stages of the project including the preliminary activities and the field and laboratory investigations.

Section 4: Analyses and discusses the results of the various field investigations and laboratory testing that were undertaken on the roads investigated, taking account, also, of the results of similar work undertaken in the region.

Section 5: Summarises the conclusions and recommendations of the project.

Annex A: Overview of relevant reports on investigation of LVSRs.

2. APPROACH, METHODOLOGY AND SCOPE

2.1 Introduction

The objective of this section is to outline the general approach that was followed in carrying out the project, the methodology that was adopted and the scope of activities that were undertaken to achieve the requirements of the Terms of Reference.

2.2 General Approach

The general approach that was adopted for undertaking the project is illustrated in Figure 2.1. As indicated in the figure, a 4-satge, sequential process was adopted as follows:

- Stage 1 - Preliminary activities
- Stage 2 - Field investigations
- Stage 3 - Laboratory testing
- Stage 4 - Analysis and reporting

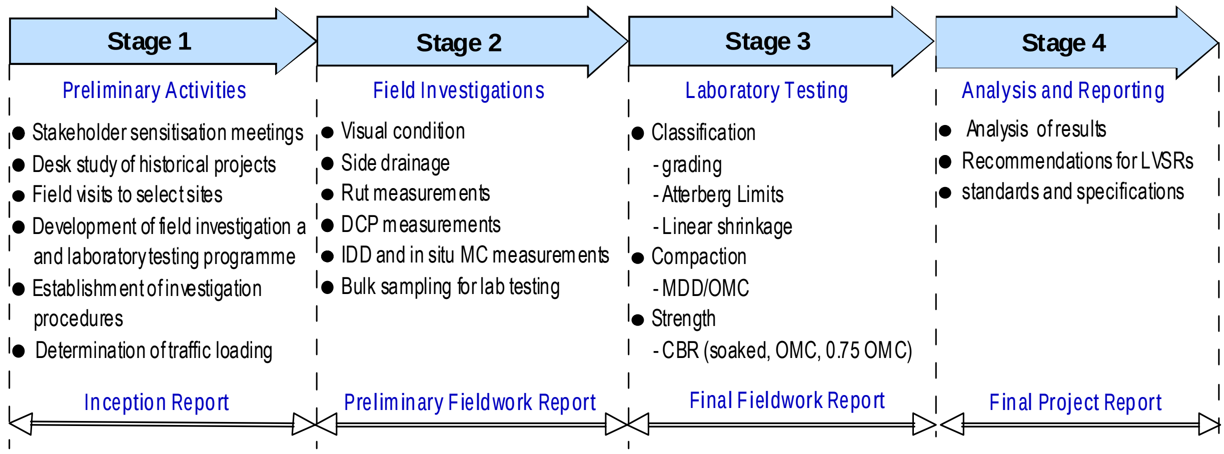


Figure 2.1 – Scoping of project

2.3 Scope

2.3.1 Stage 1 – Preliminary activities

The main objective of Stage 1 was to engender support for the project by sensitizing all stakeholders to the goal, objectives and outputs of the project and highlighting the substantial benefits that could be derived in Malawi from adopting the evidence-based LVSR approach.

Other activities undertaken in Stage 1 included:

- A desk study of historical project reports and technical monitoring reports (where available) concerning low-volume sealed road construction in Malawi;
- Development of a fieldwork programme and schedule of tests to be carried out by the Central Materials Laboratory (CML);
- Field visits to select the road sections to be investigated and initiation of the fieldwork and data collection programme.

2.3.2 Stage 2 – Field investigations

The main objective of Stage 2 was to undertake appropriate field investigations on the project roads in both the wet and dry seasons with a view to obtaining:

(a) an overall appreciation of the road drainage (visual plus cross-section profiles);

(b) the condition of the road surface (in accordance with the *Degree and Extent* method of rating distress parameters);

(c) the structural condition of the pavement (rut depth and DCP measurements);

(d) the pavement layer properties (IDD and MC).

In the event, the field investigations were undertaken in April 2010, just after the end of the rainy season, and in November 2010, towards the end of the dry season. This seasonal difference allowed important comparisons to be made of performance parameters affected by the moisture sensitivity of the pavement materials such as CBR strength and pavement bearing capacity.

2.3.3 Stage 3 – Laboratory testing

The main objective of Stage 3 was to carry out various laboratory tests as indicated in Figure 2.1 in order to determine the grading (PSD), plasticity (PI), compaction (MDD/OMC) and strength (CBR – varying moisture contents) properties of the materials samples obtained from the test pavement layers from each of the test sections.

2.3.4 Stage 4 – Analysis and reporting

The main objective of Stage 4 was to analyse all the results of the field investigations and laboratory testing as a basis for:

- developing recommendations for national design standards and technical specifications investigations;
- estimating the cost savings that can be achieved by adopting more appropriate design standards for low volume roads;
- producing a final report that would serve as the means of disseminating the outcome of the project and gaining acceptance of the LVSR approach amongst various stakeholders in Malawi.

3. RESULTS, FINDINGS AND OBSERVATIONS

3.1 Introduction

The objective of this section is to present the results, findings and observations arising from the four stages of the project in the sequence indicated in Figure 2.1. The outputs of this chapter provide input to Chapter 4 – Analysis and Discussion.

3.2 Stage 1 – Preliminary Activities

3.2.1 Start-up meeting with stakeholders

The following is a summary of the key issues arising from the inaugural meeting with stakeholders from the RA, the Roads Fund Administration, the Ministry of Transport and Public Infrastructure and the Ministry of Local Government and Rural Development.

- A number of LVSRs had been constructed in Malawi with "non-standard" materials dating back over 20 years. They had all performed well. However, no proper records had been kept.
- More recently, experience was gained from the construction of about 20 km of LVSRs using "non-standard" materials on reasonably engineered alignments, adopting a simple approach, viz:
    - Grade/rehabilitate the existing road without unduly affecting the existing pavement and alignment – varying widths for different roads. No upfront, formal design;
    - Take advantage of existing, well-consolidated pavements after many years of traffic compaction and wetting and drying cycles;
    - Place gravel (even marginal) on the reshaped roadbed, compacted to 98% MDD;
    - Surface with a Cape Seal (typically 19mm aggregate plus two 5mm layers of slurry;
    - Use simplified bidding documentation with very few global work items;
    - Use medium scale local contractors.
- Significant cost savings were achieved with the original LVSRs at USD$90,000/km. Currently, such roads could be constructed at about USD$150,000/km compared with about US$500,000/km for Class I roads and about USD$300,000/km for Class II roads.
- All the recently constructed LVSRs had performed extremely well and remain in good condition after 3 to 7 years of trafficking. Some of the roads had carried in excess of 6000 vpd. Theoretically, these roads should have already failed!
- No formal evaluation has so far been undertaken of the LVSRs and no conclusions have been drawn yet.
- Could the AFCAP project provide the FINAL ANSWER?
- The use of "negative" terminology such as "low-cost", "low-volume" "non-standard"; "marginal" materials, etc. had adversely affected some stakeholders' attitudes to LVSRs which were often considered to be "low standard". Need to change mind sets with well documented examples of cost-effective LVSRs, using more "positive" terminology.

- A clear distinction should be drawn between provision of "accessibility" with LVSRs and "mobility" with Class I and II roads. Over-riding need to provide all-weather accessibility to rural communities as cost-effectively as possible – LVSRs just need to be "fit for purpose" with initially relatively narrow roads and appropriate (NOT Class I or II) geometric standards. Due account to be taken of time horizon and anticipated traffic growth in assessing what is an appropriate width for a LVSR.
- Road safety is a very important issue with LVSRs. Accident rates in Malawi are some of the highest in the region. However, recent studies had shown that this was due largely to general driver attitude on all classes of roads rather than due to geometry, particularly narrower width, of LVSRs. Nonetheless, there is a critical need to provide appropriate mitigation measures for the large numbers of pedestrians and cyclists on LVSRs taking due account of rural versus urban/peri-urban environments.

3.2.2 Desk study of historical projects

The following reports were reviewed in detail as they provide a wealth of relevant and well-documented information on LVSRs from Malawi as well as from Botswana and South Africa:

(1) *Malawi Low Volume Roads Study: An investigation into the use of Laterite instead of crushed stone or stabilised material as a base course for bituminous surfaced roads.* Report by Scott Wilson Kirkpatrick & Partners/Henry Grace & partners and Imperial College of Science and Technology, UK. December 1988.

(2) *Collaborative Research Programme on Highway Engineering materials in the SADC Region: Volume 1 – Performance of Low Volume Sealed Roads: Results and Recommendations from Studies in Southern Africa.* Report by Transport Research Laboratory, UK. November 1999.

(3) *Recommendations on the use of marginal basecourse materials in low volume roads in South Africa.* South Africa Dept. of Transport. Research Report RR 91/201. November 1996.

(4) *Analysis of Pavement Monitoring Sections in Botswana.* InfraAfrica (Pty) Ltd./CSIR. Jan. 2010.

In view of the relevance of the above reports to the project, an overview of their objectives and main findings is presented in Annex A.

Although not completely documented, the information available on the LVSR sections constructed by the RA was also reviewed, mostly in terms of the bidding documents used for constructing these roads.

The above reports and documentation from Malawi, plus other documented evidence from a number of countries in the SADC region, as captured in the SADC Guideline on Low-Volume Sealed Roads, all provide compelling evidence of the potential for successfully and cost-effectively using many of the so-called non-standard materials (laterite, quartzite and weathered granite) in the construction of LVSRs that provide both a mobility and an accessibility function. The challenge was to present the evidence in a quantitative, convincing and rationale manner.

3.2.3 Selection of test sections

Following discussions with the RA, site visits were made to a number of LVSRs which entailed travel to the northern, central and southern regions of the country. During the 4000 km trip, over a period of five and a half days, some 14 sites were visited as a basis for selecting a manageable number for detailed investigation.

Following the site visits, a number of criteria were used to select the final list of projects for investigation. These criteria included consideration of the following:

- A range of climatic conditions
- A range of material types
- Coverage of as much of the country as possible
- A range of traffic volumes

Based on the above criteria, Table 3-1 lists the LVSR roads that were selected for detailed investigation:

Table 3-1: List of sealed LVSRs roads selected for detailed investigation

Region	Road Section	Date of Construction	Base Type
Central	Ntchisi (School) Ntchisi (Hospital) Ntchisi (Standard)*	2002 2002 2006	Laterite
Central	Dowa Boma	2004	Weathered granite
Northern	Rumphi Boma	2004	Weathered granite
Southern	Cape Maclear	1985	Quartzitic gravel
Central	Lilongwe ABC road	1985	Quartzitic gravel

* This section was constructed in the traditional manner as a 3-layer pavement system using conventional design standards and specifications and is contiguous with the LVSR sections.

As indicated in Figure 3-1, the road sections are located in areas where the annual rainfall falls in the range 600 – 1200 mm. In terms of the Weinert 'N' value, a climatic index that has been found to correlate well with the macro climate, as well as the Thornthwaite Moisture Index I_m, which gives an indication of the overall availability of moisture during the year (in arid or dry areas I_m will be negative whilst in more humid areas I_m will be positive) the project roads fall within the relatively wet sub-humid and humid climatic zones (Table 3-2).

Table 3-2: Climatic zones: Approximate mean annual rainfall, N-Values and Thornthwaite Moisture Index

Descripton	Typical Mean Annual Rainfall	Weinert N Value	Thornthwaite Mositure index (I_m)
Arid	< 250mm	5+	< -40
Semi-arid	250 - 500mm	4 – 5	-20 to -40
Semi-arid to sub-tropical	500 - 1000	2 – 4	0 to +20
Humid tropical	> 1000mm	< 2	+20 to +100

The Weinert N-values and climatic zones provide an important insight into the properties and engineering characteristics of naturally occurring materials that occur in the southern African region. This facilitates a clear understanding of the likely behaviour of these materials in particular climatic environments and allows practitioners to design and construct LVSRs with a greater degree of confidence in a wide range of circumstances.

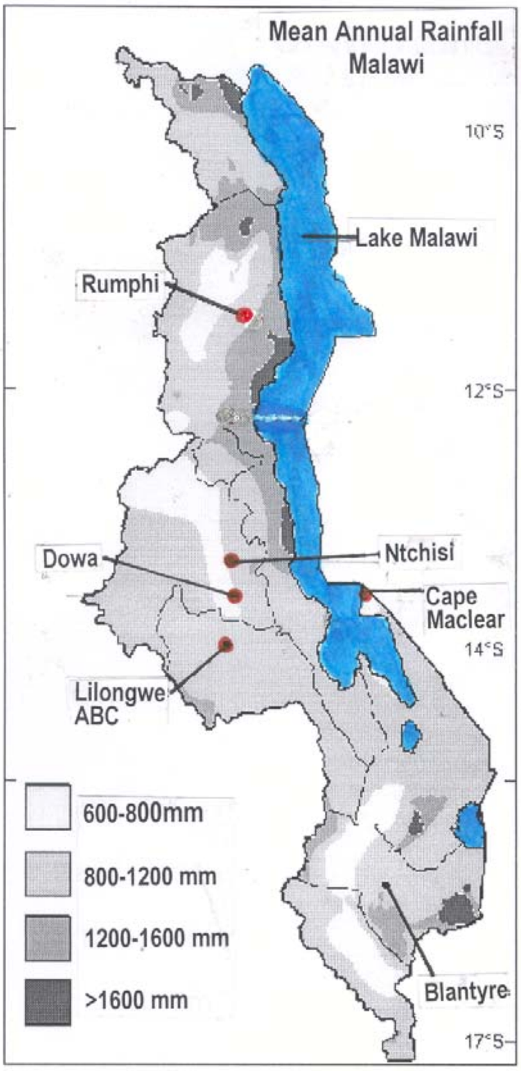


Figure 3-1: Mean annual rainfall map showing location of road sections

In addition to the LVSR sections, the roads listed in Table 3-3, which were monitored and reported upon previously by TRL, still exist in-tact, and were selected for updating in terms of traffic and condition (via rutting measurements). These roads were all constructed as a traditional 3-layer system, but the materials used did not comply with traditional standards.

Table 3-3: List of TRL-monitored roads selected for review

Region	Road Section	Date of Construction	Base Type
North	Kasungu-Mzimba	1982	Laterite
Central	Lilongwe-Mchinji	1980	Laterite
South	Liwonde-Zomba	1972	Laterite

3.2.4 Development of field investigation and laboratory testing programme

In discussion with the RA, a fieldwork and laboratory testing programme was developed with the objective of investigating the selected test sections in terms of their performance, and determining the engineering properties and characteristics of the road materials as follows:

(a) Field investigations

- Road monitoring (new sections constructed by RA)
    - in situ moisture content (from test pit in outer wheel path)
    - in situ dry density (IDD) (in test pit)
    - rutting (outer wheel path)
    - DCP's (inner and outer wheel paths)
    - Bulk sampling for laboratory testing

The plan layout of the field investigations is shown in Figure 3.2

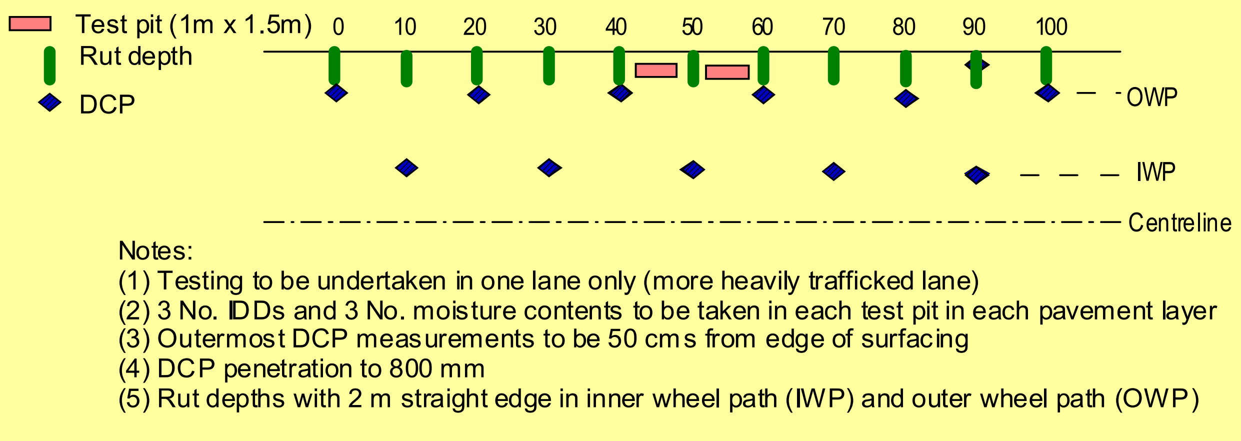


Figure 3.2 – Field testing programme

(b) Laboratory testing

- Testing (on material extracted from the pavement layers)
    - Classification (Atterberg Limits – PL and LL to determine PI)
    - Shrinkage
    - Grading
    - MDD/OMC (with CBR at each moisture content point)
    - CBR (soaked, OMC and 0.75 OMC)

3.2.5 Establishment of investigation procedures

The objective of this activity was to establish and agree the procedures to be followed by the Central Materials Laboratory (CML) in carrying out the pavement investigations of all the test sections. To this end, the Ntchisi Boma road (school section) was chosen for demonstration purposes. The focus of attention on this section was the opening up of a test pit for determination of the IDD and moisture content in each pavement layer, the extraction of a bulk sample from each pavement layer for laboratory testing and the re-instatement of the test pit. Photos 2.1 and 2.2 illustrate aspects of this activity.

Photo 3-1: Marking of test pit area prior to removal of surfacing and commencement of sampling and in situ testing

Photo 3-2: Excavation of test pit to top of subbase/subgrade layer prior to undertaking IDD and MC tests

3.2.6 Assessment of traffic loading

The nature and volume of the traffic using the project roads are significant parameters that influence their performance. In this regard, the cumulative number of passes of an "Equivalent Standard Axle" (ESAs) is a direct determinant of the life expectancy of the pavement structure of these roads. For these reasons, it was necessary to determine the cumulative ESAs carried to date by the road sections as a basis for assessing their proven, and estimating their future, traffic carrying capacity.

Ideally, the determination of the total cumulative ESAs carried by a road since its construction would be based on historic, classified traffic counts from the date of construction of the road sections coupled with a knowledge of both the vehicle equivalence factors (the no. of ESAs/vehicle - derived from axle load surveys or based on national average values) and the traffic growth rate by vehicle type.

The only traffic data available for the project roads was from a special 7-day count that was undertaken in 2010. This information has been used as the basis for back-calculating the cumulative ESAs carried by the roads since their construction. The vehicle equivalence factors used for converting the HV AADT to cumulative ESAs, as well as the HV traffic growth rates assumed over the life of the project roads is presented in Table 3-4.

Table 3-4: Assumed VEFs and HV growth rates

Heavy Vehicles		Average ESA/Vehicle*	Growth rate (%) by years		
Classification	**Description**		**1-5**	**6-10**	**11-15+**
LGV	2-axle truck	0.70	3	4	5
Bus	2-axle bus	0.75	3	4	5
MGV	3-axle truck	1.75	2	3	4
	4-axle truck				
HGV	5-axle truck	2.80	1	2	3
	6-axle truck				

* Based on power exponent, n, of 4.2.

Results

(a) **AADT:** The 2010 AADT of the project is shown Table 3-5.

Table 3-5: 2010 traffic counts on project roads

Road Section	Year of Traffic Count	2010 AADT of Project Roads													
		Motorised Traffic									Non-Vehicular & Non-Motorised Traffic				
		Cars	Pick-up	4WD	Mini-bus	LGV	Bus	MGV	HGV	AADT	Tractor	Motor Cycle	Bicycle	Animal Cart	AADT
Ntchisi	2010	87	28	37	2	27	0	1	0	182	1	18	201	0	220
Dowa	2010	96	54	107	49	60	41	35	33	475	11	38	715	0	764
Rumphi	2009		502		155	75	19	35	4	790	0	-	430	0	430
C. Maclear	2010	28	23	32	8	18	0	4	0	113	0	18	428	0	446
Lilongwe	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Traffic categories contributing to ESA loading. * No data available

(b) **Cumulative ESAs**

Based on the 2010 AADTs (Table 3-5) and the assumed VEFs and HV growth rates (Table 3-6), the estimated cumulative ESAs for the project roads are shown in Table 3-6. Since the project roads are all 2-lane roads, and based on the assumption that both lanes are carrying approximately the same volume of traffic, a distribution factor of 0.5 would be appropriate for pavement evaluation purposes. However, in order to take account of the uncertainty of such factors as the base AADT, ESA growth rate and VEFs a sensitivity factor of +/- 50% has been applied to the base cumulative ESAs to allow minimum and maximum scenarios to be analysed.

Table 3-6: Cumulative ESAs on project roads

Road Section	Service Period (Yrs)	Cumulative ESAs (both directions)					Cum MESA (one direction)	
		LGV	Bus	MGV	HGV	Total	Mean	Range
Ntchisi	8	48,921	-	4,690	-	53,611	0.026	0.013-0.040
Dowa	6	85,354	64,062	127,607	197,364	474,387	0.237	0.118-0.355
Rumphi	6	106,689	29,687	127,606	23,923	287,905	0.143	0.072-0.216
C. Maclear	25	72,528	0	45,880	0	118,108	0.118	0.059-0.177

* No data available

Findings and observations:

The project roads can all be defined as “low volume” roads in that although their ADT in some cases (Dowa and Rumphi) exceeds 300 vpd, the traffic loading carried in service is less than 0.5 million ESAs *in one direction*.

The volume of non-motorised traffic, particularly in the form of bicycles, is significant and in most cases (except for Rumphi) is far higher than the motorized traffic. Whilst non-motorised traffic has a negligible effect on the structural performance of the project roads, it is of paramount importance as regards road safety and the critical importance of catering for such traffic within the road cross section. This issue is considered further in Section 5.

3.3 Stage 2 – Field Investigations

3.3.1 Visual condition

A visual condition survey was carried out for each of the LVSR sections as well as the Ntchisi standard section with a view to ascertaining their condition (good, fair or poor). This condition was assessed in accordance with the Degree and Extent method of rating distress parameters (Botswana Roads Department, 2000) which may be summarized as follows:

(a) *Good/Sound:* Distress is difficult to discern visually. Isolated occurrence of distress which is not representative of the section being evaluated.

(b) *Fair/warning:* Distress is notable with respect to possible consequences. Intermittent occurrence of distress over most of the section being evaluated or extensive occurrence over a limited portion of the section.

(c) *Poor/severe:* Distress is extreme with respect to possible consequences. Extensive occurrence.

Results: On the basis of the above rating system, the condition of the various sections was determined as summarized in Table 3-7.

Table 3-7: Road condition rating

Road Section	Pavement Condition Rating		
	Good/Sound	Fair/Warning/	Poor/Severe
Ntchisi Boma	X		
Ntchisi (Standard)*	X		
Dowa Boma	X		
Rumphi Boma	X		
Cape Maclear	X		
Lilongwe ABC road	X		

Findings and observations: As indicated in Table 3-7, all of the road sections investigated were assessed to be in good/sound condition. Photos 3-3 and 3-4 provide typical examples of the good/sound condition of all the LVSR sections that were investigated.

Photo 3-3: Ntchisi road (school) - constructed in 2002
Condition: Good/sound

Photo 3-4: Dowa road – constructed in 2004
Condition: Good/sound

3.3.2 Side drainage

Side drainage is one of the most important factors affecting pavement performance. Such drainage may be quantified in terms of a "drainage factor" which is the product of the height of the crown of the road above the bottom of the ditch (h) and the horizontal distance, d, from the centerline of the road to the bottom of the ditch (Figure 3-3) (TRL, 2002). The minimum desirable value of h is 0.75m (derived from performance-related surveys – TRL 1996), whilst the horizontal distance d is related to the width of the paved carriageway plus shoulder (d3), the horizontal component of the side slope (d2) (side slope typically 1:3) and the half width of the trapezoidal drain (d) (see Figure 3-3.

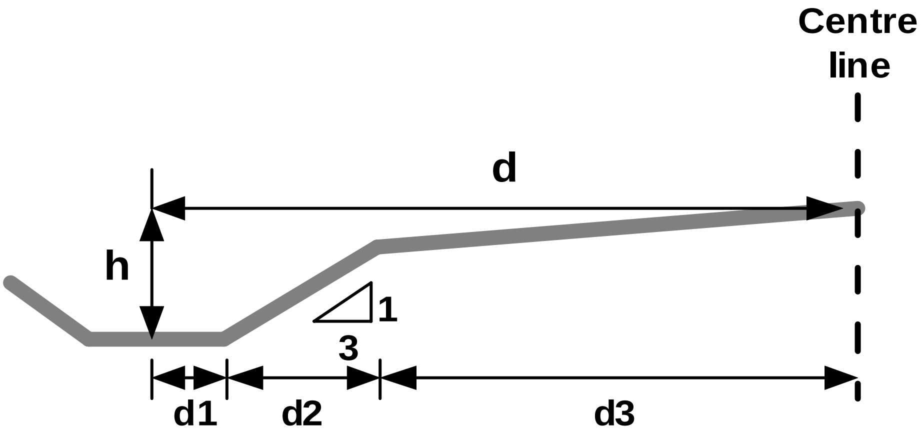


Figure 3-3: Drainage parameters for classifying side drainage

Based on a range of values of d and a minimum value of h of 0.75m, the classification of road drainage for LVSRs in terms of their drainage factor is presented in Table 3-8.

Table 3-8: Classification of road drainage

Drainage parameters		Drainage Classification by Drainage Factor DF (= d x h)			
d (m)	**h (m)**	**Good**	**Moderate**	**Poor**	**Very Poor**
10.00	0.75	≥ 7.5	5.1 – 7.5	2.6 – 5.0	≤ 2.5
9.50	0.75	≥ 7.1	4.8 – 7.1	2.5 – 2.7	≤ 2.4
9.00	0.75	≥ 6.8	4.6 – 6.8	2.4 – 4.5	≤ 2.3
8.50	0.75	≥ 6.4	4.4 – 6.4	2.2 – 4.3	≤ 2.1
8.00	0.75	≥ 6.0	4.2 – 6.0	2.1 – 4.1	≤ 2.0

Photo 3-5 is an example of a well-drained pavement where the drainage is classified as "good", i.e. the drainage factor DF (d x h) > 7.5.

Photo 3-5: Example of a well-drained pavement (DF >7.5) (unlined drain)

The drainage classification system presented in Table 3-8 applies to unlined drains which is typically the case with LVSRs in the rural rural areas of Malawi. However, in urban or peri-urban areas, the drains are often lined in which case the drainage classification should move up one class. In addition, where the longitudinal gradient is greater than one per cent, the drainage classification should also move up one class. Thus, for a LVSR with lined drains situated in rolling terrain with a longitudinal gradient of > 1%, the unlined drainage factor should move up two classes as would be the case with the section of the Ntchisi road shown in Photo 3-6.

Results: The drainage parameters, h and d as defined above, were measured at 10m intervals on both sides of all of the road sections. The results of these measurements allowed the Drainage Factor to be determined for each of the road sections as shown in Table 3-9.

Table 3-9: Drainage classification of road sections

Road Section	Drainage Classification			
	LHS		RHS	
	Unlined	Lined*	Unlined	Lined*
Ntchisi	Very Poor-Poor	Moderate-Good	Very Poor-Poor	Moderate-Good
Dowa	Very Poor-Poor	Moderate-Good	Very Poor-Poor	Moderate-Good
Rumphi	Very Poor-Poor	Moderate-Good	Very Poor-Poor	Moderate-Good
Cape Maclear	Very Poor-Poor	Moderate-Good	Very Poor-Poor	Moderate-Good

* Generally on longitudinal slopes > 1%

Findings and observations: As indicated in Table 3-9, and illustrated in Photos 3-6 and 3-7, which are generally representative of all the road sections, drainage is rated as either:

(c) moderate-good in those urban/peri-urban sections where the lined drains are on a longitudinal slope (see Photo 3-6), or

(d) very poor to poor in those sections where there are no drains and the terrain is flat (see Photo 3-7).

It is also noteworthy from Photo 3-6, that the bituminous surfacing does not extend across the full width of the carriageway in those road sections with lined drtains, leaving an unsurfaced, approximately 50cm, strip between the edge of the surfacing and the drain. This strip is used as a walkway by pedestrians and, with constant use, gradually becomes rutted and acts as a catchment for rain water. During the rainy season, this depression could facilitate lateral infiltration of water into the outer wheel path of the road which increases the moisture content of the pavement materials and reduces their shear strength which could adversely affect the performance of the pavement. Such a situation should be avoided and measures for doing so are discussed in Section 5.

Photo 3-6: Brick-lined drain on longitudinal gradient of peri-urban section of the Ntchisi (school) road.

Photo 3-7: Poorly drained section of the Ntchisi (school) road.

3.3.3 Rut depth

Rutting – the formation of longitudinal depressions that form in the wheel path of a road under traffic loading - is one of the principal ways in which the road fails. Measuring rutting gives a direct indication of the structural condition of the road. For this reason, a rut depth survey was carried out in the more heavily loaded lane of each of the road sections with the objective of determining the degree and extent of the occurrence of rutting in the outer wheel path of the road. The survey was carried out at 10m intervals using a 2m straightedge (see Photo 3-8).

Photo 3-8: Rut depth measurement: Ntchisi (standard) road

The rutting of the various road sections was assessed in accordance with the Degree and Extent method of rating distress parameters which may be summarized as follows:

- Low < 10 mm
- Moderate 10 – 15 mm
- Severe > 15 mm

Results: The results of this survey are summarized in Table 3-10.

Table 3-10: Results of rut depth survey

Road Section	Rut Depth (mm)	
	Mean Value	Range
Ntchisi (LVSR)	3.1	2 - 4
Ntchisi (Standard)	3.8	0 - 8
Dowa	3.7	0 -12
Rumphi	4.4	2 - 6
Cape Maclear	2.9	1 - 4
Lilongwe ABC road	2.6	0 - 7

Findings and observations: As indicated in Table 3-10, rutting to date on all the road sections is very low. This is reflective of pavement which is sound condition and has not suffered from compaction or shear deformation in service through the actions of traffic which might otherwise indicate the presence of a structural problem.

3.3.4 Dynamic Cone Penetrometer (DCP) measurements

The DCP instrument measures the penetration per blow into a pavement through each of the different pavement layers. This penetration is a function of the in situ shear strength of the material. The profile in depth thereof gives an indication of the in situ properties of the materials in all the pavement layers down to the depth of penetration, typically 800mm (see Figures 3-4 and 3-5). Research has shown that a good correlation exists between DCP measurements and the well known CBR of materials (Kleyn and Van Heerden, 1983).

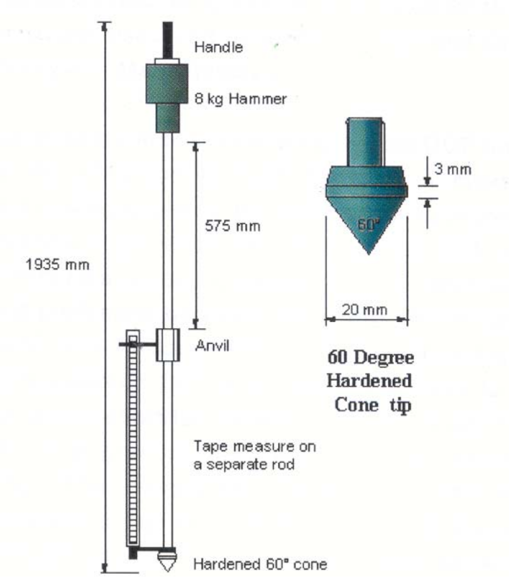


Figure 3-4: The Dynamic Cone Penetrometer

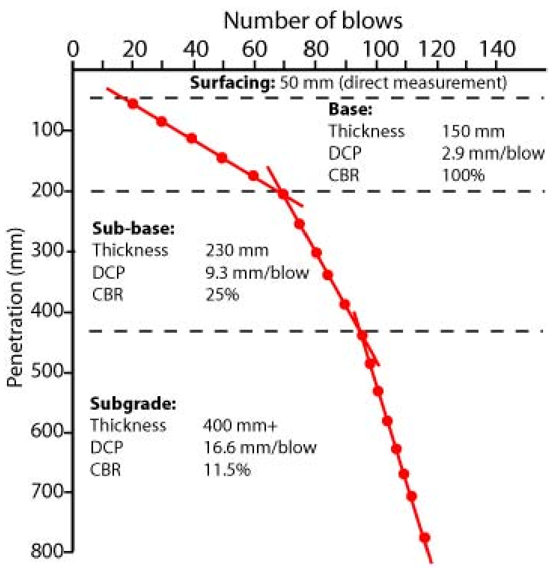
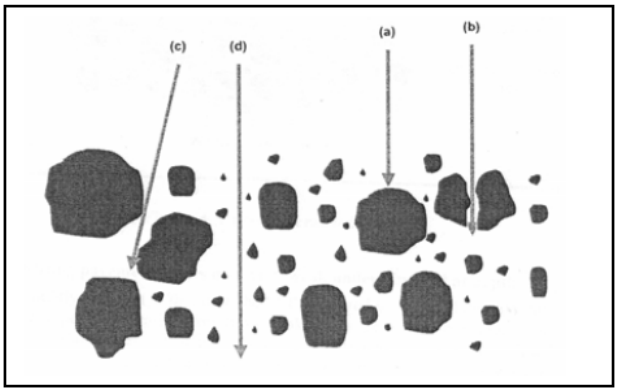


Figure 3-5: Typical DCP plot

Care was exercised in interpreting the results of the DCP tests by omitting any anomalous results which could arise for a variety of reasons, particularly where large stones occur in the pavement layer as illustrated in Figure 3.6.



Typical DCP effects with large stones in pavement layer:

(a) cone cannot penetrate at all and the test needs to be re-done;

(b) cone breaks stone but penetration is uncharacteristically hard and DSN_{800} is high;

(c) cone tries to push stone aside. Result is high because of side friction generated on cone shaft;

(d) Usually provides a normal result

Figure 3.6 – Typical DCP effects with large stones in pavement layer

DCP measurements were undertaken at 20 m intervals in both the outer and inner wheel paths as indicated in Figure 3-1. The key parameters obtained from the DCP measurements are presented below in order to explain the basis on which the results were interpreted.

(a) **Pavement balance:** Normally, the strength of the pavement decreases with depth and, in principle, if this decrease is smooth and without discontinuities, the pavement is regarded as balanced. Ideally, a perfect strength-balanced pavement would exhibit a deep, well balanced structure in which the upper (stronger) layers contribute a relatively higher proportion of the total strength of the pavement than the lower (weaker) layers. In order to group together pavements with similar characteristics, they can be categorised into any one of nine pavement-strength categories as given in Table 3-11.

Table 3.11 – DCP pavement balance categories

Pavement Type (DCP Category)								
Deep			Shallow			Inverted		
Well balanced (WBD)	Averagely balanced (ABD)	Poorly balanced (PBD)	Well balanced (WBS)	Averagely balanced (ABS)	Poorly balanced (PBS)	Well balanced (WBI)	Averagely balanced (ABI)	Poorly balanced (PBI)

(b) **DN value:** The **DN** value is the *average* penetration rate in mm/blow of the DCP in a pavement layer and applies to granular materials as originally developed by Kleyn (Kleyn and Van Heerden, 1983). Thus, a DN_{150} value of 2.5 mm represents the average penetration rate of 2.5 mm/blow in a 150 mm pavement layer.

(c) **DSN_{800} value**: This is the total number of blows required to penetrate the pavement to a total depth of 800 mm. This parameter allows pavements of relatively high and relatively low strength to be distinguished from each other and for the structural capacity of the pavement in ESAs to an additional rut depth of 20 mm to be estimated.

Results: The results obtained from the DCP measurements undertaken at each test pit location in both the outer and inner wheel paths have been statistically analysed using the CSIR WIN DCP programme Ver. 5.1 (Average Analysis option for all the DCP results obtained for a particular section). The results of this analysis for the in situ pavement structure are summarized in Table 3.12 for the following assumed parameters:

- Selected DCP Design Curve: Light traffic = < 0.2 MESA
  Medium traffic = 0.2 – 0.8 MESA
  Heavy traffic = 0.8 – 12 MESA
- Road category: C (Relatively lightly trafficked rural road)
- Base type: Granular
- Moisture condition of base: Optimum (based on in situ moisture measurements)

Table 3-12: Results of DCP measurements on paved road sections

Road Section	DSN_{800}	Pavement Balance	Ave DCP CBR		80%ile DN		Est. Traffic (MESA)*
			0-150mm	150-800mm	0-150mm	150-800mm	
Ntchisi	94	ABD	45	20	9.2	22.2	0.03
Dowa	129	WBD	47	30	9.0	14.0	0.24
Rumphi	272	ABI	123	57	6.0	7.8	0.14
C. Maclear	174	WBD	97	28	5.0	11.6	0.06

* Estimated cumulative traffic already carried in one direction.

Findings and observations: The results of the DCP measurements indicate a distinct difference in pavement characteristics in terms of both the bearing capacity (as indicated by the DSN_{800} parameter) and the DCP CBRs. Both the Ntchisi and Dowa roads exhibit similar characteristics which are quite different to the more substantial bearing capacity and strength characteristics of the Rumphi and Cape Maclear roads. The former roads appear to be more reflective than the latter of the concept of “low volume” roads in terms of bearing capacity and material quality – a finding that will be taken into account in Chapter 4 which deals with the analysis of all the results of the pavement investigations.

It is also apparent that the DCP CBRs at the prevailing pavement IDD and MC in both the base and subbase/subgrade layers are well below the traditional strength requirements normally specified for such roads. The significance of these findings is discussed further in Section 4 of the report.

3.3.5 In situ dry density (IDD) and field moisture content

In situ dry density and field moisture contents were undertaken in both the base and subbase/subgrade layers. The IDD of the base layer was undertaken by the sand replacement method whilst that in the subbase/subgrade was determined by the core cutter method as shown in Photos 3.9 and 3.10 below.

Photo 3-9: Determination of the IDD of the base layer by the sand replacement method.

Photo 3-10: Determination of the IDD of the subbase/ subgrade layer by the core cutter method.

Samples were taken in triplicate from both the base and subbase/subgrade layer, placed and sealed in plastic bags and transported to the CML offices for subsequent content determination. Care was taken to ensure that these samples were representative of grading of the full depth of each layer.

Results: The results of the IDD and in situ field moisture content (FMC) determinations (mean value of triplicate measurements) are shown in Tables 3-13 and 3-14 respectively. These parameters provided the input for determining the relative compaction (RC) and the Field Moisture Content/Optimum Moisture Content (FMC/OMC) ratios which are presented and discussed in Section 4.

Table 3-13: Results of IDD determinations

Road Section	Pavement Layer	In situ Dry Density (kg/m^3)
Ntchisi (School)	Base SB/SG	1852 1712
Ntchisi (Hospital)	Base SB/SG	1869 1790
Ntchisi (Standard)	Base SB SG	1989 1999 1870
Dowa	Base SB/SG	1870 1730
Rumphi	Base SB/SG	1928 1857
Cape Maclear	Base SB/SG	1948 1753

Results: The IDD results in themselves are not very significant, other than as a means of determining the more important relative compaction parameter which is presented and discussed in 3.3.2.

Table 3-14: Results of in situ moisture content determinations

Road Section	Pavement Layer	Location	Mean Field Moisture Content (%)	
			Wet Season	Dry Season
Ntchisi (School)	Base	OWP IWP	8.9 3.0	7.2 10.6
	Subbase/Subgrade	OWP IWP	15.6 12.1	11.2 13.2
Ntchisi (Hospital)	Base	OWP IWP	- -	9.9 10.1
	Subbase/Subgrade	OWP IWP	- -	10.4 12.1
Ntchisi (Standard)	Base	OWP IWP	6.9 3.9	6.4 7.0
	Subbase	OWP IWP	8.5 7.3	10.8 11.4
	Subgrade	OWP IWP	9.0 8.2	11.1 11.5
Dowa	Base	OWP IWP	6.0 5.0	10.5 9.0
	Subbase/Subgrade	OWP IWP	12.7 11.2	12.9 11.6
Rumphi	Base	OWP IWP	6.3 4.3	3.4 4.2
	Subbase/Subgrade	OWP IWP	7.3 6.3	4.4 4.8
Cape Maclear	Base	OWP IWP	4.5 2.8	2.2 3.8
	Subbase/Subgrade	OWP IWP	8.1 4.6	4.1 4.5

Findings and observations: The following general trends may be discerned from the in situ moisture content measurements:

1 During the wet season, the OWP moisture content in all pavement layers is higher than that of the IWP, with the converse occurring in the dry season, i.e. the OWP moisture content is lower than of the IWP.

2 In both the wet and dry seasons, the moisture content of the upper (base) layer is lower than the lower (subbase/subgrade layers).

3 The moisture contents in all layers of those sections located in the relatively dry areas of the country (Cape Maclear) are generally lower than those sections located in the wetter regions of the country (Ntchisi, Dowa, Rumphi).

4 The above findings are to be fully expected. However, their significance can only be appreciated when viewed in the context of the pavement service conditions in terms of their FMC/OMC ratios, particularly in the wet season, as discussed in Section 4.

3.3.6 Bulk sampling for laboratory testing

During this stage of the investigations, a sufficient volume of material was taken from both the base and subbase/subgrade layers to allow the full range of laboratory tests indicated in Section 3.2.4 (b) to be undertaken (see Photos 3-11 and 3-12). The results of the laboratory testing are presented in Section 3.4 below.

Photo 3-11: Sampling of base material following completion of in situ testing

Photo 3-12: Sampled base material for transport to laboratory for testing

3.4 Stage 3 – Laboratory Investigations

3.4.1 Classification

Limits are normally set for such soil classification parameters as grading and Atterberg Limits (LL and PI) for the various layers of a pavement as they are believed to provide a reliable indication of the inherent properties of the materials and their likely behaviour when incorporated in a road pavement.

The results of the classifications tests carried out on samples extracted from the upper layers of the project roads are summarized in Table 3-15 which also shows the specification requirements employed in Malawi (based on the UK Overseas Road Note 31 (TRL, 1997) which is normally used for pavement design purposes.

Table 3-15: Results of classification tests

Road Section	Pavement Layer	Soil Parameter									
		P425		P075		Max. LL		Max. PI		Max. PM	
		Value	ORN31	Value	ORN31	Value	ORN31	Value	ORN31	Value	ORN31
Ntchisi (School)	Base	46	10 – 30	30	5 - 15	36	-	16	6	736	90
	SB/SG	80	10 - 60	52	5 - 25	38	35 – 55[1]	19	6 – 20[2]	1520	-
Ntchisi (Hospital)	Base	61	10 – 30	36	5 - 15	33	-	16	6	976	90
	SB/SG	82	10 - 60	52	5 - 25	42	35 - 55	19	6 – 20[2]	9.3	-
Ntchisi (Standard)	Base	47	10 – 30	17	5 - 15	NP	-	NP	6	-	90
	Subbase	54	10 – 60	30	5 – 25	30	35 – 55	14	6 – 20[2]	756	-
	Subgrade	59	-	31	-	35	-	18	-	1062	-
Dowa	Base	41	10 – 30	29	5 - 15	43	-	17	6	697	90
	SB/SG	80	10 - 60	45	5 - 25	34	35 - 55	13	6 – 20[2]	1040	-
Rumphi	Base	31	10 – 30	15	5 - 15	32	-	18	6	558	90
	SB/SG	43	10 - 60	22	5 - 25	NP	35 - 55	NP	6 – 20[2]	-	-
Cape Maclear	Base	37	10 – 30	19	5 - 15	24	-	14	6	518	90
	SB/SG	29	10 - 60	21	5 - 25	35	35 - 55	16	6 – 20[2]	464	-

1- Depends on climate. For moist tropical/wet tropical (annual rainfall > 1000mm) LL <35; for seasonally wet tropical (annual rainfall 500 – 1000mm) LL < 45; for arid/semi-arid (annual rainfall < 500mm) LL < 55.

2- Depends on climate: For moist tropical/wet tropical (annual rainfall > 1000mm) PI <6; for seasonally wet tropical (annual rainfall 500 – 1000mm) PI < 12; for arid/semi-arid (annual rainfall < 500mm) PI < 20.

Indicates results that are non-compliant with the ORN 31 specifications

Findings and observations: The following general trends may be discerned from the soil classification measurements:

1- Most of the materials used in the pavement layers of the project roads are non-compliant with the ORN 31 grading requirements for P425 and P075.

2- All the materials used in the pavement layers of all the project roads comply with the LL requirements for the road base.

3- All the materials used in the base layer of the project roads, except for Ntchisi (standard), are non-compliant with the ORN 31 requirements and almost all of the materials used in the subbase/subgrade layers of the project roads, except for Ntchisi (standard) and Rumphi, are non-compliant with respect to PI.

4- All the materials used in the pavement layers of all the project roads are vastly non-compliant with the ORN 31 requirements for plasticity modulus (PM).

In summary, although the materials used in the pavement layers of the project roads are generally non-compliant with the traditional grading and plasticity specifications of ORN 31, they have, nonetheless, performed well since construction and show no significant signs of any distress in the prevailing service environment. This finding is supported by a growing body of evidence not only from other similar projects in Malawi, e.g. the TRL sections referred to at the end of Section 3.2.3, but also regionally and internationally.

3.4.2 Compaction

Adequate compaction of the pavement layers in terms of their relative compaction (IDD/MDD) as well as the moisture environment in which they operate (FMC/OMC ratio) are critical factors that affect the long term performance of road pavement.

Results: The results of the laboratory compaction tests (MDD/OMC) as well as the derived RC (IDD/MDD) and FMC/OMC ratios are shown in Tables 3-16 and 3-17 respectively.

Table 3-16: Results of compaction tests

Road Section	Pavement Layer	MDD (Kg/m^3)	OMC (%)
Ntchisi (School)	Base SB/SG	1916 1814	11.2 12.3
Ntchisi (Hospital)	Base SB/SG	1920 1810	9.6 11.0
Ntchisi (Standard)	Base SB SG	2059 2007 2080	8.1 10.0 7.8
Dowa	Base SB/SG	1941 1854	10.7 15.7
Rumphi	Base SB/SG	2060 2057	8.8 9.8
Cape Maclear	Base SB/SG	2053 1996	7.8 8.2

Table 3-17: Results of RC and FMC/OMC determinations

Road Section	Pavement Layer	Relative Compaction (%)	FMC/OMC		
			Location	Wet Season	Dry Season
Ntchisi (School)	Base	96.7	OWP	0.76	0.62
			IWP	0.27?	0.91
	SB/SG	94.4	OWP	1.02	0.91
			IWP	0.79	1.07
Ntchisi (Hospital)	Base	97.3	OWP	-	0.94
			IWP	-	1.05
	SB/SG	98.9	OWP	-	0.95
			IWP	-	1.10
Ntchisi (Standard)	Base	98.6	OWP	0.82	0.79
			IWP	0.46	0.86
	SB	99.8	OWP	0.85	1.08
			IWP	0.73	1.14
	SG	90.3	OWP	1.36	1.42
			IWP	1.24	1.47
Dowa	Base	96.3	OWP	0.56	0.67
			IWP	0.44	0.86
	SB/SG	93.3	OWP	0.95	0.71
			IWP	0.84	0.74
Rumphi	Base	93.8	OWP	0.80	0.39
			IWP	0.54	0.49
	SB/SG	93.4	OWP	0.81	0.45
			IWP	0.51	0.49
Cape Maclear	Base	94.9	OWP	0.63	0.28
			IWP	0.39	0.49
	SB/SG	87.8?	OWP	0.92	0.50
			IWP	0.55	0.55

Findings and observations: The MDD and OMC results in themselves are not very significant, other than as a means of determining the more important relative compaction (RC) and FMC/OMC ratio parameters as discussed below.

The following points may be observed from the results of the RC and FMC/OMC ratio.

1- Compared with the normally stipulated RC requirements of the Base layer (98% BS Heavy MDD), the subbase layer (95% BS Heavy) and upper subgrade layer (93% BS Heavy): MDD;

- none of the project roads appear to comply with the minimum compaction requirements in the road base (RC mean = 95.7%, range = 93.4 – 97.3%),
- some of the project roads comply with the subbase (subbase/subgrade for a 2-layer pavement system) requirement (RC mean = 93.5%, range = 87.8 – 98.9%).

2- In general, the average densities achieved in the pavement layers are satisfactory. Nonetheless, in view of the sensitivity of the strength (CBR) of the pavement materials to both density and moisture content (see Table 3-17), cognizance should be taken of this during future design and construction of such roads as discussed in Section 4.

3- In both the wet and dry seasons, the mean FMC/OMC ratio in both the OWP and IWP of the base layer of all the project roads is generally well below OMC (mean value = 0.65, range 0.28-1.05). For the subbase/subgrade layer: mean value = 0.80, range 0.45–1.14). The FMC/OMC ratios are also relatively lower (all layers and all locations within the pavement) in the drier regions (e.g. cape Maclear) than the wetter regions (e.g. Ntchisi).

4- In the wet season, the FMC/OMC ratio in the OWP of both base and subbase/subgrade layers is generally higher than in the IWP whilst the converse is the case in the dry season, i.e. FMC/OMC ratio is lower in the OWP than the IWP.

5- The important finding from the above is that, even with the relatively poor prevailing drainage conditions, in terms of the Drainage Factor of the roads (ref. Section 3.3.2), and even at the wettest time of the year, ***the pavement materials are operating at an in-service moisture content below their OMC.*** This information draws attention to the critical importance of understanding the strength sensitivity to moisture of the pavement materials as a basis for assessing their likely performance in the prevailing environmental conditions as discussed below.

3.4.3 Strength (CBR)

In order to resist the full application of traffic loading where thin bituminous surfaces are used, the base must possess sufficient strength to sustain this loading without shear failure. The strength of the base material will be dependent on both its compacted density and moisture content. The inter-relationship between the strength, moisture content and density of the pavement materials was therefore investigated in the laboratory in order to compare the values obtained with those likely to prevail in the most adverse service conditions;

Results: The results of the laboratory strength (CBR) determinations at varying densities and moisture contents is presented in Table 3-18.

Table 3-18: CBR values at various moisture contents and densities

Road Section	Pavement Layer	Moisture Content	CBR(%) at % BS Heavy Compaction				% Increase 93%-98%
			93	95	98	100	
Ntchisi (School)	Base	Soaked	23	32	45	52	95.7
		OMC	36	45	63	80	75.0
		0.75 OMC	111	123	150	180	35.1
	SB/SG	Soaked	19	22	29	35	52.6
		OMC	21	28	36	40	71.4
		0.75 OMC	74	85	95	100	28.3
Ntchisi (Hospital)	Base	Soaked	24	28	37	45	54.2
		OMC	41	58	74	80	80.5
		0.75 OMC	84	96	137	165	63.1
	SB/SG	Soaked	10	14	26	30	160.0
		OMC	20	29	37	42	85.0
		0.75 OMC	39	45	57	65	46.2
Ntchisi (Standard)	Base	Soaked	41	53	82	95	100.0
		OMC	68	102	134	250	109.4
		0.75 OMC	100	155	245	310	146.0
	SB	Soaked	22	27	47	62	113.6
		OMC	56	68	81	90	44.6
		0.75 OMC	88	105	138	190	56.8
	SG	Soaked	19	42	56	65	194.7
		OMC	42	64	92	115	119.1
		0.75 OMC	143	158	184	210	28.7
Dowa	Base	Soaked	18	32	55	55	205.6
		OMC	21	43	60	65	185.7
		0.75 OMC	46	64	81	85	76.1
	SB/SG	Soaked	9	13	30	40	233.3
		OMC	16	24	52	60	225.0
		0.75 OMC	36	44	67	70	86.1
Rumphi	Base	Soaked	22	27	64	70	190.9
		OMC	47	50	82	90	74.5
		0.75 OMC	71	143	168	185	136.6
	SB/SG	Soaked	11	?	40	55	263.6
		OMC	24	41	62	85	158.3
		0.75 OMC	54	90	138	160	155.6
Cape Maclear	Base	Soaked	71	92	148	195	108.5
		OMC	98	120	189	250	92.3
		0.75 OMC	114	146	230	290	101.8
	SB/SG	Soaked	24	32	58	60	141.7
		OMC	36	66	84	90	133.3
		0.75 OMC	68	103	165	210	142.7

Note: The procedure adopted for determining CBRs at OMC and 0.75OMC was as follows:

1. Mix and split CBR sample into three portions for CBR testing (a) soaked, (b) at OMC and (c) at 0.75 OMC.
2. After compaction at BS Heavy OMC test one set soaked. This will provide the soaked CBR value.
3. **Seal** the second sample in a plastic bag and **allow to stand for 4 days to dissipate compaction stresses** and determine UNSOAKED CBR at OMC the next day.

4. Place the third sample in the oven to maximum 50 degrees Celsius to remove moisture. Check from time to time to determine when sufficient moisture has been dried out to produce a sample moisture content of about 0.75 OMC. Once this approximate moisture content is reached, seal the sample in a plastic bag and keep for **4 days to allow moisture equilibration** before undertaking the CBR test at approximately 0.75 OMC. Weigh again before CBR testing to determine the exact MC at which the CBR will be determined..

Findings and observations: The strength/moisture/density investigations highlight the strength sensitivity of the pavement materials to both moisture and density as follows:

1- All the base materials used in the LVR pavements (except Cape Macelar) have typical soaked CBR values (mean value 50% at 98% BS Heavy, range 37-64%) much lower than the currently specified minimum CBR of 80% at 98% BS Heavy (as per ORN 31).

2- All the subbase/subgrade materials used in the LVR pavements have typical OMC CBR values (mean value 30% at 95% BS Heavy, range 24-41%) which are similar to the currently specified minimum CBR of 30% at EMC and 95% BS Heavy (as per ORN 31).

3- The base and subbase/subgrade CBR values indicated above are laboratory determinations at the normally specified compaction levels of 98% and 95% MDD respectively. However, as indicated in Table 3-16, the field RC levels are less than the specified ones (mean RC value in base and subbase/subgrade of of 95.3% and 93.9% respectively. Thus, at those field densities, the field CBR would be approximately 10-15% lower (see Figure 4-2).

4- In general, there is a significant increase in CBR strength as the compacted density increases and compacted moisture content decreases. For example:

- An average increase in base CBR strength of about 58% may be achieved by ensuring that the service moisture content is at OMC rather than soaked.
- An average increase in CBR strength of about 100% may be achieved by compacting the base material at 98% rather than 93%.

5- The above findings highlight the critical importance of compacting the pavement materials to the maximum, practicable density that can be obtained in the field and, also, ensuring that the side drainage is such that the materials in the OWP of the pavement are kept relatively low in the most adverse service moisture conditions (toward the end of the rainy season when the pavement is usually at its wettest).

4. ANALYSIS AND DISCUSSION

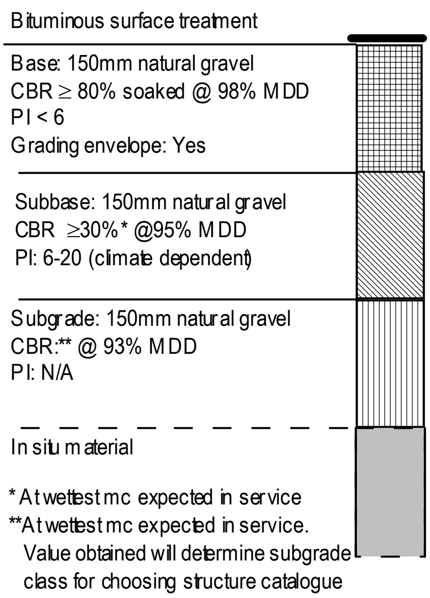
4.1 Introduction

The objective of this section is to analyse and discuss the results of the various field investigations and laboratory testing that were undertaken on the six project roads as presented in the previous section. In so doing, the section draws on other similar work undertaken in the region which provide an important frame of reference for analyzing the results obtained from the Malawi roads.

4.2 Pavement Structure and Performance

4.2.1 Pavement structure

The 2-layer granular pavement structure (base + subbase/subgrade) of the LVR sections differs from the more traditional 3-layer granular pavement structures (base + subbase + subgrade) as illustrated in Figure 4-1.



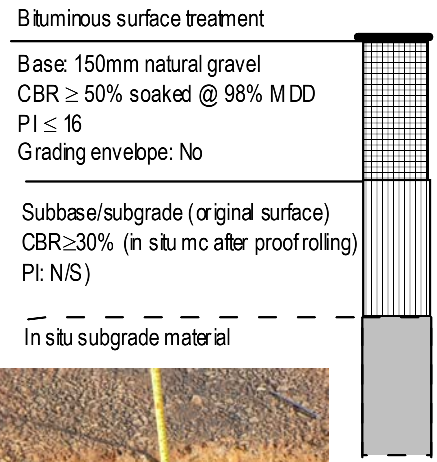


Photo 4-1: Typical 2-layer LVR pavement structure : Ntchisi (school) road

Figure 4-1: Typical traditional 3-layer pavement structure (left) and 2-layer LVR structure (right)

In general, other than at low lying or in poorly drained areas, the construction of the LVR sections entailed grading, watering and proof-rolling of the existing running surface followed by the placement and compaction of a nominal 150mm base layer to 98% MDD (BS Heavy) and finally surfacing. This simplified approach utilised the inherent strength of the existing running surface which has benefitted from in service consolidation from traffic as well as from wetting and drying cycles over many years. Removal or disturbance of this well consolidated foundation by ripping and re-compacting, as followed in the traditional construction process, will not only be an additional expense but, also, is likely to be counterproductive in that the compaction of the upper layers of the running surface are unlikely to be superior to the original consolidated running surface.

4.2.2 Pavement performance

Based on the outcome of the performance monitoring of all the project roads, a general absence of any significant roughness, rutting, potholing or cracking indicates clearly that all the project roads are structurally sound and have performed well in the prevailing service environment (moisture regime, materials quality, traffic loading, etc.).

The investigations showed that there is no discernible relationship between any of the performance parameters and traffic. This is not totally unexpected as the project roads have all carried to date (2010) less than about 0.25 MESA in one direction. When viewed in terms of the relationship between the contribution of traffic and the environment to pavement deterioration (Gourley and Greening, 1999), shown as Figure 4-2 and highlighted in the SADC Guideline on Low Volume Sealed Roads, the importance of the environment dominates which explains the poor relationship between pavement deterioration and observed traffic.

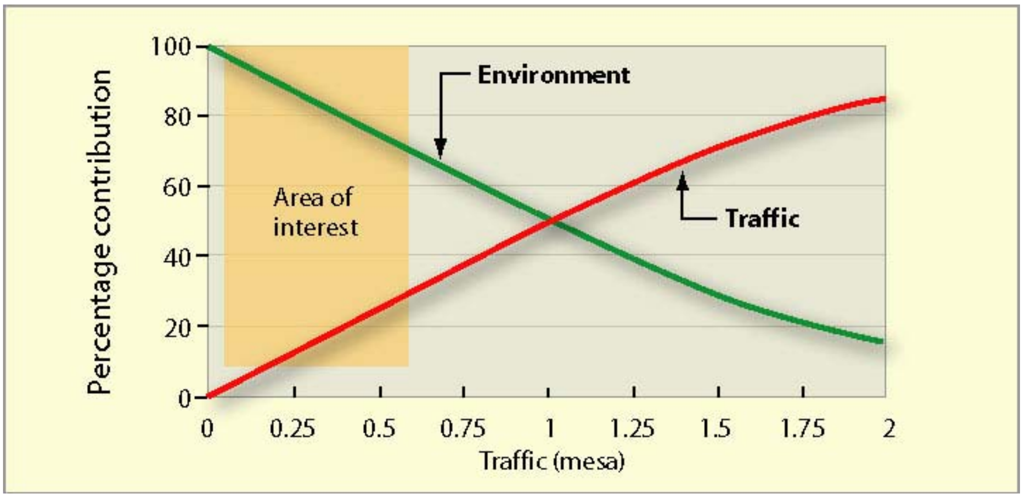


Figure 4-2: Traffic loading versus dominant mode of distress

It is noteworthy that, according to conventional pavement design standards, the LVR sections would be deemed to be *inadequate and substandard* and should have failed soon after construction in terms of insufficient bearing capacity. However, these standards have been developed from structural pavement performance studies of conventional relatively high volume roads and it is now apparent from many LVR investigations carried out, not only in Malawi, but elsewhere in the region, that these standards are not appropriate for LVSRs.

4.3 Traffic Loading

For pavement evaluation and design purposes a reliable estimate of the cumulative traffic (in ESAs) carried per lane is required. This estimate is much more difficult to derive for LVSRs as the passage of heavy vehicles during relatively short periods (e.g. during the harvesting season) are often difficult to estimate accurately unless frequent, properly designed traffic counts are carried out. Moreover, the vehicle equivalence factors (VEF) are often based on published data which may not apply to the road in question.

In Malawi, heavy traffic is classified into four categories: Light Goods Vehicles (LGV), Buses, Medium Goods Vehicles (MGV) and Heavy Goods Vehicles (HGV) and, for traffic estimation purposes, the VEF's used are those recommended in the Table 3 of the *SATCC Code of Practice for the Design of Road Pavements.* This Code of Practice applies to the design of trunk roads for which the VEFs may be appropriate (VEF_{LGV} =1.7; VEF_{Bus}= 1.4, (VEF_{MGV} =2.5; VEF_{HGV}= 4.5. However, they are considered to be unrealistically high for the types of vehicles using the LV project roads for which the VEFs in Table 3-4 were considered to be more reasonably representative of the prevailing traffic conditions on the roads investigated.

In future, in order to reduce uncertainty in the estimation of traffic loading, 24 hour classified counts should be carried out two or three times per year taking account of seasonal variations in traffic movements. In addition, axle load surveys should also be carried on or close to the road under consideration to allow reliable VEF's to be determined as any errors in axle loads are amplified by the fourth power law when calculating cumulative ESAs. Such errors can lead to over-estimation or under-estimation of the cumulative ESAs which, in turn, can lead to adoption of unnecessarily under- or over-designed LVSRs.

4.4 Pavement Materials

4.4.1 Materials Quality

The quality of materials used in the road pavement, whilst not complying with traditional requirements in terms of grading, plasticity and strength, are certainly "fit for purpose" in terms of being adequate to carry the traffic loading in the prevailing road environment. It is noteworthy, however, that the typical, conventional specifications for the road pavement used in Malawi rely on "ideal" materials having restrictive grading requirements, low plasticity (e.g. PI<6 for road base) and relatively high strength (e.g. soaked CBR>80% at 98% BS Heavy compaction for road base).

There is now overwhelming evidence from other road investigations in Malawi (Scott Wilson Kirkpatrick & Partners/Henry Grace & partners and Imperial College of Science and Technology, UK, 1988, South African Dept. of Transport, 1996, InfraAfrica/CSIR, 2010) that for lightly trafficked roads constructed of naturally occurring granular materials and thin surface treatments:

- Traffic below about 0.5 MESA was not the dominant factor affecting pavement deterioration;
- None of the traditional grading parameters correlate significantly with the performance of the roads;
- There is little relationship between PI and performance;
- Neither the in situ nor laboratory CBRs showed significant correlation with performance;
- The performance of the road base materials depends to a large extent on the drainage and seasonal moisture variations;

The above findings indicate clearly that mere non-compliance with traditional specifications should not be used as a criterion for ruling out the use of various natural gravels in LVR pavements, provided the roads are well drained and the other influential factors addressed in this report, such as adequate compaction and , shoulder sealing are adhered to.

4.4.2 Moisture/strength/density

A good understanding of the relationship between the moisture, strength and density of the materials being considered for use in a LVR pavement is crucial for successful performance. Laboratory assessments of this inter-relationship can be used to determine the moisture and density sensitivities of the CBR strength which are important in designing the drainage and defining the density requirements.

As indicated in Table 3-17 and illustrated graphically in Figure 4-3, the strength of the road base materials typically used in the project roads is sufficiently sensitive to both density and moisture to warrant careful consideration of how these parameters should be specified during the design and construction processes.

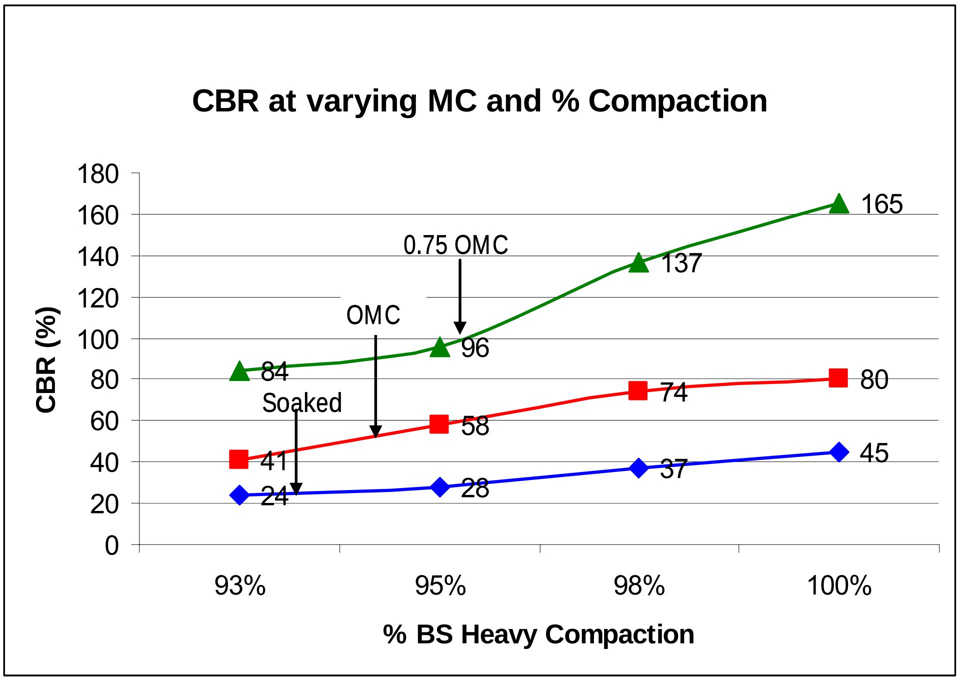


Figure 4-3: Effect of compaction and moisture on road base strength (Ntchisi LVR section)

Although the inter-relationship between strength, moisture and density is very much material specific, nonetheless, the general findings are of paramount importance with regard to the setting of appropriate density requirements and the achievement of a minimum standard of side drainage.

4.4.3 Compaction

Figure 4-4 illustrates clearly that the strength potential of the road base materials and, indeed, the underlying subbase/subgrade layer as well, can be maximised by compacting, not necessarily to a pre-determined RC level, as is traditionally done, but, rather, to the highest uniform level of density practicable (so-called “compaction to refusal”) by employing the heaviest rollers available. Such compaction ensures that the soil has been compacted to its near elastic state as illustrated in Figure 4.4 at which point the near-zero air void condition is reached (Parsons, 1992) with the significant benefit of reduced pavement deflection, increase in pavement life (Figure 4-5), reduced susceptibility to rutting and reduced permeability (making the material strength less moisture sensitive). These benefits will invariably outweigh the additional cost of compacting to refusal rather than a pre-determined RC level. It is also important not to over-compact the soils which may result in their degradation. This can be avoided by using on-board compactometers during the compaction process.

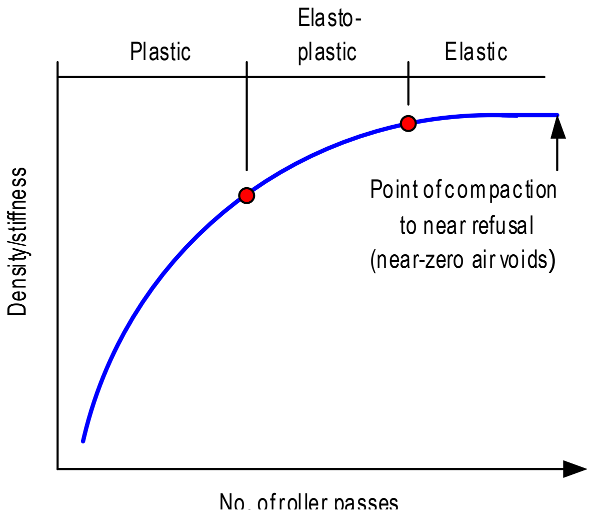


Figure 4-4: Illustration of concept of "compaction to refusal"

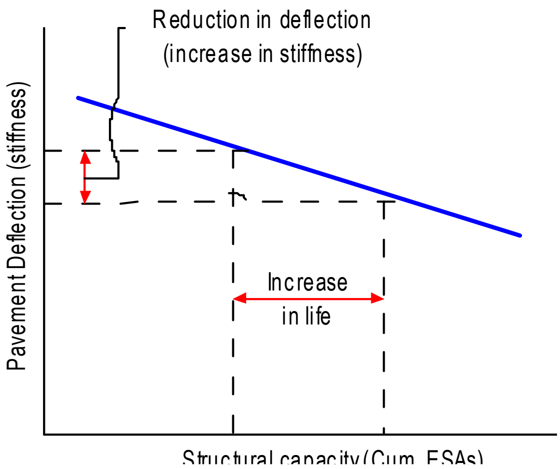


Figure 4-5: Deflection-life relationship showing benefits of "compaction to refusal"

4.5 Moisture and Drainage

Previous investigations (e.g. South Africa Dept. of Transport, 1996) have shown that all the parameters which correlated well with performance were related directly to moisture in the pavement layers (FMC/OMC ratio in the OWP at the wettest time of the year) which, in turn, is related to side drainage. The good performance of the LVR sections investigated is attributed in no small measure to the likelihood that, even in their most vulnerable state, the FMC/OMC ratio in the OWP of the pavements was generally below OMC. At this moisture content, the material strength was adequate to sustain the stresses imposed by the traffic loading.

Notwithstanding the good performance of the LVR pavements, it is noteworthy that their side drainage was generally rated as poor-very poor. Thus, in future, an additional factor of safety can be achieved by ensuring that side drainage meets the minimum requirements indicated in Table 3.8, coupled with the sealing of the LVSR from drain to drain for the reasons given at the end of Section 3.3.3.

4.6 Construction and Maintenance

4.6.1 Construction issues

It is apparent from the field investigations, both the DCP and the test pits, that the nominal 150mm thickness of the base layer was very often not attained. For example, the mean thickness on the Ntchisi LVR section was only 100mm. In addition, as indicated in Table 3-16, the field densities specified for both the base layer (RC ≥ 98% MDD) and that which should have been attained in the proof-rolled subbase/subgrade layer (≥ 95% MDD) were generally not attained. This emphasises the critical importance of ensuring that a minimum level of quality control and assurance is attained in practice with respect to careful selection of the base material in the borrow pit and achieving the base layer thickness and base and subbase/subgrade densities. Failure to adhere to the above requirements will increase the risk of poor performance, particular where drainage is poor and shoulders are not sealed.

In order to attain the specified densities, it is essential to ensure the uniform application of water and the uniformity of mixing and compaction at OMC. In addition, it is also necessary to ensure that premature sealing does not lock in construction moisture. This can be avoided by allowing a significant amount of drying back to occur before the sealing takes place, particularly for the relatively plastic materials that rely partly on soil suction forces for strength gain and improved stability.

4.6.2 Construction methodology

For the relatively low traffic carried, the performance of LVSRs constructed directly on the traffic-consolidated and proof-rolled subgrade (essentially a 2-layer pavement system) proved to be just as good as the traditionally constructed roads having a subbase (essentially a 3-layer pavement system). Tthe use of a single imported layer of appropriate quality base material on a proof rolled subbase/subgrade offers significant cost savings in the construction of LVSRs compared with the more traditional 3-layer pavement structure..

4.6.3 Costs comparison and bidding documentation

Based on typical construction cost figures provided by the RA, it is apparent from Table 4-1 that there are significant cost savings to be derived in the construction of LVSRs by using the LVSR approach (standards, specifications and simplified bidding documentation) rather than the traditional approach embodied in the current national design manuals.

Table 4-1: Comparison of road costs - LVSR versus traditional design approach

Road Design Standard	Typical Construction Cost/km (US$)	Cost Difference (%)
LVSR	150,000	-
Class II	400,000 – 500,000	166 - 233
Class I	> 500,000	> 233

The above LVR costs savings were attributed not just to lower construction costs but also to the following factors:

1- The use of simplified bidding documents using global work items;
2- The use of medium scale local contractors
3- The need for minimal compensation as the upgraded roads followed largely the existing alignment.

For a given level of resources, the above factors enable a significantly greater kilometrage of LVSRs to be constructed than would be the case if the traditional design standards and specifications were to be used. The use of simplified bidding documents using global work items, rather than conventional documents using numerous work items, has been found to be a significant contributory factor to the cost savings offered by the LVSR approach.

4.6.4 Maintenance aspects

The use of a Cape Seal – essentially a single chip seal plus a layer of slurry – has provided a durable type of bituminous surfacing on the LVSRs which, so far, has not required any significant periodic maintenance. However, suffice it to say that careful attention to both routine maintenance, particularly clearing of side drains, and periodic maintenance, are absolutely essential if the performance of the relatively thin and moisture sensitive LVR pavement structure is not be to endangered.

4.7 Risk

The main risk factors for LVSRs are:

- Quality of the materials (strength and moisture susceptibility)
- Construction control (primarily compaction standard)
- Environment (particularly drainage)
- Maintenance standards (drainage and surfacing)
- Traffic and overloading

The risk of premature failure will depend on the extent to which the above factors are negative – the greater the number of factors that are unsatisfactory, the greater the failure of risk. However, this risk can be greatly reduced by minimizing material variability, ensuring that the construction quality is well controlled, maintenance is carried out as discussed in Section 4.6 above and, importantly, that drainage measures are strictly implemented as indicated in Table 3.8.

4.8 Standards and Specifications

4.8.1 General

The results of the investigations have shown clearly that many of the traditionally held concepts of what constitutes appropriate road standards and specifications, as well as failure criteria and residual life estimation, all require some modification or a different interpretation for lightly trafficked LVSRs. This is manifested in no better way than by comparing two adjacent sections of the Ntchisi road, one of which was constructed to “traditional” standards (Ntchisi-Standard) and the other to “LVR” standards (Ntchisi-LVR) as shown in Photo 4-2.

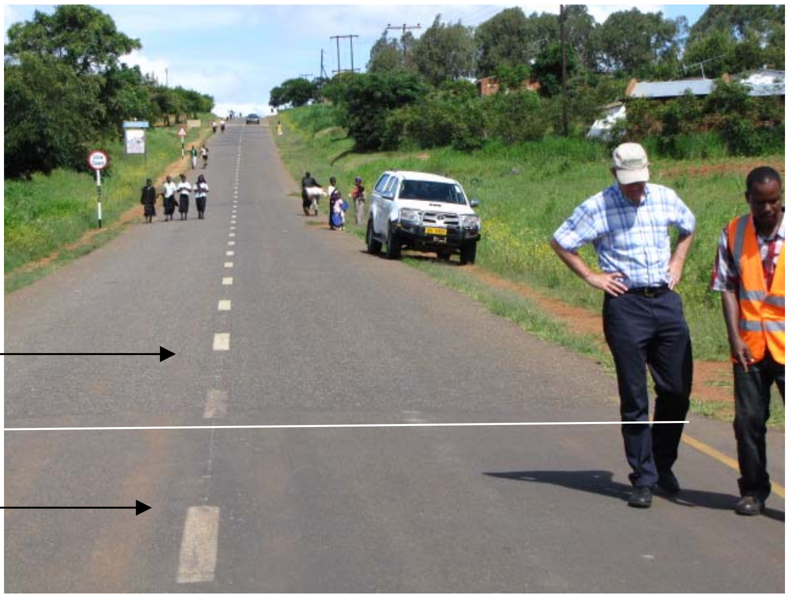


Photo 4-2: Standard construction (foreground),
LVR construction (background) - Ntchisi road

As would be evident from Photo 4-2, in an identical road environment (moisture regime, traffic loading, topography, etc.), after 8 years in service of the LVSR section there is no discernible difference in structural or functional performance when compared to the Ntchisi-Standard section. However, there is one major significant difference – that of construction cost which is standard related – with the Ntchisi-Standard section costing more than three times that of the Ntchisi-LVR section!! **What this clearly illustrates is that the application of traditional standards and specifications to the design of LVSRs can be very conservative, unnecessarily costly (ref. Section 4.6.2) and, in the final analysis, inappropriate for application in Malawi.** Accordingly, the next section proposes design standards appropriate to the road environment in Malawi.

4.8.2 Approach to development of standards

DCP design method

The 2-layer pavement system adopted in Malawi should be a fundamental feature of any national LVR design standard. In this approach, the main emphasis is on using the existing road without disturbing its inherent strength derived from consolidation by traffic over many years and on adding a minimum thickness base layer of appropriate quality.

The DCP lends itself to evaluating in situ conditions and, by integrating the design strength profile optimally with the in situ soil strength profile, to designing light road pavement structures (Kleyn, Maree and Savage, 1982; Kleyn and van Zyl, 1987). In essence, the design process entails using the DCP data in terms of the layer strength diagram and comparing this profile with minimum specified standards called DCP master design curves, shown in Figure 4-6, to determine the adequacy of the various pavement layers in depth for the expected future traffic loading. Points lying to the right of the DCP design curve for a specific traffic category indicate material of inadequate at that depth.

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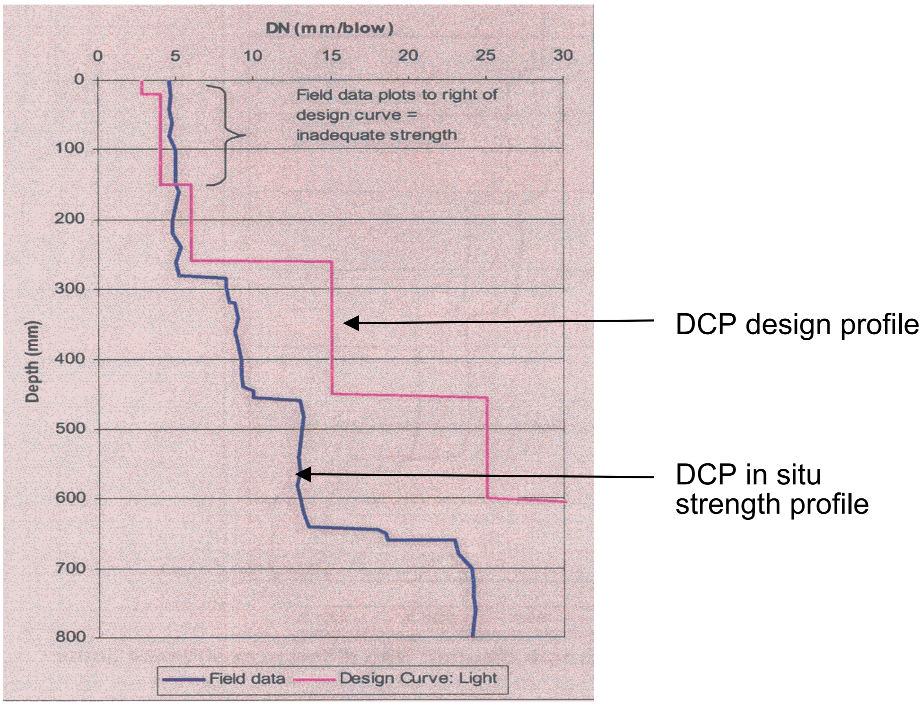

Figure 4-6: Layer Strength Diagram: Field data vs Master Design Curve

DCP design catalogue

The catalogue of designs presented in Table 4-2 has been developed on the basis of investigations of LVR roads carried out in the region (Van Zyl and Kleyn, 1987; Wolff et al, 1995), and has been calibrated by the results of the DCP measurements undertaken on the project roads.

Table 4-2: Pavement design catalogue for different LVR categories

Pavement Class E80 x 10^6	LV 0.01 0.003 – 0.010	LV 0.03 0.010 – 0.030	LV 0.1 0.030 – 0.100	LV 0.3 0.100 – 0.300	LV 1.0 0.300 – 1.000
Base 150 mm ≥ 98% BSH	DN ≤ 8	DN ≤ 5	DN ≤ 4	DN ≤ 3.2	DN ≤ 2.5
Subbase 150 mm ≥ 95% BSH	DN ≤ 19	DN ≤ 14	DN ≤ 9	DN ≤ 6	DN ≤ 3.5
Selected 150 mm ≥ 93% BSH	DN ≤ 33	DN ≤ 25	DN ≤ 19	DN ≤ 12	DN ≤ 6

Plots of the required strength profiles for the different traffic categories in this catalogue are provided in Figure 4-7. It is essential that the traffic categories are carefully defined and that the calculation of the cumulative standard axles is accurate.

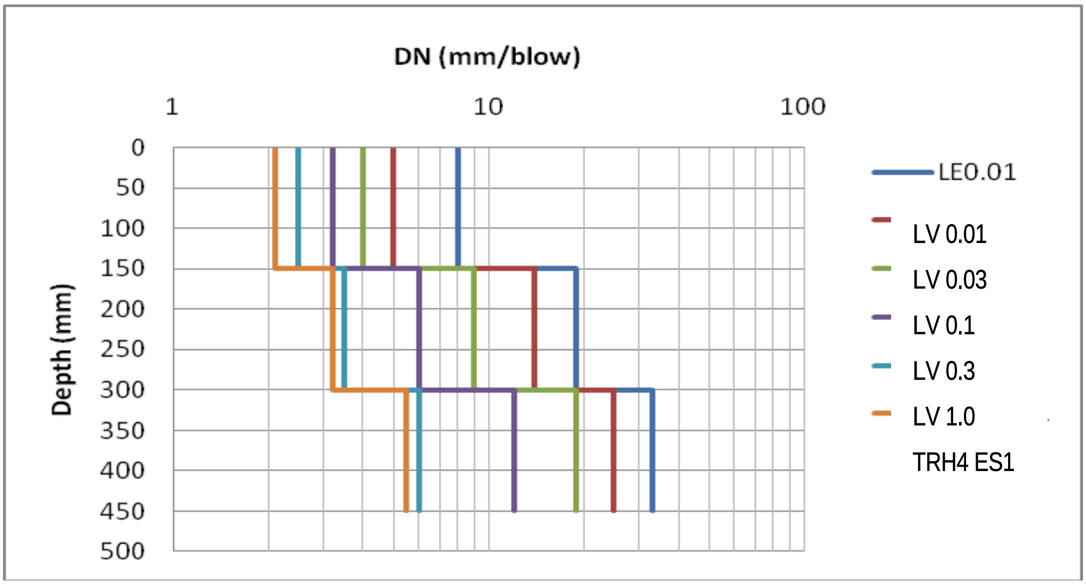

Figure 4-7: Required DCP strength profiles for different LVR traffic categories

Moisture regime

As the in situ strength of any material is a function of the moisture (as well as the density), with some materials being more moisture sensitive than others, this needs to be taken into account. The moisture regime at the time of the DCP survey needs to be assessed in relation to the expected moisture regime of the planned road in service. The best solution is to carry out the DCP survey when the prevailing moisture regime is similar to that expected in the pavement, bearing in mind the effects of equilibrium moisture content beneath the pavement as well as those of seasonal moisture variation in the outer wheel track area of a road with unsealed shoulders.

The effects of varying moisture conditions at the time of DCP testing are best accounted for by using various percentiles of the DCP penetration data depending on the in situ moisture conditions at the time of the DCP survey. This requires a broad assessment of whether the road/soil conditions at the time of the DCP survey are wetter, drier or more or less equivalent to the anticipated in-service conditions during use of the road. The percentiles of the minimum penetration rates obtained from the DCP tests would then be as in Table 4-3.

Table 4-3: Percentiles of maximum DCP penetration rate to be used to assess in situ material conditions

Site moisture condition during DCP survey	Percentile of minimum strength profile (maximum penetration rate)	
	Materials with strengths not moisture sensitive	Materials with strengths that are moisture sensitive
Wet	80	80 - 90
Expected in service	50	50 – 80
Dry	20	20 – 50

The above table indicates that if the DCP testing was carried out during the wet season, the in situ material is probably at or close to its worst condition (i.e., lowest strength). The 80th percentile value shows that 20 per cent of the total data set is weaker than this value (ie higher penetration rates or lower in situ strength (CBR) values indicating the worst case scenario). By taking the 80th percentile of the maximum DCP penetration rates for the respective design layers along the road, the risk incorporated in the design is considered to be acceptable for this standard of road, i.e. the design strength will increase as the material dries out. This will result in a design that is not over-conservative.

If the DCP testing was carried out during the dry season, the recorded penetration rates will be considerably lower than the equivalent rates in the wet season, i.e. the in situ material is much stronger than that which will affect the pavement performance during the wet season (the best case scenario). The 20th percentile value shows that 80 per cent of the total data set has values lower than this figure (i.e. higher penetration rates or lower in situ strength (CBR) values). By taking the 20th percentile of the maximum DCP penetration rates for the respective design layers along the road, the risk incorporated in the design is considered to be acceptable for this standard of road, i.e. the design strength will decrease as the material wets up but will still be within the expected strength range.

Pavement design

A flow diagram of the DCP design process is shown in Figure 4-8. In essence, the design process needs to fit the pavement structure (Figure 4-6) to the in situ conditions on each uniform section of the existing road determined from a DCP design survey. Where the in situ strength is less than the design strength, an imported base layer of appropriate quality would be required.

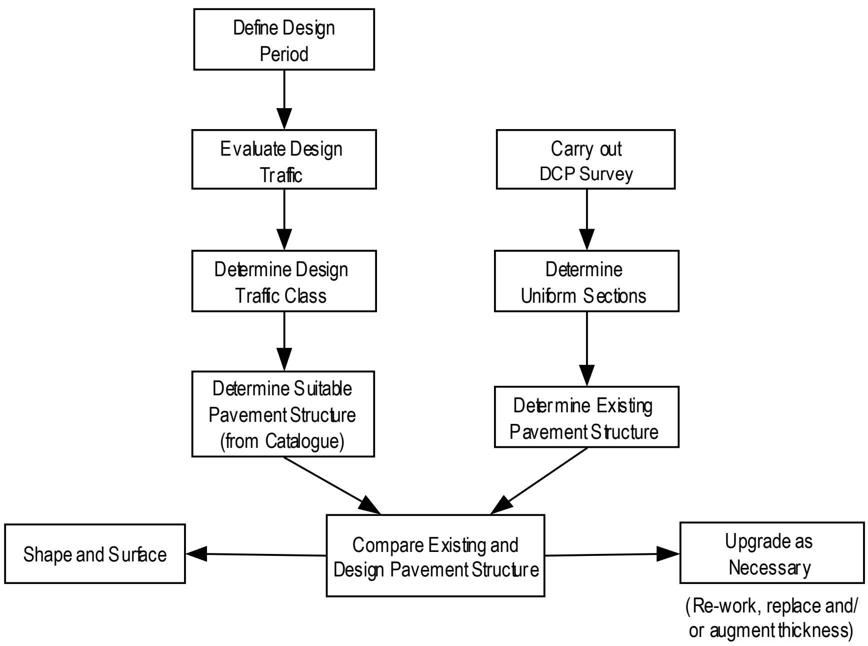

Figure 4-8: Flow diagram of DCP design process

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary of Conclusions

5.1.1 LVSR performance

All the LVSRs investigated have performed extremely well in the prevailing service environment. These relatively lightly trafficked roads, which have all carried less than 0.25 MESA since construction, remain structurally sound with no significant signs of distress. According to conventional pavement design standards, these roads should have already failed. This can be interpreted as indicating that traditional design standards and specifications are inappropriate for use with LVSRs – a conclusion that has also been reached from similar investigations carried out in other countries in the region.

5.1.2 Traffic estimation

The current manner of classifying commercial vehicles for traffic estimation purposes (LGV, Buses, MGV and HGV) and the use of tabulated values representing average rather than road specific VEFs, are not sufficiently accurate for determining the traffic loading on LVSRs and need to be improved in order to avoid the costly impact of over- or under-estimation of the traffic growth which can lead to unnecessarily conservative or risky road designs.

5.1.3 Materials

None of the materials used in the construction of the LVSRs comply with the traditional standards and specifications normally applied in Malawi in terms of the commonly specified plasticity, grading and strength requirements. Nonetheless, they are "fit for purpose" and should not be rejected for use in LVSR pavements merely because of their non-compliance with traditional standards and specifications. It is also noteworthy that the use of BS test methods in Malawi is not directly comparable with AASHTO standards and due account should be taken of this difference when setting materials specifications.

A knowledge of the inter-relationship between the moisture, density and strength of the materials used in the construction of LVSRs provides critical insight into how best to use such materials to ensure good performance in the prevailing road environment. A laboratory investigation of this relationship is of paramount importance in deciding how best to use these materials in the construction of LVSRs.

5.1.4 Compaction

The investigation has shown that "compaction to refusal" (with the heaviest plant available) not only maximizes the strength potential of the construction materials, but also reduces their moisture susceptibility and, in so doing, contributes to improved pavement performance (longer life).

5.1.5 Moisture

The FMC/OMC ratio proved to be a significant contributory factor related to the good performance of the LVSRs in that, even at the wettest time of the year, this ratio was generally below OMC, even in the relatively vulnerable OWP of the road. If, through effective drainage, the materials in the road pavement can be maintained at a moisture content that does not rise above OMC in the rainy season, then more extensive use can be made of local, relatively plastic materials that might otherwise not be suitable if they were to become soaked in service.

In the relatively warm climate of the country, with pronounced dry seasons, the road base and subbase/subgrade of the reasonably well constructed LVSRs (indeed, all roads) remain relatively dry (< OMC) under the bituminous surface treatment and, under such conditions, quite high cohesive (suction) strengths are developed in the pavement layers under the combined actions of initial compaction, repeated wetting and drying cycles, and further compaction under traffic.

5.1.6 Drainage

Despite the good performance of the LVSRs investigated, the side drainage was rated to be generally poor-very poor in terms of the Drainage Factor, DF (the product of the height of the crown of the road above the bottom of the ditch (h) and the horizontal distance from the centerline of the road to the bottom of the ditch (d)). Adherence to a minimum DF > 7.5 will significantly improve the performance and life of LVSRs.

5.1.7 Bidding documentation

The use of simplified bidding documents using global work items, rather than conventional documents using numerous work items, has been found to be a significant contributory factor to the cost savings offered by the LVSR approach.

5.1.8 Construction

For the relatively low traffic carried, the performance of LVSRs constructed directly on the traffic-consolidated and proof-rolled subgrade (essentially a 2-layer pavement system) was just as good as the traditionally constructed roads having a subbase (essentially a 3-layer pavement system). Thus, the use of a single imported layer of appropriate quality base material on a proof rolled subbase/subgrade offers significant cost savings in the construction of LVSRs.
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A minimum level of quality assurance and control is required with respect to careful selection of natural gravels in borrow pits and attainment of minimum base layer thickness and maximum pavement layer densities. This will ensure that the assumptions on which the designs are based are actually realised during construction.

5.1.9 Costs

There are significant costs savings to be achieved in the construction of LVSRs using the standards and specifications applied on the project roads instead of the traditional standards and specifications embodied in national documents. The LVSR approach offers savings of the order of 166 – 233% when compared with traditionally constructed Class II using standard bidding documentation and > 233% when compared with Class I roads using standard bidding documentation.

5.1.10 Standards and Specifications

The results of the investigations have shown clearly that the application of current, traditional standards and specifications to the design of LVSRs can be very conservative, unnecessarily costly and, in the final analysis, inappropriate for application in Malawi. A new design manual for LVSRs is therefore required for Malawi.

The 2-layer pavement system adopted in Malawi for the construction of LVSRs should be embodied in any future national design standard. The DCP design method which involves evaluating in situ conditions and integrating the design strength profile optimally with the in situ soil strength profile, is well suited for use in Malawi.

5.1.11 Risk

The adoption of appropriate design standards and specifications does not necessarily mean an increased risk of road failure, but, rather, requires a greater degree of pavement engineering knowledge, local experience and judgment which is supported by local investigation and research.

The primary requirements for mitigating against the risk of LVR failure in Malawi is to ensure that the pavements are well drained, construction quality is tightly controlled, high compaction standards are achieved, the road is timeously and effectively maintained and overloading is avoided.

5.1 Summary of Recommendations

5.1.1 New standards and specifications

A new manual for the design and specification of LVSRs in Malawi should be prepared based on the body of local research information that is available from this and previous investigations carried out in Malawi and other countries in the region.

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ANNEX A

OVERVIEW OF RELEVANT REPORTS ON LOW VOLUME ROADS

(a) Malawi Low Volume Roads Study: An investigation into the use of Laterite instead of crushed stone or stabilised material as a base course for bituminous surfaced roads. Report by Scott Wilson Kirkpatrick & Partners/Henry Grace & partners and Imperial College of Science and Technology, UK. December 1988.

The objective of the investigation was to ascertain if plastic “as-dug” nodular laterite could be used successfully instead of crushed stone or stabilised material as base course for low volume roads beneath a thin bituminous surface. The report discusses the results of a one kilometre trial which was part of a 51 km road contract on Route M12 in the Vipya highlands of Northern Province during 1984 and 1985.

The report concluded that after five years of trafficking the trial length of pavement had performed as effectively as the adjacent lengths with more expensive crushed stone, which confirms similar experience in Kenya that with appropriate construction techniques these lateritic gravels can be sued to provide the advantages of durable bituminous surfaced pavements at low cost.

(b) ***Collaborative Research Programme on Highway Engineering materials in the SADC Region: Volume 1 – Performance of Low Volume Sealed Roads: Results and Recommendations from Studies in Southern Africa.*** Report by Transport Research Laboratory, UK. November 1999.

The overall aim of the research programme was to investigate the use of natural gravels for road bases and to recommend innovative approaches for their use in a way that is cost-effective and environmentally sensitive. Sections of road were selected in four SADC countries, including nine sections in Malawi. The research focused on measuring how road pavements performed with time and traffic, and in different climatic conditions. It also identified features which need to be included in the road design to minimise risk.

One of the many far-reaching conclusions arising from the study was that road base materials commonly found in the SADC region, including Malawi, which would be considered to be of “marginal” quality using traditional specifications, can give satisfactory performance on low volume rural roads carrying typical rural traffic (typically < 200 vpd with about 20% commercial traffic). However, appropriate precautions must be taken to ensure adequate drainage of the road pavement and to prevent moisture ingress into the pavement. Such measures include the sealing of shoulders and adoption of a minimum height of about 0.75 m between the crown of the road and the invert level of the drain.

(c) ***Recommendations on the use of marginal base course materials in low volume roads in South Africa.*** South Africa Dept. of Transport. Research Report RR 91/201. November 1996.

An investigation into the performance of 57 sections of road in South Africa identified by the Provincial Road Authorities as being constructed using marginal quality base course materials was carried out. The investigation showed apart from conserving precious construction materials and reducing the maintenance of the previously unpaved roads, a significantly better level of service was achieved with a concomitant reduction in road user costs.

The investigation showed that current material standards are generally too high for affordable low volume roads and that more appropriate, performance-based standards and specifications should be used. The study also showed that good drainage and construction quality are the primary requisites for successful low volume roads. More appropriate strength requirements for these roads were proposed.

(d) ***Analysis of Pavement Monitoring Sections in Botswana.*** InfraAfrica (Pty) Ltd./CSIR. Jan. 2010.

One of the main objectives of the project was to provide the data required for revising the Botswana Roads Design Manual with regard to the design and specification of low volume roads.

Most of the successful base courses were constructed from materials that do not comply with traditional standards. Good drainage and high standards of construction were considered to be contributory factors explaining the good performance of the roads.

The main findings from the project were that the majority of the LVSRs significantly outperformed their expected performances, with the strong subgrades contributing significantly to the good road performances. It was concluded that that materials conventionally regarded as marginal or sub-standard according to existing standards, can perform very well in roads carrying in excess of 3 million standard axles.