# Development of Guidelines and Specifications for Low Volume Sealed Roads through Back Analysis

**Phase 3 Final Report**

TRL Ltd

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For further information, please contact: Nkululeko Leta, nkululeko.leta@cardno.com

ReCAP Project Management Unit
Cardno Emerging Market (UK) Ltd
Clarendon Business Centre

Level 5, 42 Upper Berkeley Street

Marylebone, London W1H5PW

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Cover photo: Field Testing in Mozambique / Francis Dangare

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# Contents

## Tables and Figures

## Abstract

Development of Guidelines and Specifications for Low Volume Sealed Roads (LVSRs) through Back Analysis is a project that was carried out in three phases. Phase 1 and Phase 2 were completed whereas Phase 3 started in December 2018 and is scheduled for completion in June 2020.

Phase 1 involved the identification of data sources; collection of historical performance data from previous studies; processing of the data; and creation of a Database for Low Volume Roads (LVRs).

Phase 2 involved refining and adding more data into the Database; training of counterparts from the participating road agencies of the 12 Africa Community Access Partnership (AfCAP) partner countries on how to use the Database; and identifying gaps for further studies to refine standards and design catalogues.

Phase 3 involves field and laboratory investigations to fill the critical knowledge gaps that were identified in Phase 2; data analysis, corroboration or revision of existing specifications in guidelines and catalogues for pavement design for LVSRs; further population of the Database; capacity building of participating road agencies counterpart staff who will be involved in the project activities; dissemination of findings; and production of a scientific paper.

This report describes the activities undertaken during Phase 3 including revision of specifications, capacity building, lessons learnt from SEACAP, and minutes of the regional workshop. It also sets out the recommended revisions to the specifications for low volume road pavement materials and pavement design catalogue.

Dissemination of findings, and support for the lvroadsdata.com database will continue to be provided until June 2020.

## Key words

Regional Back Analysis, Sub-Saharan Africa, Low Volume Sealed Roads, Performance of Low Volume Roads.

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## Research for Community Access Partnership (ReCAP)

**Safe and sustainable transport for rural communities**

ReCAP is a research programme, funded by UK Aid, with the aim of promoting safe and sustainable transport for rural communities in Africa and Asia. ReCAP comprises the Africa Community Access Partnership (AfCAP) and the Asia Community Access Partnership (AsCAP). These partnerships support knowledge sharing between participating countries in order to enhance the uptake of low cost, proven solutions for rural access that maximise the use of local resources. The ReCAP programme is managed by Cardno Emerging Markets (UK) Ltd.

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## Acronyms, Units and Currencies

| | |
|---|---|
| AASHO | American Association of State Highway Officials |
| AASHTO | American Association of State Highway and Transportation Officials |
| ACV | Aggregate Crushing Value |
| AIV | Aggregate Impact Value |
| ADT | Average Daily Traffic |
| AfCAP | Africa Community Access Partnership |
| ALD | Average Least Dimension |
| ANE | National Road Administration of Mozambique |
| CBR | California Bearing Ratio |
| CMA | Cold Mix Asphalt |
| DBST | Double Bituminous Surface Treatment |
| DCP | Dynamic Cone Penetrometer |
| DFID | Department for International Development |
| DFR | Department of Feeder Roads (Ghana) |
| DSD | Double Surface Dressing |
| DSS | Double Sand Seal |
| ESDAC | European Soil Data Centre |
| FI | Flakiness Index |
| FWD | Falling Weight Deflectometer |
| GHA | Ghana Highway Authority |
| GM | Grading Modulus |
| HMS | Highway Management System |
| IGAD | Intergovernmental Authority for Development |
| Km | Kilometre |
| LAA | Los Angeles Abrasion |
| LHS | Left Hand Side |
| LTPP | Long Term Pavement Performance |
| LVR | Low Volume Road |
| LVSR | Low Volume Sealed Road |
| MDD | Maximum Dry Density |
| MESA | Million Equivalent Standard Axles |
| Mm | Millimetres |
| MoU | Memorandum of Understanding |
| MRH | Ministry of Roads and Highways (Ghana) |
| M-S-K | Matugga – Semuto – Kapeeka |
| NRFA | National Road Fund Agency (Zambia) |

| | |
|---|---|
| OMC | Optimum Moisture Content |
| OWP | Outer Wheel Path |
| PI | Plasticity Index |
| PMO-RALG | Prime Minister’s Office-Regional Administration and Local Government of Tanzania |
| PSD | Particle Size Distribution |
| RAFU | Road Agency Formulation Unit |
| RDA | Road Development Agency (Zambia) |
| ReCAP | Research for Community Access Partnership |
| ReCAP PMU | Research for Community Access Partnership Programme Management Unit |
| RHS | Right Hand Side |
| RRC | Road Research Centre |
| SSD | Single Surface Dressing |
| TFV | Ten per cent Fines Value |
| TRL | Transport Research Laboratory |
| UNRA | Uganda National Roads Authority |
| UKAid | United Kingdom Aid (Department for International Development, UK) |
| VCI | Visual Condition Index |
| VEF | Vehicle Equivalence Factor |
| vpd | Vehicles per day |

## Executive summary

This report presents a summary of the activities carried out during Phase 3 of the project entitled Development of Guidelines and Specifications for Low Volume Sealed Roads through Back Analysis (referred to as the 'Back Analysis' project throughout this report). It further presents recommended revisions to specifications for low volume sealed road pavement materials and pavement design catalogues that are based on the CBR method. Phase 3 of this project commenced in December 2018 and is scheduled to be completed in June 2020.

During Phase 2 of the Back Analysis Project, a Database of research studies in low volume roads in Sub-Saharan Africa was created. A gap analysis was then conducted to identify gaps in the Database for which data would be required to revise specifications and pavement catalogues. The main gaps identified are presented in section 1.2 of this report and are detailed more fully in the Phase 2 Final Report. Phase 3 of the project therefore carried out field and laboratory (see Phase 3 Fieldwork Report) studies to fill the crucial data gaps identified in Phase 2. Budget restrictions did not allow all the gaps identified to be investigated.

Fieldwork and laboratory testing were carried out on road sections in Ghana, Mozambique, Uganda and Zambia. In order to enhance capacity and knowledge transfer, the activities were undertaken jointly with counterparts from the participating roads agencies. The overall capacity building aim was to develop a culture of systematic research that leads to revision or development of standards and preservation of study data. This was exercised through involvement of the counterparts in all activities being undertaken. The counterparts from the participating roads agencies have been encouraged to write scientific papers for conference or journal publication to help in enhancing and retaining the skills acquired. Tables of contents for these papers have been discussed with the participating countries.

A major challenge exists in the provision of affordable, durable surfacings for LVSR. A study was carried out under the SEACAP programme in South East Asia looking at the performance of various surfacings. Given that the areas of study are high rainfall areas (up to 2500 mm/yr), lessons from this study are beneficial in road provision for Africa. The lessons from the performance of these surfacings are included in the report. A key lesson was that well-constructed penetration macadam performs as well as, and in some instances better than, double bituminous surface treatments or double stone chip emulsion seals.

Joint Analysis Workshops were held in each of the 4 participating countries. During these workshops the data pertaining to the respective countries were analysed together with the counterparts and other invitees. A joint regional workshop was then held in August 2019 in Tanzania. In this workshop, countries shared experiences and findings from their country component studies. TRL then made presentations based on amalgamated data from the Phase 3 country studies and other studies contained in the Database. The proposed revisions to the specifications and the catalogue were presented in the workshop.

In order to make the revisions to the specifications and pavement catalogues, data on the materials, traffic and climate from existing LVSR research studies contained in the Database were selected and analysed along with data from the field and laboratory study (Phase 3). The data from the field and laboratory study of Phase 3 have yet to be incorporated into the Database but this will be completed by March 2020.

It was found that most of the pavements studied had carried much more traffic than the existing LVSR specifications suggested they would be capable of carrying. This meant that revisions to the specifications and catalogues would be appropriate. The proposed revisions to the specifications include a widened materials particle size distribution envelope, a change in the maximum plasticity index for base material at 1 MESA (from 9 to 13), a change in the plasticity modulus from 180 to 270, and CBR 60% material now replaces CBR 80% material. Materials specifications for surfacings remain unchanged.

A scientific paper was prepared for presentation at the CAPSA 2019 conference in South Africa 13th – 16th October 2019. The paper set out the key steps used in the data analysis and proposed revisions to the specifications and catalogue. The paper is similar in content to Chapter 2 of this report.

Another paper will be prepared and submitted to a journal in May 2020.

# 1 Introduction

## 1.1 Background and objectives

This report presents a summary of the activities carried out during Phase 3 of the project entitled Development of Guidelines and Specifications for Low Volume Sealed Roads through Back Analysis (referred to as the 'Back Analysis' project throughout this report) and the recommended revisions to the specifications for low volume road pavement materials and pavement design catalogues.

The Back Analysis project is being carried out under the Africa Community Access Partnership (AfCAP), a research programme that is funded by the UKAid - Department for International Development (DFID) and managed by Cardno.

The overall objective of the project is to undertake a review of the performance of Low Volume Sealed Roads (LVSRs) constructed in the last four decades in order to achieve the following:

1. Provide a Database of existing LVSRs that have been investigated in relation to pavement type and materials, performance and environmental conditions, and consequently:

- Refine existing generic guidelines for selection of surfacing type as well as pavement design based on life-cycle costs.
- Corroborate and refine existing catalogues for pavement design of LVSRs in order to ensure their applicability to a wider range of materials and geographic conditions.

2. Provide a base level for information on the performance of non-standard designs and material specifications in comparison with conventional designs and specifications for roads carrying high traffic volumes i.e. >300 vehicles per day (vpd).

The project was divided into three phases. A summary of the activities for each of the phases is listed below.

- Phase 1 involved the identification of data sources; collection of historical performance data from previous studies; processing of the data; and the creation of a Database for Low Volume Roads (LVRs). The link to the Database that was developed is: www.lvroadsdata.com.
- Phase 2 involved refining and adding more data into the Database; training of counterparts from the Road Research Centres (participating road agencies) of the 12 AfCAP partner countries on how to use the Database; and identifying knowledge gaps for further studies to refine standards and design catalogues.
- Phase 3 (current phase) involved field and laboratory investigations to fill the critical gaps that were identified in Phase 2; analysis of the field and laboratory data, revision of specifications for guidelines and catalogues for pavement design; further population of the Database; capacity building of participating road agencies counterpart staff who were involved in the project activities; dissemination of findings; and production of a scientific paper.

## 1.2 Structure of this Report

The report is structured as follows:

- Chapter 1 presents the project objectives, the knowledge gaps that were identified in Phase 2, and the countries that were selected for the Phase 3 investigations.
- Chapter 2 presents the proposed revision to the materials specifications and pavement design catalogues.
- Chapter 3 discusses the lessons that were learnt from SEACAP, a program carried out in South East Asia before ReCAP.
- Chapter 4 presents the capacity building carried out under Phase 3.
- Chapter 5 presents the proceedings of the Regional Workshop held in Tanzania in August 2019.
- Chapter 6 outlines the conclusions and recommendations.

## 1.3 Data gaps identified in Phase 2 of the project

Critical knowledge gaps in the performance of LVSRs were identified in Phase 2. These included:

- Insufficient data on durability and expected age of pavements and surfacings.
- Insufficient data on performance of LVSRs subjected to traffic loading ranging between 0.5 and 1 Million Equivalent Standard Axles (MESA).
- Insufficient data on the impact of high rainfall on the performance of the base and surfacing layers in LVSRs.
- Lack of data on maintenance and its impacts on performance of LVSRs – maintenance regime vs. type of surfacing vs. environment.
- Insufficient data on dealing with weak to moderate strength subgrades in LVSRs.
- Insufficient data on unconventional road bases in different environments.
- Insufficient data on locally-available materials (types and properties) and their performance under heavy traffic loading.
- Insufficient data on non-conventional surfacings (Otta seal, Sand seals, combinations seals, Road Mix, Cold Mix Asphalt – CMA, etc.).

In order to bridge the above knowledge gaps, the following investigation matrices were suggested:

- Non-conventional surfacings versus traffic, environment and age.
- Bases versus traffic loading and environment.
- Maintenance versus climate, traffic loading, age and type of surfacing.
- Weak subgrades versus traffic loading, climate and age.

A detailed description of the knowledge gaps and investigation matrices was provided in the Phase 2 Report. This phase (Phase 3) of the project has gone a step towards bridging these gaps through studies in selected AfCAP partner countries, data analysis, and dissemination.

## 1.4 Countries of field study in Phase 3

During the inception stage of Phase 3, reconnaissance visits were undertaken, and four countries were identified as having prospective study areas that would be suitable for detailed investigations in Phase 3. Table 1 presents the countries that were selected and the main reasons for their selection.

**Table 1 Proposed study countries for Phase 3 and the corresponding justification**

| Country | Reasons for selection |
|---|---|
| Ghana | ▪ Rainfall of 1250 – 2000 mm/year in a large part of the country.<br>▪ Weak subgrades. |
| Mozambique | ▪ A large percentage of the road network was constructed using marginal materials that have generally performed well after several years in service.<br>▪ Highly varied climate. |
| Uganda | ▪ A large variety of non-conventional surfacings were constructed in the eastern and northern part of the country between 2011 and 2014.<br>▪ High quantity of rainfall with many areas receiving more than 1250 mm/year.<br>▪ Large areas of swamps and thus weak subgrades. The likelihood of finding weak subgrades is therefore considered to be high. |
| Zambia | ▪ Average rainfall conditions (750 – 1500 mm/year) in a large part of the country.<br>▪ A large variety of subgrade soils. The likelihood of finding very weak to medium strength subgrades is therefore considered to be high. |

### 1.4.1 Fieldwork

The field activities were carried out collaboratively between TRL and the Road Authorities in Ghana, Uganda, Mozambique and Zambia. The activities involved identification of suitable study roads through reconnaissance visits, field investigations including visual conditions surveys, traffic counts, axle load surveys, rut depth measurements, roughness measurements, deflections tests, DCP tests, test pits and field density tests.

### 1.4.2 Laboratory testing

Samples were collected for more detailed investigations in the laboratory. The laboratory tests involved standard tests on soils including field moisture content test, determination of field densities, determination of Atterberg limits, grading analysis, modified Proctor (or equivalent) for compaction to obtain maximum dry density and optimum moisture content, and CBR. Tests on aggregate included grading, ACV, TFV, flakiness and water absorption. Tests were also carried out on surfacings and recovered binders and they included binder content, penetration and softening point.

The field and laboratory data were compiled and analysed to determine the engineering properties of the materials from the test sections.

## 1.5 Overall approach to Phase 3

Provision of low volume sealed roads relies heavily on the appropriate use of locally available materials. The challenges to the engineer are in understanding the nature of materials in his/her setting, and then in using the materials appropriately to solve road provision problems in his/her setting. The low volume roads manuals developed under the ReCAP programme mainly contain three pavement design methods, the DCP-DN, Gourley and Greening in 1999[1], and the DCP-CBR. The DCP-DN method has been recently updated, whereas the DCP-CBR uses the same catalogue as the Gourley and Greening method. The current materials specifications and pavement design catalogues that are based on the Gourley and Greening (1999) study have not been significantly revised since they were first developed. The Back Analysis Project therefore focused on updating and revision of the Gourley and Greening specifications and pavement catalogues. It is recognised amongst low volume roads practitioners in Sub-Saharan Africa that these specifications and catalogues still show elements of conservatism. The principle of empirically-developed design methods is to continually revise any specifications as new evidence is gathered. This is the approach that many countries used in adapting the design method derived as a result of the AASHO road test of the 1960s.

In order to make revisions to the specifications and pavement catalogues, data on the materials, traffic and climate from existing LVSR research studies contained in the Database developed in Phase 1 and 2 of this project were selected, and combined with data from the field and laboratory study of Phase 3, and analysed. In total, data from 11 different studies were combined for the analysis – results of which are presented in the subsequent sections.

Therefore, the proposed revised catalogues and specifications are an improvement of the Gourley and Greening methods (based on more data) currently contained in many low volume roads design manuals currently in use in Sub-Saharan Africa.

[1] Gourley, C. S., & Greening P. A. K., TRL Limited (1999). Performance of Low Volume Sealed Roads: Results and Recommendations from Studies in Southern Africa, Volume 1, PR/OSC/167/99. London: DFID.

# 2 Revision to specifications and pavement design catalogue

## 2.1 Overall methodology

As stated in Section 1.5, selected data from the Database (developed in Phase 1 and 2) were combined with data from the fieldwork and laboratory testing (Phase 3). The data were reviewed and analysed in order to revise the specifications and catalogues. The grouping of the sections is as shown in Table 2 and the range of parameter values is as shown in Table 3.

**Table 2 Summary of road condition for each of the different types of bases**

| Type of Roadbase | Number of road sections in each category | | |
|---|---|---|---|
| | Total | Performance Rating | |
| | | Good | Poor |
| Unbound bases | 57 | 40 | 17 |
| Lime or Cement Modified/Stabilised bases | 53 | 39 | 14 |
| Total | 110 | 79 | 31 |

**Table 3 Range of the properties of the roads in this study**

| Characteristic | Minimum | Maximum |
|---|---|---|
| Traffic (MESA) | 0.5 | 5.0 + |
| In situ strength of roadbase (CBR by DCP) (%) | 43 | 150 |
| DN (mm/blow) | 6.2 | 1.9 |
| PI | 0 | 23 |
| PM | 0 | 1206 |
| Roadbase thickness (mm) | 100 | 400 |
| Structural Number of Roadbase plus Sub-base | 0.95 | 3.2 |
| Subgrade support | S1 | S6 |

The principle adopted in the preliminary stage of this analysis was to compare the properties of road sections that had performed well, or were performing well, with those of similar road sections whose performance was not satisfactory. The definitions of poor and good performance were based on the condition of the road surface that included rut depth, cracking, potholing, patching, road roughness, and other visible defects. These parameters were combined into a condition index. This index was used to categorise pavements into good or poor performers.

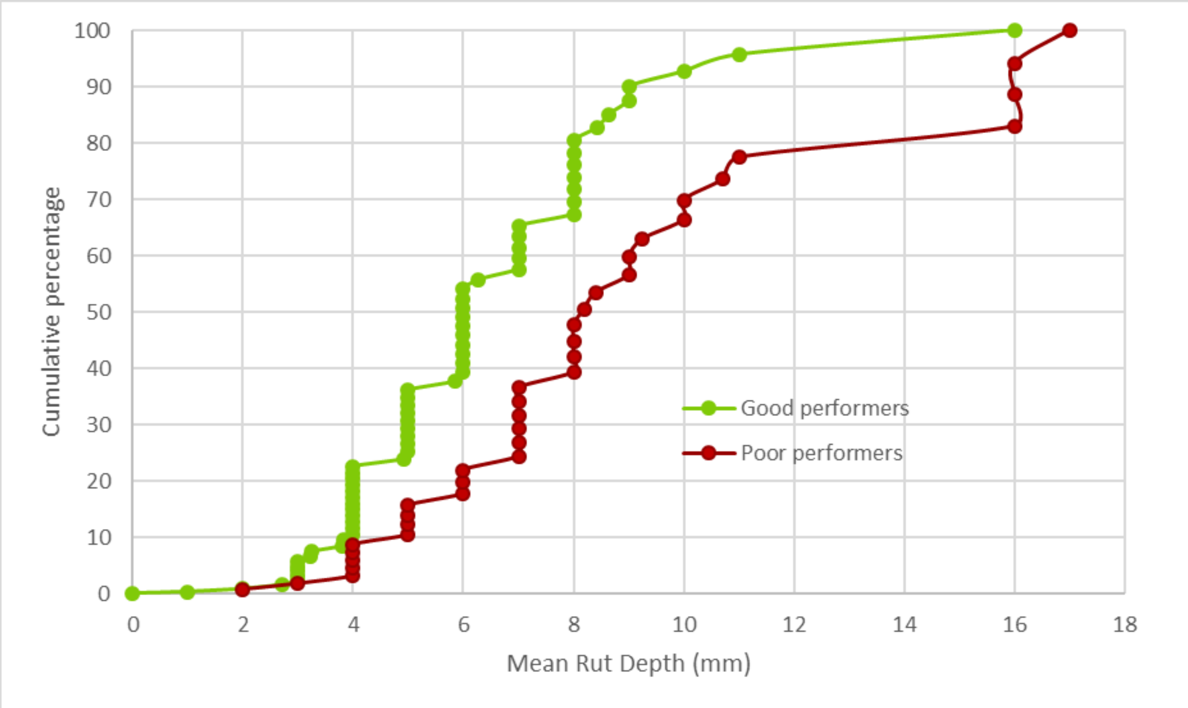
Rutting is a key structural performance defect that is used by many design methods to indicate terminal condition of pavements. Technical Recommendation for Highways 4[2] (TRH 4), Overseas Road Note 31[3] (ORN31) use a "terminal condition" of rut depth of 20 mm. In the UK, the Design Manual for Roads and Bridges (HD 29/08) identifies a rut depth of 20 mm as the intervention level of rutting. A recent study in the US Pavement Test Facility also uses rut depth as a critical structural performance parameter.

A study by Paige-Green[4] in 2015 found that several low volume sealed roads were providing satisfactory performance with rut depths well above 25 mm. Based on this, and other anecdotal evidence, it is not unreasonable to use a terminal mean rut depth of 30 mm for low volume roads.

The cumulative frequency distributions of the mean rut depths of good and poor sections analysed in this study are shown in Figure 1. Sections categorised as 'poor' on the basis of condition indices have not necessarily reached terminal rut depth (30 mm); but have marginally higher rut depths than those categorised as 'good' - meaning the poor performance is not necessarily structural.

It should be noted that any new proposed limits in the revised specifications and catalogues are based on the properties of sections categorised as 'good'.

**Figure 1 Cumulative frequency distributions of mean rut depths of sections used in the analysis**




## 2.2 Structural Number of the Pavements studied

A key method for comparing the structural capacity of two or more pavements is the Structural Number (SN). The SN is simply a total thickness parameter with each layer weighted according to its strength. SN is also the key parameter defining the traffic carrying capacity of roads in the AASHTO design method. SN has for many

[2] Department of Transport South Africa. (1996). TRH 4 Structural Design of Flexible Pavements for Inter-Urban and Rural Roads. ISBN 1-86844-218-7. Pretoria, South Africa.

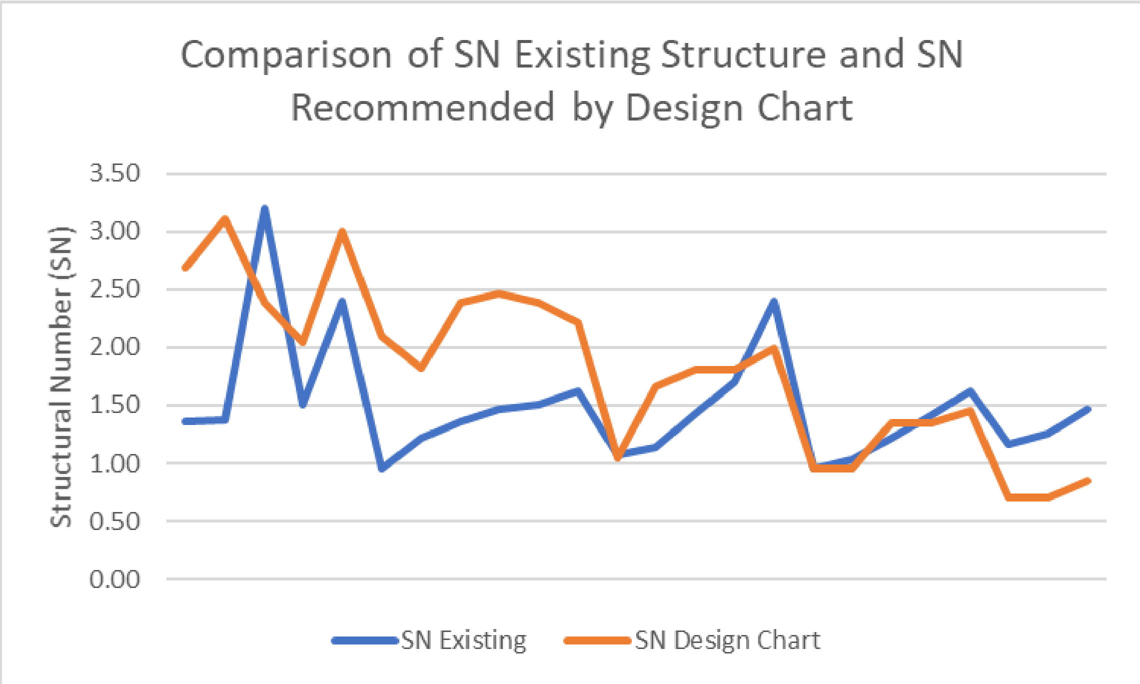
[3] Rolt, R., Smith, H. R., Toole, T., & Jones, C. R. (1993). Overseas Road Note 31 A guide to the design of bitumen-surfaced roads in tropical and sub-tropical countries. Crowthorne, Berkshire United Kingdom: Transport Research Laboratory.

[4] Paige-Green, P.(2015). An Alternative Philosophy on the Deterioration and Design of Low Volume Roads. CAPSA 2015.

years been used in the development of structural design charts as can be verified by referring to the appendix pages of many LVR manuals.

Data from the field and laboratory studies in Phase 3 were combined with data from the LVSR Database and used to compute structural numbers (SN) for all of the road sections studied. The coefficients used in the computation of the structural numbers are presented in Annex 1. They are based on 4-day soaked laboratory CBR values. The structural numbers were then compared with those computed from the design chart from Gourley and Greening (1999). A plot of this comparison is shown in Figure 2. Comparing these values shows that the design chart in many cases is specifying a significantly higher SN than was determined for the pavements in the study, despite the pavements not having reached "terminal condition". The terminal condition in this case was defined as a ninetieth percentile rut of 30 mm as appropriate for low volume sealed roads.

**Figure 2 Comparison of SN of existing structure compared with the SN recommended by the existing design catalogue**




The structural numbers of sections that had not failed structurally (limiting rut depth 30 mm) were plotted against the traffic that the sections had carried as shown in Figure 3. For ease of use, the plot was converted into a table (Table 4). These were then further converted into the strengths and thickness to develop ~~form~~ the proposed revised catalogues as shown in Table 5.

**Figure 3: Structural Number of existing pavement structure and the traffic carried without failure**

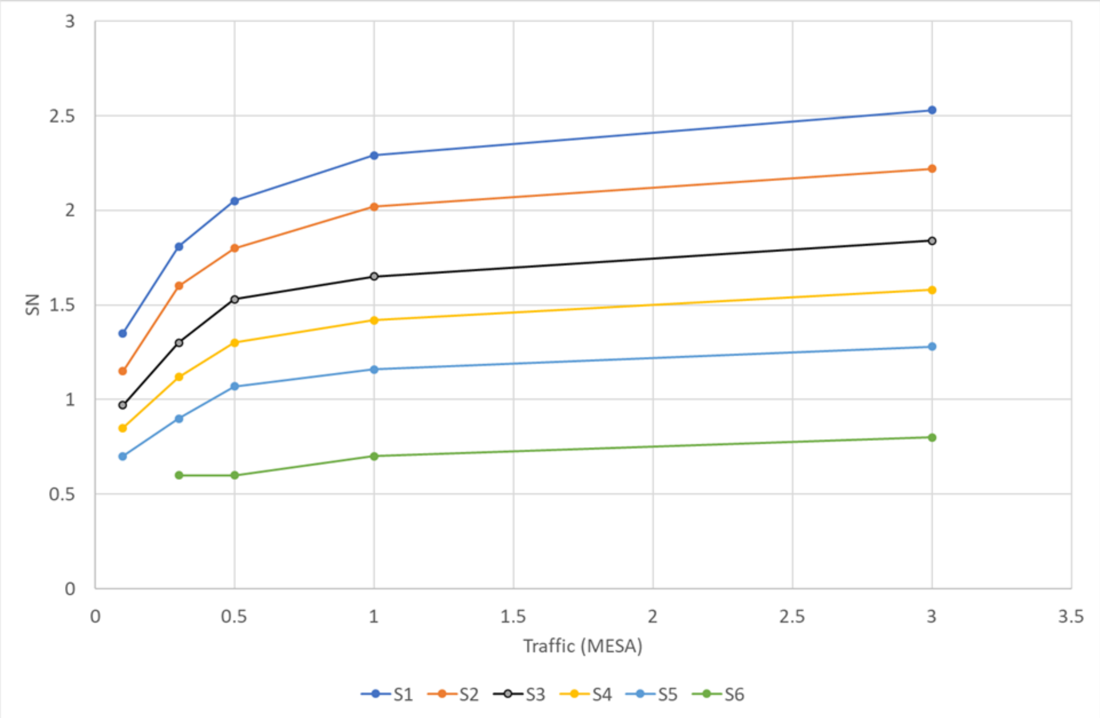



**Table 4 Proposed Revised Design Chart (SN values)**

| Subgrade Class | Traffic (MESA) | | | | |
|---|---|---|---|---|---|
| | **< 0.1** | **0.1 – 0.3** | **0.3 – 0.5** | **0.5 – 1.0** | **1.0 -3.0** |
| S1 and S2 (≤ 4%) | 1.54 | 1.56 | 1.64 | 1.66 | 1.90 |
| S3 and S4 (5% - 7%) and (8% - 14%) | 1.35 | 1.35 | 1.38 | 1.47 | 1.68 |
| S5 and S6 (15% -29%) and (≥30%) | 0.80 | 0.80 | 0.80 | 0.8 | 0.90 |

The original Gourley and Greening charts (1999) had two charts, one for regions of Weinert Number less than four (N<4) and another chart for N>4. The approach taken now is that one chart should be used, but for regions N<4 the pavement layer materials are assessed in the soaked condition whereas for regions of N>4 they are assessed at optimum moisture content (OMC).

Weinert Number N is defined as 12*E/Pa where E is evaporation in mm in the warmest month of the year and Pa is the annual precipitation in mm.

**Table 5 Revised Design Table of minimum thicknesses and minimum strengths for roads with axles < 8 tonnes**

| Structure table for roads with heavy vehicles with axles predominantly less than 8 tonnes | | | | | |
|---|---|---|---|---|---|
| **Subgrade Class** | **Traffic (mesa)** | | | | |
| | **<0.1** | **0.1-0.3** | **0.3-0.5** | **0.5-1.0** | **1.0 -3.0** |
| S1 and S2 (≤ 4%) | 150 G45 | 150 G45 | 150 G60 | 150 G60 | 150 G60 |
| | 125 G25 | 150 G25 | 125 G25 | 150 G25 | 150 G25 |
| | 150 G15 | 125 G15 | 150 G15 | 125 G15 | 150 G15 |
| S3 and S4 (5% - 7%) and (8% - 14%) | 125 G45 | 125 G45 | 150 G60 | 150 G60 | 150 G60 |
| | 125 G25 | 125 G25 | 100 G25 | 125 G25 | 125 G25 |
| | 125 G15 | 125 G15 | 100 G15 | 100 G15 | 125 G15 |
| S5 and S6 (15% -29%) and (≥30%) | 175 G45 | 175 G45 | 150 G60 | 175 G60 | 200 G60 |
| Note 1: For climatic regions N<4 or in areas where drainage is likely to be poor, the pavement layer materials should be assessed in the soaked state, for regions of N>4 the CBR of pavement layer materials should be assessed at OMC. N is defined as 12*E/Pa where E is evaporation in mm in the warmest month of the year and Pa is the annual precipitation in mm. Note 2: If the subgrade is expansive, then a protective capping of at least 600 mm compacted in 3 equal layers is required. The capping should have a PI of between 10 and 20 but the material should not be expansive. The G15 layer in this table should form part of the protective capping. Other additional treatments for expansive clays should also be applied. | | | | | |

It has been recognised that in some cases LVSRs fail prematurely due to excessive axle loads (that cause shearing of the pavement (usually base) layers) and not to the accumulated standard axles. To guard against this type of failure a second catalogue has been developed for use on roads were a significantly higher proportion of axles are heavier than the standard axle (8 tonnes) or are deemed likely to occur. This has been done by increasing the structural number values in Table 5 for subgrade classes S1 – S4 by one standard deviation and the use of G80 base material in the traffic category 1.0 - 3.0 MESA. The catalogue for this is presented in Table 6. For comparison, Table 8 shows the existing pavement structure catalogue of which the new revision is recommended.

The SNs of the good-performing roads are below the design SNs obtained using most current LVR manuals. However, for some of the newer roads the traffic carried to date is very low in comparison with the SNs. These roads would not provide a useful indication of their likely future performance and so they have not been considered in the analysis. The values shown should be considered minimum adjustments at this stage because the roads have not reached a condition that would be defined as their 'terminal condition' at which point major maintenance or rehabilitation is required.

There are several reasons as to why the roads have not yet reached terminal condition. A few of these are:

1. Although it is well-known that some roads that have been constructed using materials that do not meet the high standards specified for more heavily trafficked roads have performed well, it has not been possible to assemble enough data to confidently propose new standards until now.
2. Although it has been stated many times that the performance of LVRs depends primarily on environmental conditions and not traffic, the traditional design charts almost always show an increasing thickness (and SN) for successive revisions. As result of this, structural failure caused by a pavement that does not adequately protect the subgrade is now known to be very rare. This is

because the SNs in the catalogues are now conservative beyond the critical failure points. Therefore, designs set up to prevent this 'structural inadequacy' are not targeting the correct forms of deterioration.

3. The precise nature of this non-traffic associated deterioration has always been assumed to be related to climate and, perhaps, drainage.
4. Studies of road performance in the past have concentrated on identifying causes of failure but have often failed to reach the correct conclusions relating these causes to the structural design. This is largely because investigating the causes of road failure is not an easy exercise and to draw worthwhile and correct conclusions usually requires a large sample if statistical accuracy is to be achieved. As a result of this problem, the conclusion that a road has failed prematurely because of excess traffic, and or inadequate thickness or poor materials is understandable but has led to structures that are thicker and stronger than they need to be to fulfil their function. In the past, this has strongly affected the design of LVRs.

**Table 6 Revised Design Table of minimum thicknesses and minimum strengths for roads with axles > 8 tonnes**

| Structure table for roads with heavy vehicles with axles predominantly heavier than 8 tonnes | | | | | |
|---|---|---|---|---|---|
| **Subgrade Class** | **Traffic (mesa)** | | | | |
| | **<0.1** | **0.1-0.3** | **0.3-0.5** | **0.5-1.0** | **1.0 -3.0** |
| S1 and S2 (≤ 4%) | 150 G45 | 150 G60 | 150 G60 | 175 G60 | 175 G80 |
| | 150 G25 | 175 G25 | 175 G25 | 150 G25 | 175 G25 |
| | 150 G15 | 175 G15 | 200 G15 | 200 G15 | 175 G15 |
| S3 and S4 (5% - 7%) and (8% - 14%) | 150 G45 | 150 G60 | 150 G60 | 150 G60 | 175 G80 |
| | 150 G25 | 150 G25 | 150 G25 | 175 G25 | 150 G25 |
| | 150 G15 | 150 G15 | 175 G15 | 150 G15 | 150 G15 |
| S5 and S6 (15% -29%) and (≥30%) | 175 G45 | 150 G60 | 150 G60 | 175 G60 | 200 G80 |
| Note 1: For climatic regions N<4 or in areas where drainage is likely to be poor the pavement layer materials should be assessed in the soaked state, for regions of N>4 the CBR of pavement layer materials should be assessed at OMC. N is defined as 12*E/Pa where E is evaporation in mm in the warmest month of the year and Pa is the annual precipitation in mm. Note 2: If the subgrade is expansive, then a protective capping of at least 600 mm compacted in 3 equal layers is required. The capping should have a PI of between 10 and 20 but the material should not be expansive. The G15 layer in this table should form part of the protective capping. Other additional treatments for expansive clays should also be applied. | | | | | |

The nomenclature of the materials codes used in the catalogues in Table 5 and Table 6 are defined in Table 7.

**Table 7 Nomenclature of materials specifications used in the design catalogue**

| Code | Material | Specification Description |
|---|---|---|
| G80 | Natural gravel or modified natural gravel or crushed boulders | Min. CBR: 80% @ 98% MDD AASHTO T180 or BS Heavy Compaction and 4 days soaking<br>Max. Swell: 1.0% @ 98% MDD<br>PI: < 10 or as otherwise specified (material specific)<br>PM: <200 or as otherwise specified (material specific) |
| G60 | Natural gravel or modified natural gravel | Min. CBR: 60% @ 98% MDD AASHTO T180 or BS Heavy Compaction and 4 days soaking<br>Max. Swell: 1.0% @ 98% MDD<br>PI: < 13 or as otherwise specified (material specific)<br>PM: <270 or as otherwise specified (material specific) |
| G45 | Natural gravel or modified natural gravel | Min. CBR: 45% @ 98% MDD AASHTO T180 or BS Heavy Compaction and 4 days soaking<br>Max. Swell: 1.0% @ 98% MDD<br>PI: < 16 or as otherwise specified (material specific)<br>PM: <540 or as otherwise specified (material specific) |
| G25 | Natural gravel | Min. CBR: 25% @ 95% MDD AASHTO T180 or BS Heavy Compaction and 4 days soaking<br>Max. Swell: 1.5% @ @ 95% MDD<br>PI: <18 or as otherwise specified (material specific)<br>PM: <780 or as otherwise specified (material specific) |
| G15 | Gravel/soil | Min. CBR: 15% @ 95% MDD AASHTO T180 or BS Heavy Compaction and 4 days soaking<br>Max. Swell: 1.5% @ 95% MDD<br>PI: < 18 or 3GM + 10 or as otherwise specified (material specific) |

**Table 8 Existing pavement design catalogue**

| Subgrade CBR | Traffic (MESA) | | | | |
|---|---|---|---|---|---|
| | < 0.1 | 0.1 – 0.3 | 0.3 – 0.5 | 0.5 – 1.0 | 1.0 – 3.0 |
| S2 (3-4%) | 150 G65<br>120 G30<br>120 G15 | 150 G80<br>120 G30<br>150 G15 | 175 G80<br>150 G30<br>150 G15 | 200 G80<br>175 G30<br>200 G15 | 200 G80<br>225 G30<br>200 G15 |
| S3 (5 – 7%) | 150 G65<br>150 G30 | 175 G65<br>175 G30 | 200 G65<br>200 G30 | 200 G80<br>225 G30 | 200 G80<br>275 G30 |
| S4 (8-14%) | 150 G55<br>120 G30 | 175 G65<br>120 G30 | 200 G65<br>120 G30 | 200 G80<br>150 G30 | 200 G80<br>200 G30 |
| S5 (15 – 29%) | 120 G45<br>120 G30 | 120 G55<br>120 G30 | 150 G55<br>120 G30 | 200 G65<br>120 G30 | 200 G80<br>120 G30 |
| S6 (>30%) | 150 G45 | 150 G55 | 175 G55 | 200 G65 | 200 G80 |

## 2.3 Plasticity of the Roadbases

Plasticity is an important factor in the selection of materials for pavement layers and appears in many specifications. A material that is very plastic or which contains a high proportion of plastic fines becomes relatively weak when wet hence limiting plasticity index (PI) or, more appropriately, plasticity modulus (PM) is a method of reducing the risk of a pavement layer becoming too weak to function as intended. However, specifying PM can disqualify some materials from consideration. Figure 4 shows that there was no significant difference between the Plasticity Modulus (PM) of the roadbases of sections that are performing well and those that are performing poorly. The ranges of PI and PM values for roadbases (and sub-bases) are shown in Table 9.

The key principles of design of LVSRs were considered, which include the need to develop innovative standards and specifications that allow the wider use of locally available materials while mitigating the risks associated with relaxation of current specifications to suit LVSRs requirements. In this regard only the sections which performed well were considered for the review of the specification limits.

**Figure 4 Comparison of plasticity of base materials**

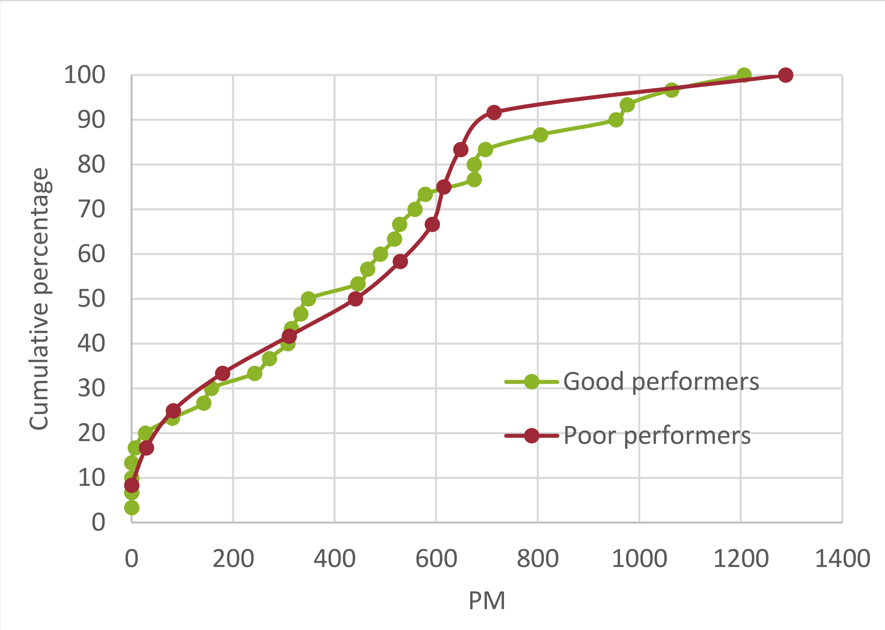



**Table 9 Plasticity characteristics for bases and sub-base**

| Value Description | Bases (> 0.5MESA) | | | | Sub-bases (> 0.5MESA) | | | |
|---|---|---|---|---|---|---|---|---|
| | PI (<9) | PM (180) | LL (45) | CBR (80) | PI (<15) | PM (600) | LL (45) | CBR (30) |
| Max | 23 | 1206 | 44 | 160 | 27 | 1755 | 50 | 100 |
| Min | 0 | 0 | 0 | 5 | 2 | 182 | 19 | 5 |
| Mean | 11 | 335 | 30 | 68 | 13 | 564 | 30 | 38 |
| 50th Percentile | 13 | 275 | 31 | 57 | 11 | 416 | 30 | 30 |
| 90th Percentile | 18 | 708 | 37 | 122 | 18 | 918 | 36 | 78 |
| 80th Percentile | 16 | 545 | 35 | 85 | 16 | 784 | 35 | 59 |
| 10th Percentile | 6 | 0 | 24 | 40 | 7 | 191 | 24 | 10 |
| Note: Table headers in brackets are specification limits | | | | | | | | |

The data show that road bases and sub-bases with PIs and PMs which were significantly higher than the specification limits on roads with significantly higher traffic loading also performed well - see Table 9.

This conclusion is significant, but the element of risk needs to be taken into account in reviewing specification limits. In developing the revised specifications, the 50th percentile values of PI and PM have been used for the high-risk situations (i.e. S3 (CBR 5%-7%) or lower and/or traffic loading is high (0.5 to 3 mesa). For other situations, the 80th and 90th percentile values have been used. Based on this principle the adjusted PI and PM specification limits given in Table 10 and Table 11 have been developed and are recommended for application in the design of LVSRs.

**Table 10 Recommended plasticity upper limits for bases**

| Subgrade Class (CBR) | Property | Upper limit of design traffic class (MESA) | | | | |
|---|---|---|---|---|---|---|
| | | 0.1 | 0.3 | 0.5 | 1 | 3 |
| S1 (< 3%) and S2 (3% - 4%) | PI | <16 (12) | <16 (12) | < 16 (9) | < 13 (9) | < 13 (6) |
| | PM | <540 (300) | <540 (240) | <540 (180) | <270 (180) | <270 (90) |
| S3 (5% - 7%) | PI | <16 (12) | <16 (15) | < 16 (12) | < 13 (9) | < 13 (6) |
| | PM | <540 (320) | <540 (320) | <540 (240) | <270 (180) | <270 (90) |
| S4 (8% - 14%) | PI | < 16 (15) | < 16 (15) | < 16 (12) | < 13 (9) | < 13 (6) |
| | PM | <540 (320) | <540 (320) | <540 (240) | <270 (180) | <270 (90) |
| S5 (15% - 29%) | PI | < 16 (15) | < 16 (15) | < 16 (12) | < 13 (9) | < 13 (6) |
| | PM | <700 (400) | <540 (320) | <540 (240) | <270 (180) | <270 (90) |
| S6 (≥ 30%) | PI | < 16 (15) | < 16 (15) | < 16 (12) | < 13 (12) | < 13 (6) |
| | PM | <700 (550) | <700 (500) | <540 (240) | <270 (240) | <270 (90) |
| Note: Values in brackets are existing specification limits | | | | | | |

**Table 11 Recommended plasticity limits for sub-bases**

| Subgrade Class (CBR) | Property | Upper limit of design traffic class (MESA) | | | | |
|---|---|---|---|---|---|---|
| | | 0.1 | 0.3 | 0.5 | 1 | 3 |
| S1 (< 3%) and S2 (3% - 4%) | PI | < 18 | < 18 | < 18 | < 16 | < 16 |
| | PM | < 780 | < 780 | < 780 | < 420 | < 420 |
| S3 (5% - 7%) | PI | < 18 | < 18 | < 18 | < 16 | < 16 |
| | PM | < 780 | < 780 | < 780 | < 420 | < 420 |
| S4 (8% - 14%) | PI | < 18 | < 18 | < 18 | < 16 | < 16 |
| | PM | < 920 | < 780 | < 780 | < 420 | < 420 |
| S5 (15% - 29%) | PI | < 18 | < 18 | < 18 | < 16 | < 16 |
| | PM | < 920 | < 780 | < 780 | < 420 | < 420 |
| S6 (≥ 30%) | PI | < 18 | < 18 | < 18 | < 16 | < 16 |
| | PM | < 920 | < 780 | < 780 | < 420 | <420 |

## 2.4 Particle Size Distribution

The ranges of particle size distributions of the base and sub-base materials from the same studies used for the SN computations were compared with the existing specifications in the LVSR manuals derived from the Gourley and Greening study. On the finer side, materials in Ghana, Uganda, and Zambia sections and other previous studies were much finer than the specification envelopes and therefore provided scope to widen the envelope on the finer side (Figure 5). Since the resultant base material envelope is wider than the sub-base envelope, the use of one envelope for both base and sub-base suffices. The proposed envelope for both base and sub-base materials is presented in Table 12.

**Figure 5 Comparison of particle size distributions for base materials**

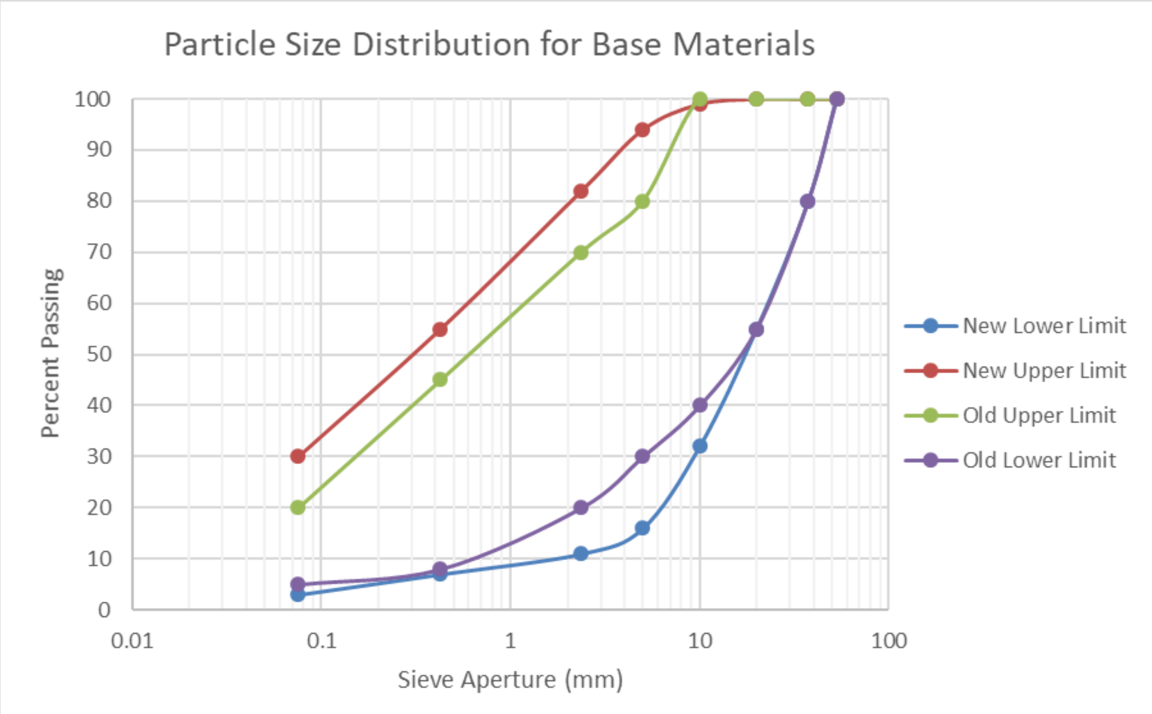


**Table 12 Revised particle size distribution for base and sub-base materials**

| Particle size distribution for base and sub-base materials for design traffic greater than 0.3 MESA | | |
|---|---|---|
| **Sieve Size (mm)** | **Percent by mass of total aggregate passing test sieve (%)** | |
| | **Lower Limit** | **Upper Limit** |
| **50** | 100 | 100 |
| **37.5** | 80 | 100 |
| **20** | 55 | 100 |
| **10** | 32 | 99 |
| **5** | 16 | 94 |
| **2.36** | 11 | 82 |
| **0.425** | 7 | 55 |
| **0.075** | 3 | 30 |
| Notes:<br>Base and Sub-base materials for design traffic less than 0.3 MESA need only meet the Grading Modulus (GM) requirement of 1.2 < GM < 2.65. | | |

Moreover, the Phase 3 fieldwork found that very coarse materials which included boulders were used successfully on Boane – Moamba Road in Mozambique and the pavements have performed exceptionally well. This road has been in existence for more than 20 years carrying mostly heavily loaded quarry trucks, and to date the mean rut depth is 7 mm and the 90th percentile rut depth is 12 mm – values well below the terminal condition rut of 30 mm. In addition, the section Macia – Chokwe Road built with a coarse Macadam base has also performed well. It has been in existence for more than 20 years in a flood plain and the mean rut depth is 6 mm and the 90th percentile rut depth is 11 mm – again values well below terminal condition rut of 30 mm. There is therefore justification in widening the envelope to include these coarse materials. The proposed envelope for coarse materials is presented in Table 13**.**

**Table 13 Particle size distribution for very coarse base and sub-base materials**

| Particle size distribution for very coarse base and sub-base materials | | |
|---|---|---|
| **Sieve Size (mm)** | **Percent by mass of total aggregate passing test sieve (%)** | |
| | Lower Limit | Upper Limit |
| **200** | 100 | 100 |
| **160** | 80 | 100 |
| **106** | 60 | 100 |
| **75** | 45 | 100 |
| **37.5** | 20 | 80 |
| **28** | 10 | 60 |
| **20** | 0 | 30 |
| Notes:<br>A blinding layer 20 mm thick consisting of 10-20 mm aggregate should to be applied on top of the base and compacted in, before applying a thin bituminous surfacing. | | |

## 2.5 Use of Proposed Revised Catalogues and Specifications

During the fieldwork carried out in Phase 3, it was apparent that poor surface and sub-surface drainage contributed significantly towards the failure of the poorly-performing sections. In general, sections with low crown heights tended to perform worse than sections with higher crowns (except where coarse or sandy materials were used in the pavement layers). It was also apparent that in some cases, failure seemed to have been induced by defects in the surfacings. Examples to show these have been discussed in the case studies presented in Section 2.6. It therefore goes without further discussion that in order to guarantee the successful application of the proposed revised catalogues and specifications, good surfacing and drainage should be ensured. This is done through carrying out timely routine and periodic maintenance (resealing or rejuvenation). Simple routine maintenance activities such as pothole patching, crack sealing, and cleaning side drains and culverts go a long way towards preserving the pavement.

In many cases, the failures observed are confined to the surfacing (high pothole and crack intensities) but are non-structural (low rut depths). This is corroborated by the Gourley and Greening 1999[5] study, Mozambique Back Analysis Study[6], and Paige-Green 2015[7] study.

It is equally important to note that good construction practices (e.g. compaction) and quality control still apply.

[5] Gourley, C. S., & Greening P. A. K., TRL Limited (1999). Performance of Low Volume Sealed Roads: Results and Recommendations from Studies in Southern Africa, Volume 1, PR/OSC/167/99. London: DFID.
[6] Rolt, J., Mukura, K., Dangare, F., & Otto, A. (2013). Back Analysis of Previous Constructed Low Volume Rural Roads in Mozambique. AFCAP/MOZ/001/G. London: DFID.
[7] Paige-Green, P.(2015). An Alternative Philosophy on the Deterioration and Design of Low Volume Roads. CAPSA 2015.

It is important when using the recommended specifications that good engineering judgement should be applied. When materials marginally outside these specifications or that do not fully comply with one or perhaps two of the specification requirements, they should not be rejected. For example, if the particle size distribution on one or two sieves, for instance is out by 3 or 5%.

## 2.6 Selected case studies

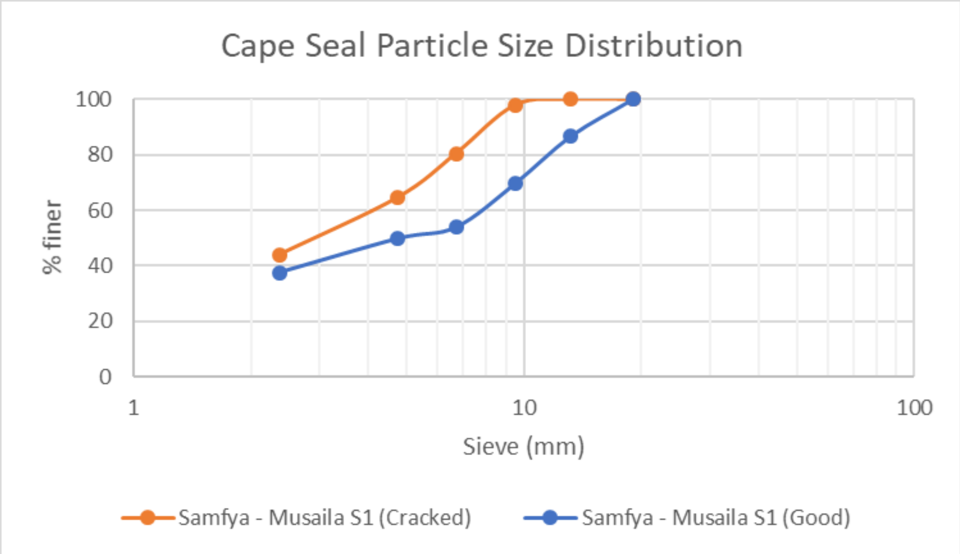
During the fieldwork, observations were made that showed that most of the pavement failures seen were caused by failures of the surfacings. No structural failures (no terminal conditions reached in case of rutting) have been observed in the bases or sub-bases or subgrade except in situations where water ingress into the base occurred after the surfacing had been breached. Two case studies illustrating this are given in below.

### 2.6.1 Case 1: Zambia, Samfya – Musaila (Wheel path cracking of the surface)

On one of the roads in Zambia (D94 Samfya – Musaila), two sections of road were studied. The road was built in 1975 and received a re-seal (slurry seal) in 2012. The characteristics of the sections studied are shown in Table 14. Section 1 (Figure 6) exhibits high levels of wheel path cracking compared to Section 2 (Figure 8) which is crack-free. The rut depth of Section 1 was marginally lower than that of Section 2. Despite the surfacing on both sections being 10 mm thick, the particle size distribution of the two seals (Figure 7) shows that the material in Section 1 is finer than that in Section 2. This could be due to a higher cement content than that in Section 2. High content of cement in slurry seals makes the seal more susceptible to cracking under load through cementation of larger particles and thus reducing the flexibility provided by bitumen.

**Figure 6 Wheel path cracking on Samfya – Musaila (Section 1)**

Figure 7 Particle size distribution of surfacing of two road sections in Zambia




The cracking has led to water ingress into the base layer of Section 1 (slightly higher Field Moisture Content to Optimum Moisture Content ratio (Table 15)) leading to a marginally weaker base layer for Section 1 than Section 2. It is likely that increased water ingress will continue to weaken the base and the rutting will increase. Thus, if no corrective action is taken, any subsequent base failure through rutting, in this case, would have been initiated by failure of the surfacing.

Table 14 Surfacing Characteristics of two road sections in Zambia

| Section | Crack Index (0-25) | Surface Thickness (mm) | Rut Depth (mm) | | Flakiness Index (%) | Bitumen Content Extraction (%) |
|---|---|---|---|---|---|---|
| | | | Mean | 90% ile | | |
| Samfya – Musaila. Section 1 (Cracked) | 20 | 10 | 5 | 9 | - | 5.8 |
| Samfya – Musaila. Section 2 (Good) | 0 | 10 | 7 | 13 | 19 | 4.3 |

**Figure 8 Good-performing surfacing Samfya – Musaila (Section 2)**


**Table 15 Moisture and strength relationship for two road sections in Zambia**

| Section | Layer | Mean FMC/OMC | Mean In-situ DCP-CBR (%) |
|---|---|---|---|
| Samfya - Musaila 1 (Cracked) | Base | 1.0 | 114 |
| | Sub-base | 1.1 | 137 |
| | Subgrade | 1.1 | 30 |
| | | | |
| Samfya - Musaila 2 (Good) | Base | 0.8 | 212 |
| | Sub-base | 1.0 | 141 |
| | Subgrade | - | 28 |

### 2.6.2 Case 2: Ghana Mpataba Junction – Half Asini (Compaction and Surfacing Induced Failure)

This road has been in service for over 12 years and has a double bituminous surface dressing. Two sections within 3 km of each other were studied (

Table 16) on this road. Section 1 (Figure 9) is cracked and rutted in the wheel paths whereas Section 2 (Figure 10) is crack-free and moderately rutted. Section 1 had highly flaky surfacing aggregates and a very low bitumen content. Maximum recommended flakiness index for surface dressing is 35% by many authorities. Table 17 shows the pavement layer characteristics of the two sections. The equivalent soaked CBR at the field density for Section 1 is only 23% whereas that for Section 2 is 57%. Section 1 was compacted to a lower density than Section 2. It is plausible that the weaker base layer of Section 1 allowed for significant rutting to occur which consequently led to cracking of the bitumen-lean surfacing. With high rainfall experienced in this area in the main rainy season, water would pond in the ruts and ingress into the base through the cracks leading to strength reduction and more severe rutting to occur.

**Figure 9 Rutting and cracking on Mpataba Junction – Half Asini (Section 1)**

**Table 16 Surfacing characteristics Road 2 in Ghana**

| Section | Crack Index (0-25) | Rut Depth (mm) | | Flakiness Index (%) | Bitumen Content Extraction (%) |
|---|---|---|---|---|---|
| | | Mean | 90% ile | | |
| Mpataba Junction - Half Asini. Section 1 (Cracked/Rutted) | 17 | 16 | 28 | 47 | 1.4 |
| Mpataba Junction - Half Asini. Section 2 (Good) | 0 | 5 | 13 | 12 | 8.1 |

Figure 10 Good-performing section on Mpataba Junction – Half Asini (Section 2)

Table 17 Pavement characteristics of Road 2 in Ghana

| Road/Section | Layer | Relative Compaction (% MDD) | CBR soaked @ Field density | CBR soaked @ design density |
|---|---|---|---|---|
| Mpataba Junction - Half Asini. Section 1 (Cracked/Rutted) | Base | 92 | 23 | 85 |
| Mpataba Junction - Half Asini. Section 2 (Good) | Base | 95 | 57 | 75 |

## 2.7 Surfacings

Most of the surfacings studied had aggregates that were well within specifications. Those that did not have materials within specifications showed defects or failures (for example as seen in Section 2.5). In addition, properties of some good performing sections in Uganda and Mozambique are presented below.

### 2.7.1 Case 3: Surfacing in Uganda (Bitumen ageing)

The inverted double surface treatment (DBST) on Ishaka - Katunguru lasted for 30 years without any reseal. Section 1 had moderate cracking (random) and Section 2 (Figure 11) showed remarkable performance with only minor defects. The binder (80/100 pen) recovered from surfacing samples collected during the study showed penetration values of 68 dmm and 57 dmm (Table 18). Because the seal has been in service for almost 30 years, much lower values of penetration, for example 10 – 15 dmm were expected.

On Matugga - Semutto road, Section 6A constructed with inverted double surface treatment also shows a low difference between initial penetration (80/100 pen) and the current penetration 91 dmm despite being in service for almost 12 years in an environment with a high ultraviolet radiation Index (14). This could be a combination of good quality binder, good construction and a more resilient inverted DBST which insulates the binder from weather elements thus minimising oxidation and loss of volatiles.

**Figure 11 Good-performing inverted Double Surface Dressing on Ishaka - Katunguru**

**Table 18 Long life Surfacings on Matugga – Semuto Road in Uganda**

| Road Section | FI (%) | TFV (kN) | TFV Ratio | Fines: 0.425 (%) | Dust: 0.075 (%) | Bit. Cont. (%) | Bit. Pen. (dmm) | Bit. Soft. Pt. (°C) |
|---|---|---|---|---|---|---|---|---|
| Ishaka - Katunguru (1) **Inverted DBST** | 11 | 285 | 79 | 6 | 0.3 | 8.7 | 68 | 49 |
| Ishaka - Katunguru (2) **Inverted DBST** | 17 | 293 | 82 | 6 | 1.1 | 8.7 | 57 | 47 |
| Matugga - Semuto (6A) **Inverted DBST** | 8.2 | 258 | 88 | 9.5 | 2.7 | 7.2 | 91 | 42 |
| **Specifications** | **35 Max** | **100 Min** | **75 Min** | **2 Max** | **1 Max** | | | |
| **Road Condition Colour Code** | Good | | Fair | | | | | |

## 2.7.2 Case 4: Thin long-life Amalgamated Surfacings on Boane – Moamba Road in Mozambique

A very thin (≤ 10mm) surfacing was built on a Telford type stone base built using large stones up to 200 mm in size. The road pavement and the surfacings have lasted for over 22 years without any reseals. Details are summarised in Figure 12.

**Figure 12 Illustration of good performance of Amalgamated Surfacings**

| | |
|---|---|
|  | Sections 1:<br>The bituminous surfacing is very thin, approx. 10 mm. However, the construction is such that the surfacing is amalgamated with the base course, which is composed of big stones and it was not possible to remove the surfacing without removing the stones attached to it. |
|  | Section 1:<br>The surfacing showed exceptional performance exhibiting minor or no cracking in the thin surfacing (approx. 10 mm). Rut depth was very low ranging from 0 – 7 mm |
|  | Section 2:<br>Some sections had cracked badly, exhibiting extensive crocodile cracking. Unexpectedly, very few potholes had developed. |
|  | This photo illustrated the type of haulage trucks which use this road. The trucks are generally overloaded with wet sand and material from the quarries. Axle loads as high as 21 tonnes were measured during the study. |

# 3 Lessons from SEACAP Pavement Trials in Vietnam

This chapter presents key lessons learnt from research that was undertaken by Intech-TRL and OTB Vietnam Ltd on pavement trials in Vietnam under the South East Asia Community Access Programme (SEACAP). The chapter shows the relative performance of the different seals and pavement options in very wet environments. The research was funded by DFID in association with the World Bank and the Ministry of Transport (Vietnam).

The objective of the research was to compare new pavement options in terms of construction and in-service performance against unsealed Vietnamese "control" sections. Thus, pavement trials were constructed with different surfacing options in different provinces of Vietnam. These Rural Road Surfacing Trials (RRST) were constructed in 3 phases. Construction was completed in 2005, 2006 and 2012 for Phase I, Phase II and Phase III respectively. The lessons represent years of pavement monitoring that was carried out, the last one being in 2019 by OTB Vietnam Ltd.

## 3.1 The pavement trials

Several pavement layer options were considered in the RRST research programme. The selection of trial options was based on the following guiding principles:

- Designs should be appropriate to the road environments.
- Local construction materials should be used where possible.
- Maintenance requirements must be closely matched to local community arrangements and resources.
- Construction techniques should be suitable for small contractors and encourage local employment.

Table 19 summarises the options that were used in Vietnam.

**Table 19: Pavement Layer Options**

| Pavement Layers | Materials Options | |
|---|---|---|
| Surfacing Layers | Bituminous seals | Double emulsion chip seal |
| | | Double hot bitumen chip seal |
| | | Emulsion sand seal and single chip seal |
| | | Single emulsion sand seal |
| | | Double emulsion sand seal |
| | Unsealed surfaces | Gravel wearing course |
| | | Water-bound macadam |
| | Block surfacing | Stone setts |
| | | Cobble stone |
| | | Fired clay brick |
| | | Concrete brick |
| | Concrete surfaces | Steel reinforced concrete |
| | | Bamboo reinforced concrete |
| | | Non-reinforced concrete |

| | |
|---|---|
| Base and Sub-base Layers | Water-bound macadam |
| | Dry-bound macadam |
| | Emulsion-stabilised sand |
| | Cement-stabilised sand |
| | Lime-stabilised clay |
| | Armoured gravel |
| | Graded crushed stone |
| | Natural sand |
| | Natural gravel |

All the pavement trials were in high rainfall areas with an annual mean rainfall of 1500 – 2500 mm/year. Therefore, the roads were subjected to wet condition for the biggest part of the year. Seasonal flooding is also experienced in these areas.

Monitoring of trials commenced immediately after completion of construction of the RRST roads.

The following data was collected during monitoring:

- Traffic data from 12-hour traffic counts
- In-situ strength using the Dynamic Cone Penetrometer (DCP)
- Condition data from visual condition surveys
- Roughness using the MERLIN
- Gravel loss using cross-section level data

The performance of the surfacing options was assessed based on the parameters presented in Table 20.

**Table 20: Performance Indicators for the Surfacing Trials**

| Surfacing Option | Performance Indicators |
|---|---|
| Bituminous seals | Crack extent, ruts, potholes |
| Unsealed surfacing | Erosions, ruts, potholes |
| Block surfacing | Block condition, joint condition, ruts, potholes |
| Concrete surfacing | Joint condition, surface condition, edge condition, crack extent |

The strengths of the base and sub-base layers were assessed in-situ through DCP tests.

## 3.2 Traffic data of the trial sections

From the traffic counts, it was established that the trial sections generally carried low levels of traffic predominantly comprising motorcycles, pedestrians and bikes. Table 21 shows 12-hour traffic count data obtained over a period of 3 days in a traffic survey that was undertaken on Thong Nhat road (Hue province) in 2019. This traffic data is typical of what was encountered on the rest of the pavement trials in this study.

**Table 21: Typical 12-hour traffic data for the pavement trials**

| Vehicle category | 14-Jul-19 | 15-Jul-19 | 16-Jul-19 | Average 12-hour traffic volume per day |
|---|---|---|---|---|
| Truck ≥ 5t | 9 | 6 | 9 | 8 |
| Light truck ≤ 5t | 21 | 14 | 22 | 19 |
| Minibus | 0 | 0 | 0 | 0 |
| 4-wheel car | 27 | 18 | 30 | 25 |
| Cong Nong (tri-cycle) | 14 | 9 | 15 | 13 |
| Motorcycle | 226 | 152 | 237 | 205 |
| Pedestrians | 172 | 109 | 186 | 156 |
| Bicycle | 192 | 161 | 202 | 185 |
| Animal/hand cart | 1 | 3 | 2 | 2 |

With this low traffic loading, performance of the pavement trials was assessed with the view point that the predominant cause of deterioration was the wet road environment.

## 3.3 Performance of lime-stabilised bases and sub-bases in the Mekong Delta

This sub-section presents in-situ strength data for the base and sub-base layers of 2 roads – My Phuoc Tay road (Tien Giang province) and Tan Thuan Tay road (Dong Thap province), abbreviated as TG6 and DT6 respectively. Their construction was completed in May – June 2005 and monitoring of the performance of their bases and sub-bases took place between then and 2010. Both roads are located in the Mekong Delta of Vietnam, a low-lying coastal region that floods seasonally.

They were built on an embankment comprising soft clayey soil with CBR ranging between 1 and 5%. The base and sub-base layers of the roads consisted of soft clayey soil with average pre-stabilisation CBR of 3% and 4% for TG6 and DT6 respectively. After stabilisation with lime, the target design CBR was 55% (base layer) and 25% (sub-base layer) for both roads.

The details of the road sections are summarised in Table 22.

**Table 22: Pavement Structures of DT6 and TG6**

| Section | From (km) | To (km) | Length (m) | Pavement Structure |
|---|---|---|---|---|
| DT6 | 0.758 | 0.933 | 175 | 20 mm sand emulsion seal on stone chip seal<br>150 mm lime modified clayey soil base (7% lime)<br>150 mm lime modified clayey soil sub-base (5% lime) |
| TG6 | 1.600 | 1.800 | 200 | 20 mm sand emulsion seal on stone chip seal<br>150 mm lime modified clayey soil base (7% lime)<br>150 mm lime modified clayey soil sub-base (5% lime) |

Figure 13 and Figure 14 present strength variation data for TG6 and DT6 respectively. There is drastic drop in strength post construction; this could be due to initial moisture migration into the pavement layers.

It was noted that for both roads, the in-situ CBR deteriorated continuously with time. This was attributed to seasonal water level movement within the embankment and pavement immediately following construction[8]. Moreover, throughout the time of monitoring, the in-situ CBR values of the base and sub-base layers were below their corresponding target design CBR values.

**Figure 13: Variation of in-situ strength of TG6 with time**

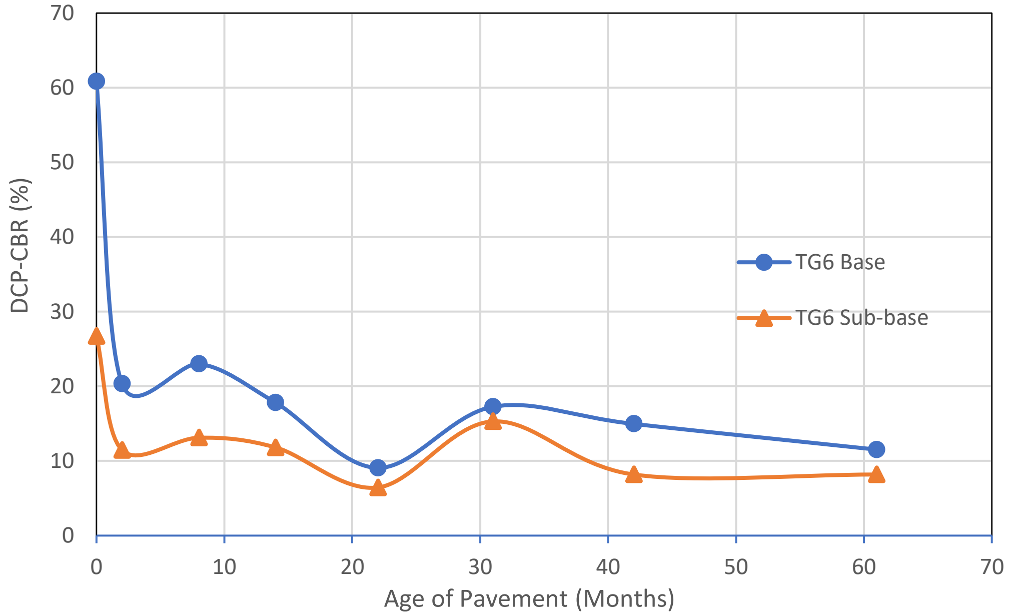
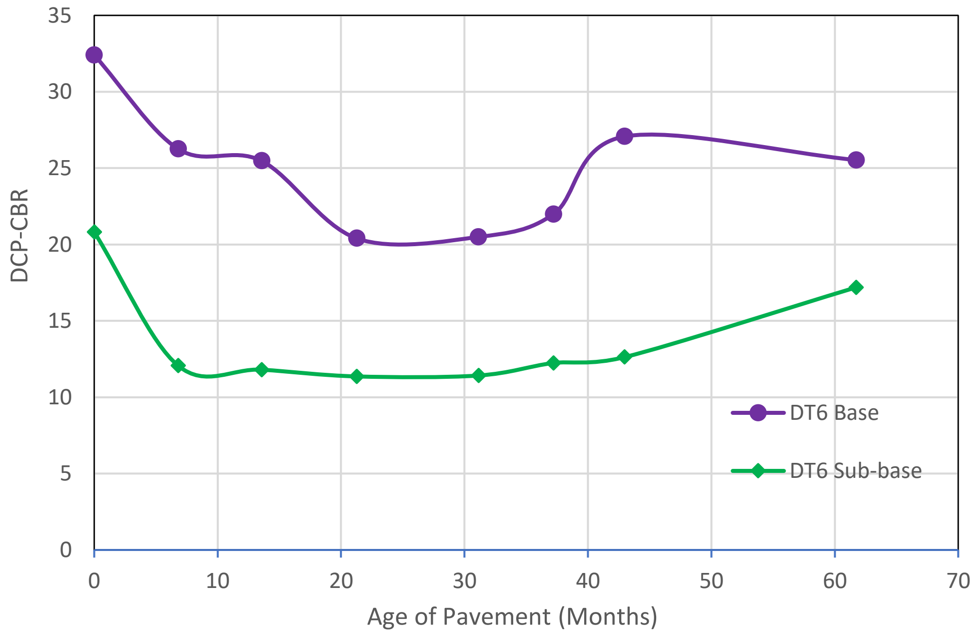



**Figure 14: Variation of in-situ strength of DT6 with time**




[8] Cook, J. & Tuan, Pham G. (2014) Rural Road Pavement and Surfacing Design Options. Improving Vietnam's Sustainability World Bank Report 919620

According to the results from visual condition survey that was undertaken in 2009, both TG6 and DT6 exhibited minor rutting (maximum 7 mm) as well as surface reflection cracking which was associated with the lime-stabilised base layers – the performance was good.

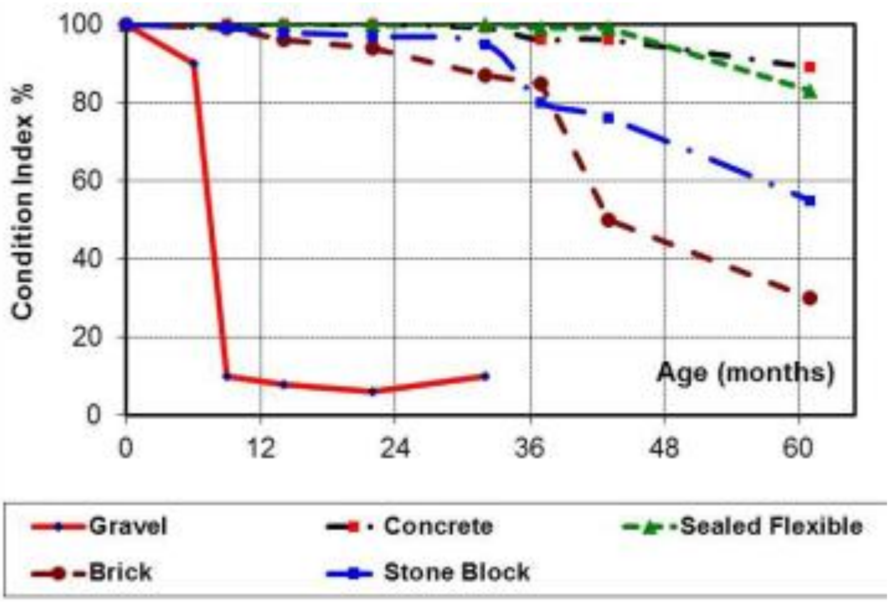
### 3.4 Performance of Surfacing Options

The performance of different surfacing options was assessed based on the overall pavement deterioration obtained from visual condition surveys from the time the construction of the sections was completed.

#### 3.4.1 Performance of unsealed (gravel) sections

An assessment of the performance of unsealed (gravel) sections in Hue province, a high rainfall area which experiences occasional flooding, revealed that unsealed (gravel) sections deteriorated rapidly within the first few months of construction (Figure 15). These findings confirmed conclusions from previous studies such as the Rural Road Gravel Assessment Programme[9] (RRGAP) that unsealed gravel wearing course (GWC) or water-bound macadam (WBM) surfacings are not sustainable options in areas of flood, high rainfall, or steep gradient.

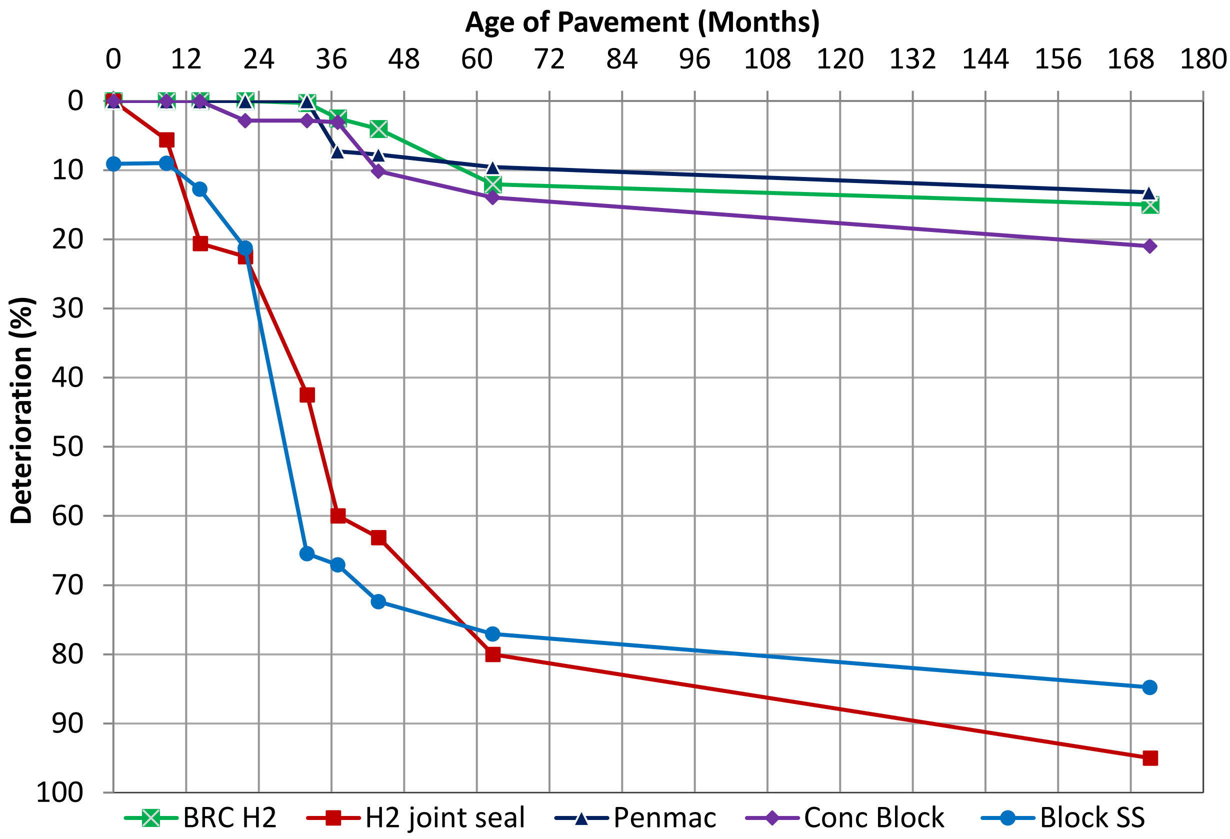
Figure 15: Performance of different surfacing options in Hue province




For the sealed sections, monitoring undertaken after 60 months of in-service pavement performance showed that concrete and sealed flexible surfacing trials performed much better than their brick and stone block counterparts. Moreover, even after 14 years of pavement service, the trials of surfaces with bamboo-reinforced concrete (BRC), concrete blocks (Conc block) and penetration macadam (Penmac) outperformed those with inter-concrete slab construction joints (H2 joint seal) and single sand seal over blocks (Block SS) – Figure 16.

[9] Cook, Jasper R. and Petts. R. C., 2005. SEACAP 4. The RRGAP Final Report. London: DFID

**Figure 16: Deterioration of different surfacing options with age of pavement in Hue province**




The performance of the different surfacing trials is further discussed in the sub-sections below.

### 3.4.2 Performance of concrete pavements

In general, the trial sections with concrete surfacing performed well. Even though cracking manifested on some sections, most of the pavement slabs performed adequately without any on-carriageway maintenance.

Other key findings on the performance of the concrete surfacing trials included:

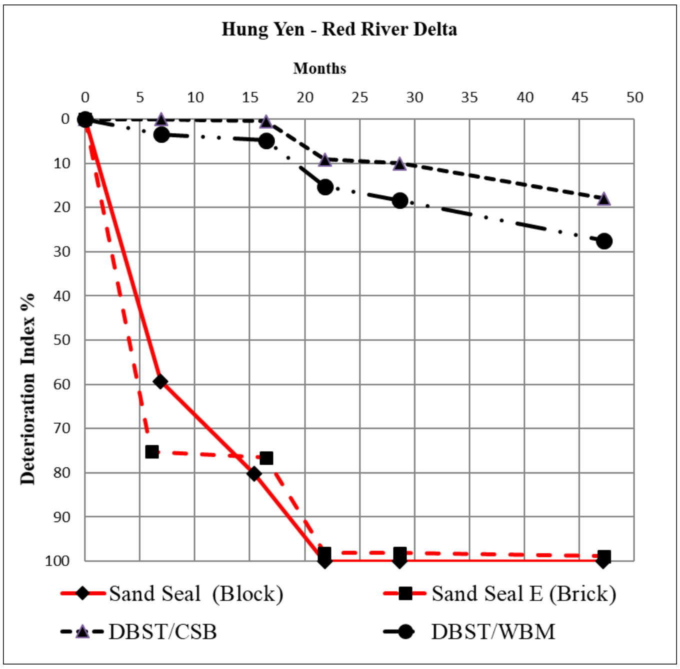
- Bamboo reinforcement in concrete did not yield any advantage over properly constructed non-reinforced concrete.
- Poor construction and curing procedures and sub-standard sub-base contributed to premature cracking of the concrete slabs.
- Poor shoulder maintenance and consequent erosion and under-cutting of concrete slabs gave rise to cracking and eventual failure.

### 3.4.3 Performance of bituminous seals

Penetration macadam (Penmac) trials were among the best performing options (Figure 16 and Figure 18). However, evidence from some monitored sections indicated that they were susceptible to shallow potholing and ravelling under heavy truck traffic. Despite good performance, penetration macadam uses a high quantity of bitumen per unit area making it an inefficient use of this expensive and high carbon footprint material.

Additionally, it was found that surfacing options with Double Bituminous Surface Treatments (DBST) overlaying Water-bound Macadam (WBM) and cement-stabilised soil (CSB) performed well (Figure 17). Although not presented graphically, it was also observed that the combination of emulsion double chip seal on dry-bound macadam base/sub-base performed as well or better than the Vietnamese standard option of hot bitumen seal over water-bound macadam base/sub-base.

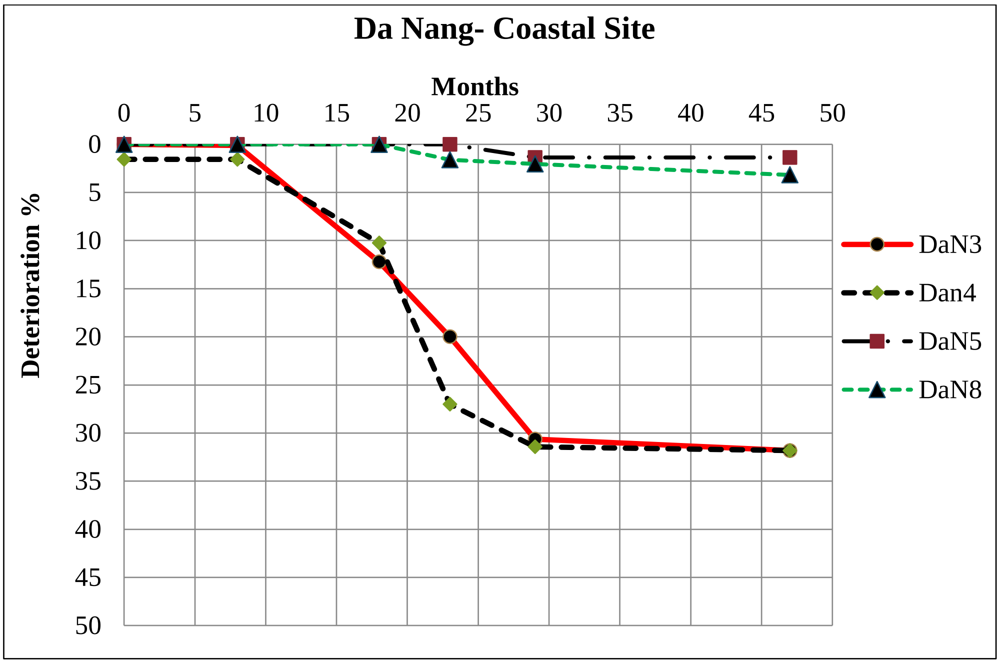
**Figure 17: Comparison of the performance of single sand seals over bricks and single sand seals over blocks with that of other surfacing options in Hung Yen province**




Single sand emulsion seals showed distinct signs of erosion. However, at the time of the last round of monitoring, most of these seals were more than 5 years old. Given that current international advice recommends that a second layer of sand seal should be laid within six to 12 months of construction, the performance of these sections could not be entirely condemned.

Sand emulsion seal on stone chip emulsion seal over emulsion-stabilised sand base performed better than sand emulsion seal on stone chip emulsion seal over cement-stabilised sand base (Figure 18).

**Figure 18: Performance of sand-emulsion seal on stone chip emulsion seal**




Notes:

The composition of the pavement layers presented in Figure 18 is summarised in Table 23.

**Table 23: Pavement Structure of sections in Da Nang Province (Figure 18)**

| Section | Pavement Structure |
|---|---|
| DaN3 | Sand emulsion seal on stone chip seal<br>Cement-stabilised sand<br>Cement-stabilised local soil |
| DaN4 | Sand emulsion seal on stone chip seal<br>Cement-stabilised sand<br>Emulsion-stabilised local soil |
| DaN5 | Penetration macadam<br>Water-bound macadam |
| DaN8 | Sand emulsion seal on stone chip seal<br>Emulsion-stabilised sand<br>Emulsion-stabilised local soil |

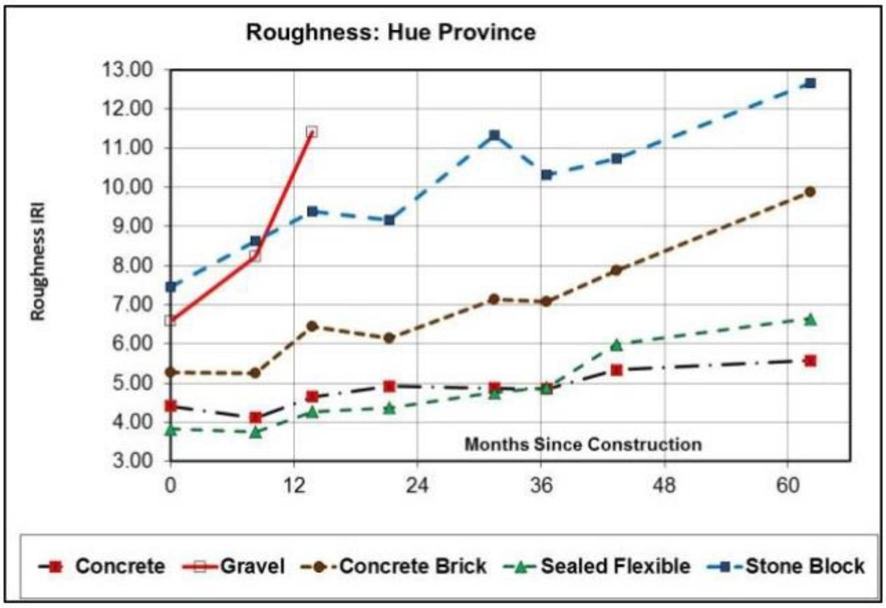
### 3.4.4 Performance of brick/block pavements

The performance of fired clay or concrete block pavements was variable. It was observed that bricks or blocks beneath single sand seals performed poorly (Figure 17). Despite this, the brick pavements themselves continued to perform satisfactorily with little or no maintenance. On the defective sections, joint and surface deterioration were the dominant defects. It was also observed that the use of mortared joints was more effective than sealed sand joints in high erosion environments.

### 3.4.5 Performance of stone block pavements

Stone cobble or stone sett (shown as stone block in Figure 19) trial pavements not only performed well but were also found to be highly resistant to rain-storm and flood erosion even in mountainous areas. However, their roughness increased significantly with time (Figure 19). Consequently, two-wheeled traffic opted to use the road shoulders.

**Figure 19: Variation of roughness of surfacing options with age of pavement in Hue Province**



### 3.5 Summary of Technical Lessons

The key technical lessons that were drawn from the SEACAP research trials in Vietnam are summarised below. For the road environment and traffic levels encountered on the pavement trials in Vietnam:

1. Gravel roads are not a suitable option in high rainfall areas (> 1000 mm/yr) and especially where longitudinal gradients are greater than 6%. Good performance can only be ensured by regular regravelling, grading, and good compaction. The frequency of maintenance would be highly uneconomical.
2. Well-constructed penetration macadam performs as well as, and in some instances better than, double bituminous surface treatments (DBST) or double stone chip emulsion seals (DBSTe).
3. There is evidence that DBSTe seals are performing at least as well as standard hot bitumen DBST seals.
4. Single sand emulsion (SBSTe) seals generally deteriorate significantly within 1 – 2 years.
5. Poor performance of concrete surfacing trials is mainly driven by sub-base or subgrade issues.
6. Bamboo reinforcement of concrete slabs did not appear to offer any improvement in performance with the well-constructed, non-reinforced concrete slabs performing equally well.
7. There is need for training of local contractors in the construction and application of DBSTe surfacings.

# 4 Capacity Building and Dissemination

## 4.1 General

In order to enhance capacity and ensure knowledge transfer to the participating roads agencies, all activities were undertaken jointly with counterparts from road agencies. This started with the site reconnaissance and continued throughout the fieldwork, laboratory testing and data analysis. The overall capacity-building aim was to develop a culture of systematic research that leads to revision or development of standards and preservation of study data. The counterparts have been asked to write conference or journal papers on the findings in their countries during the Phase 3 activities. Writing papers helps to retain and consolidate the skills gained. Possible tables of contents have been discussed with the counterparts.

Joint Analysis Workshops (JAWs) were held in Uganda (12th and 15th July 2019), Zambia (17th and 18th July 2019), Ghana (14th and 15th August 2019), and Mozambique (21st and 22nd August 2019) with teams from the research departments and the LTPP monitoring consultant. In all four countries, the joint analysis was held for two days. The road agencies and a number of consultants in the various countries participated in the joint analysis of the performance of the different sections.

The objectives of the joint analysis workshop were:

1. To empower the participants with the knowledge to query and revise existing catalogues and specifications.
2. To evaluate the implications of the study for the design, construction, maintenance, and cost-effectiveness of provision of low volume sealed roads.
3. To demonstrate the importance of accurate measurements both in the field and in the laboratory.

## 4.2 Workshop Schedule

The schedule followed for the JAWs is shown in Table 24 and Table 25. Altogether, 37 people attended the JAWs. The list and roles of participants are shown in Annex 4 – however, some participants preferred not to register.

**Table 24 Joint Analysis Workshop Schedule Day 1**

| Interval | Item | Description | Presenter |
|---|---|---|---|
| 08:00-08:30 | 1 | Registration of participants | All |
| 08:30-08:40 | 2 | Welcome remarks | Host |
| 08:40-08:50 | 3 | Introduction of participants | All |
| 08:50-09:00 | 4 | Background to the Back Analysis Project | TRL |
| 09:00-10:00 | 5 | Visual Condition Indices (Computations and Plotting) | All |
| 10:00-10:30 | Refreshment Break | | |
| 10:30-11:30 | 6 | Completion of Item 5 and discussions | All |
| 11:30-12:00 | 7 | Rainfall analysis and discussion | TRL |
| 12:30-12:30 | 8 | Introduction to DCP Analysis | TRL |
| 12:30-13:30 | Lunch Break | | |

| | | | |
|---|---|---|---|
| 13:30-14:00 | 9 | Item 8 Continued | TRL |
| 14:00-15:00 | 10 | DCP Analysis | All |
| 15:00-15:10 | 11 | Day 1 Closing Remarks | All |
| 15:10-15:30 | Refreshment Break | | |

**Table 25 Joint Analysis Workshop Schedule Day 2**

| Interval | Item | Description | Presenter |
|---|---|---|---|
| 08:00-08:30 | 1 | Registration of participants | All |
| 08:30-08:45 | 2 | Recap of Day 1 | TRL |
| 08:45-10:00 | 3 | Collation of Laboratory Data | All |
| 10:00-10:30 | Refreshment Break | | |
| 10:30-11:00 | 4 | Completion of Item 3 and discussions | All |
| 11:00-11:30 | 5 | Rainfall analysis and discussion | TRL |
| 11:30-12:00 | 6 | Introduction to Structural Number Analysis | All |
| 12:00-12:30 | 7 | Comparisons and discussions | All |
| 12:30-13:30 | Lunch Break | | |
| 13:30-14:00 | 8 | Item 7 Continued | All |
| 14:00-14:30 | 9 | Particle Size Distribution discussions | All |
| 14:30-15:00 | 10 | Summary and scope for revision of manuals and specifications for LVSRs | TRL |
| 15:00-15:10 | 11 | Closing remarks | Host |
| 15:10-15:30 | Refreshment Break | | |

## 4.3 Analysis Exercises

Samples of materials taken from the study sections were tested in laboratories in the respective countries. These test results provided the data used in the joint analysis required to develop cells in the design catalogues and specifications for the use of local materials. The data were collated, and various calculations were carried out to determine visual condition indices; structural numbers were used to make strength comparisons between the structures that existed in-situ and those that would be recommended in the pavement catalogue.

Various discussions on technical issues ensued between the team members during and following the analysis. The topics included the definition of terminal road failure conditions in terms of rutting and cracking, the potential benefits of sealing shoulders, benefits and problems of chemical stabilisation, the testing and properties of local materials and their use in the various road pavement layers, and problems with surfacing materials.

The issue of testing materials at various moisture contents to enable decisions on the exploitation of drier climatic conditions and pavement environment on material choice was also discussed. It was explained that laboratory testing of material strength in this way enables a strength/moisture relationship to be developed and provides improved options for the selection of materials that satisfy the strength requirements at the likely/required field in-situ moisture condition. This applies equally to California Bearing Ratio (CBR) and Dynamic Cone Penetrometer test methods.

Day 2 involved guiding the participants in the use of the field and laboratory data to produce the various parameters required to calculate the Structural Number of the pavement at the selected trial site; this is needed in order to calculate the strength values required to fill a cell in the design catalogue. Various technical issues arose during the exercise which included material properties and availability, discussions of Plasticity and Plastic Modulus, with some perception that the values of plasticity in the specifications tending to be rather restrictive, and the provision of sealed shoulders.

There was also considerable discussion on the subject of climate change, the impact of extreme climatic events on drainage structures, the cost of these impacts and of climate resilience measures. The consensus and conclusion reached was that climate resilience should be a serious consideration of the provision of LVSRs. Detailed information on the subject should be obtained from the ReCAP project GEN2014C Climate Adaptation: Risk Management and Resilience Optimisation for Vulnerable Road Access.

## 4.4 Feedback

Feedback from the participants was sought by means of anonymous questionnaire from participants of the Joint Analysis Workshop. The following key points were captured:

1. All participants were of the view that their knowledge of low volume road materials was greatly improved by their participation in the workshops; they rated their knowledge of low volume road materials between 1 and 3 (on a scale of 5) before the workshop and at 4 or 5 after the workshops.

2. Participants in the workshops stated that all parts of the analysis were useful especially structural number analysis.

3. Other topics that they felt should have been included in the analysis were high volume roads, sealing shoulders and traffic analysis. Traffic analysis was however addressed in all the analysis sessions.

## 4.5 Scientific paper

A scientific paper was prepared for presentation at the CAPSA 2019 conference in South Africa 13$^{th}$ – 16$^{th}$ October 2019. The paper contains the key steps used in the data analysis and proposed revisions to the specifications and catalogues. The paper is similar in content to Chapter 2 of this report.

Another scientific paper will be prepared and submitted to a journal in May 2020.

These papers count towards the dissemination activities of the project.

# 5 Regional Workshop

## 5.1 General

The Regional Workshop for the 4 participating countries was held in Dar Es Salaam, Tanzania on 29th and 30th August 2019.

The main objectives of the workshop were to:

- Share knowledge of LVSR performance between the four participating countries
- Encourage networking among the four countries participating in the field studies (Ghana, Mozambique, Uganda, Zambia) and Tanzania
- Discuss the next steps and way forward after the project.

The programme for the workshop was as presented in Table 26.

**Table 26 Programme for the Regional Workshop in Dar Es Salaam, Tanzania**

| | Item | Period | Activity | Lead |
|---|---|---|---|---|
| Day 1 Thursday 29th August 2019 | 1 | 08:30 - 09:00 | Registration of Participants | All |
| | 2 | 09:00 - 09:15 | Welcome Remarks | TARURA/PORALG |
| | 3 | 09:15 - 09:30 | General Remarks | ReCAP |
| | 4 | 09:30 - 09:45 | Opening of the Workshop | Chief Guest/Chairperson |
| | 5 | 09:45 - 10:00 | Overview of the design and performance of LVRs | Senior Researcher - TRL |
| | 6 | 10:00 - 10:15 | Overview of the Back Analysis Project | TRL Team Leader |
| | 7 | 10:15 - 10:45 | Morning Tea/Coffee Break | All |
| | 8 | 10:45 - 11:30 | General Exercises | All |
| | 9 | 11:30 - 12:30 | Presentation/Discussion of Ghana Study Component | Ghana Participants |
| | 10 | 12:30 - 13:30 | Lunch Break | All |
| | 11 | 13:30 - 14:30 | Presentation/Discussion of Mozambique Study Compone | Mozambique Participant |
| | 12 | 14:30 - 15:15 | General Discussions | All |
| | 13 | 15:15 - 15:30 | Summary of Day 1 | LVRR Specialist - TRL |
| | 14 | 15:30 - 16:00 | Afternoon Tea/Coffee Break | All |
| | | | | |
| Day 2 Friday 30th August 2019 | **Item** | **Period** | **Activity** | **Lead** |
| | 1 | 09:00 - 09:30 | Registration of Participants | All |
| | 2 | 09:30 - 09:45 | Day 2 Opening Remarks/Recap of Day 1 | Chairperson |
| | 3 | 09:45 - 10:45 | Presentation/Discussion of Uganda Study Component | Uganda Participants |
| | 4 | 10:45 - 11:15 | Morning Tea/Coffee Break | All |
| | 5 | 11:15 - 12:15 | Presentation/Discussion of Zambia Study Component | Zambia Participants |
| | 6 | 12:15 - 12:35 | Presentation by Low Volume Roads Specialist | Tony Greening |
| | 7 | 12:35 - 13:30 | Lunch Break | All |
| | 8 | 13:30 - 14:45 | Presentation/Discussion of Amalgamated Study | TRL Team |
| | 9 | 14:45 - 15:00 | Summary Remarks | ReCAP |
| | 10 | 15:00 - 15:15 | Closing Remarks | Chairperson |
| | 11 | 15:15 - 15:45 | Afternoon Tea/Coffee Break | All |

## 5.2 Welcome Remarks, General Remarks and Opening of the Workshop

Participants were welcomed by Engineer Digaga from the Tanzania Rural Road Agency who also chaired the workshop. The Workshop was opened by Engineer Haule, the Team Leader for ReCAP, who outlined the aims of ReCAP and the context of the workshop in meeting the aims of the programme.

## 5.3 Overview of the design and performance of LVRs

The TRL Senior Researcher explained the implications of the various tests that had been carried out in the field studies and the implications for design. He presented various performance charts and raised the important issue of failure criteria and the different methodologies used to analyse data.

## 5.4 Overview of the Back Analysis Project

A presentation was given by the TRL team leader, who outlined the objectives and scope of the Back Analysis project. The project has three main themes in common with other ReCAP projects which are Research, Capacity Building, Knowledge Exchange and Uptake and Embedment.

## 5.5 Ghana Presentation

The key lessons learnt from this presentation were:

- The Particle Size Distributions were outside the current design envelope even for the good performers.
- The Plasticity Indices and Plastic Modulus were outside the design specifications even for the good performers.
- Poor drainage and surface cracking were the cause of poor performance.
- The research indicated that specifications could be modified, and further research is required for additional evidence for confirmation.

## 5.6 Mozambique presentation

The key lessons learnt from this presentation were:

- The defects found were not structural but were influenced by surface deterioration.
- The Weinert value for the Macia -Chokwe road was greater than 4 thus indicating a dry region but the subgrade tended to be wet due to the effects of run off in the flood plain from rivers originating in other countries. In addition, since the area experiences occasional extreme climatic events, its annual rainfall was greater than the average – thus in those years the Weinert Number would be well below 4.
- The values of the plastic modulus were greater and material grading outside the envelope than specified values but road performance was good.
- The Back Analysis project is highlighting the need for further research to understand how non-standard materials perform under local conditions.
- There is a need to update existing manuals and specifications based on the performance evidence collected.

## 5.7 Uganda presentation:

The key lessons learnt from this presentation were:

- In comparison with other seals, the inverted double surface treatment, and single Otta plus sand seal performed well.
- The cement contents applied to the base and sub-base along the Matugga road were too high for low volume roads.
- The current low volume road design manual needs to be revised to eliminate errors including the equation for calculating traffic.
- The plasticity product and plasticity modulus should be included in the specifications.
- The in-situ structural numbers were lower than the values in the design chart.
- The current upper limit of 1 mesa in the design manual appears to be too low.

## 5.8 Zambia presentation

The key lessons learnt from this presentation were:

- The plasticity index values for all sections were within specification apart from the base and sub-base on the Mansa-Samfya road.
- The particle size distributions were slightly out of specification but performed well.
- The defects that were observed could be traced to poor drainage or thin slurry seals.
- The SN values generally complied with the chart requirements.
- The differences in the sensitivity of strength in relation to compaction of materials was noted.

## 5.9 Presentation by the consultant Low Volume Road Specialist

The presentation concentrated on the outcomes of studies conducted in Botswana, Malawi and Zimbabwe in the late 1990s.

Important lessons were learnt from both these studies:

- Models and catalogues are only guides for engineers.
- Sharing knowledge is beneficial but catalogues need local calibration.
- Local performance-based evidence is the best method for cost-effective design.
- This is best carried out by local engineers with local knowledge derived through research.
- Relevance of the Back-Analysis Project:
    - DFID through ReCAP and this project is providing opportunities for countries to take full control of their research and design catalogues.
    - The project provides opportunities to access data from studies in other countries which can provide a guide for local research.

## 5.10 Presentation and Discussions of Amalgamated Study

### 5.10.1 Lessons from SEACAP

The performance of surfacing trials initiated in Vietnam, Cambodia and Laos under the UK DFID-funded SEACAP in 2004 and continued in Vietnam under the World Bank's Rural Transport Programme until 2012 was presented by a member of the TRL team on behalf of OTB Ltd.

None of the trials have had significant 'on carriageway' maintenance. The charts presented showed the usual pattern of poor performance of single seals, especially sand seals, compared with double seals and this is confirmed in the summary of technical lessons learnt:

- Gravel roads are not economically suitable in high rainfall areas (>1250 mm/yr) and especially at gradients greater than 6%.
- Block paving is durable but can become rough and uncomfortable for road users.
- Penetration macadam is performing as well as, or better than, double surface treatments.
- Double surface treatments are performing better than single treatments.
- Double emulsion-based seals are performing as well as hot bitumen-based seals.
- Emulsion-based single sand seals deteriorated in 1–2 years.
- Poorly performing concrete sites were influenced by sub-base or subgrade conditions.
- Bamboo reinforcing of concrete has no effect and unreinforced slabs perform equally well.
- Cement stabilised bases and sub-bases have performed well but some are cracking.
- Lime stabilisation on roads in a flood plain can a problem due to leaching.
- Poor supervision is an issue.
- Designs are still conservative.
- New approach required based on climate-induced degradation rather than traffic and subgrade.
- The level at which traffic becomes the predominant mode of pavement deterioration, as opposed to climate, was observed to be around 0.8 MESA.

#### 5.10.2 Presentation by TRL LVRR Specialist

The TRL LVRR Specialist presented a summary of the analysis of the materials properties, namely, particle size distribution envelope, plasticity index, plasticity modulus, and strength characteristics for base and sub-base materials. He explained how the particle size distribution envelope had been widened using the test results. He also explained how percentiles were used to determine the revised limits for plasticity index, plasticity modulus, and strength characteristics of base and sub-base materials. Significant changes had been made to these limits. The changes allow for a wider range of materials to be used.

#### 5.10.3 Final presentation by the Senior Researcher

The TRL Senior Researcher reviewed the principles of the procedures used to assess the performance of the roads in the programme which also provided guidance to researchers to enable them and other users to undertake the process of evaluating their pavements and the data contained in the Database produced in the earlier phases of the project. He explained that only a relatively small percentage of the road surface needs to fail for the road to be considered to be in a poor condition. It is not average values that are important but the behaviour of the weakest part. He described the processes that can be used to assess the various defects and the importance of understanding the need for appreciating the coefficients of variation. The presentation concluded with a comparison of the sections in the trials that had performed well with the relevant design charts and included a draft prospective design catalogue based on the current information available and analysed to date in which the recommended design standards for low volume roads (up to 3mesa) are significantly relaxed from those in current use.

#### 5.10.4 Closing remarks and closure of the workshop

The closing speaker stated that the Back Analysis project and the presentations and discussions at the workshop re-confirmed the need, identified by ReCAP, to transfer responsibility for the development of local design catalogues to local engineers, the need for further research and the continued monitoring of trials through the LTPP. In this way, the provision of access roads for rural communities could be accelerated by lowering costs (cost-effectiveness) which is the goal of the DFID-funded ReCAP. Local participation and ownership of the programme after ReCAP ends is needed to ensure the continuance of collaboration and local investment in research.

A vote of thanks to Tanzania was proposed for hosting the workshop after which copies of all presentations made during the workshop were distributed to all participants.

### 5.11 Questionnaire Feedback

Feedback was obtained from 21 respondents and is presented in the bullet list below. The detailed feedback matrix is included in Annex 3:

- When asked 'How would you rate your knowledge of low volume roads materials before the Back Analysis Project or this workshop?', twelve participants rated their level as 3 out of 5 and five rated their level as 4 out of 5.
- The 12 participants who had rated their level as being 3 out of 5 were subsequently asked 'How would you rate your knowledge of low volume roads materials after the activities and trainings carried out in the Back Analysis Project or this workshop?'. They responded with a rating of 4 or 5 out of 5.
- When asked 'How much have you learned from this training?' Twenty participants rated their level as 4 or 5 out 5.
- When asked 'What part/s of this workshop did you find most useful?' the following responses were obtained:
    - Sharing knowledge
    - Discussions
    - Interactions
    - All parts
    - John Rolt's presentations on the approach to analyse the data

    - Discussion of Ghana Study Component, Presentation by Low volume roads specialist Tony Greening
- When asked 'Are there any subjects you feel should have been included (added)?'
    - How to conduct tests for high quality results
    - stakeholder buy in, climate change, risk management
    - Guidelines and specifications for unsealed roads by back analysis
    - Research for guidelines towards maintenance of unsealed roads
    - Detailed use of FWD in assessing road pavement structural strength
- When asked 'How do you rate this workshop overall?' All participants rated it as 4 or 5 out of 5.
- When asked 'How do you rate the facilities of the training?' 18 participants rated it as 4 or 5 out of 5, and 3 participants rated it as 3 out of 5.
- Other comments received:
    - Get together and tours should be organised for such workshops
    - More practicals and at least a week workshop, routine feedback
    - More frequent meetings/workshops of such nature needed.

# 6 Conclusions and recommendations

## 6.1 Conclusions

Fieldwork and laboratory testing have been carried out on road sections in Ghana, Mozambique, Uganda and Zambia. In order to enhance capacity and knowledge transfer, the activities were undertaken jointly with counterparts from the participating roads agencies. The overall capacity building aim was to develop a culture of systematic research that leads to revision or development of standards and preservation of study data.

Joint Analysis Workshops were held in each of the 4 participating countries. During these workshops the data pertaining to the respective countries were analysed together with the counterparts and other invited stakeholders. A joint regional workshop was then held in August 2019 in Tanzania. In this workshop, countries shared experiences and findings from their country component studies. TRL made presentations based on amalgamated data from the Phase 3 country studies and other studies contained in the Database. The proposed revisions to the specifications and the catalogues were presented in the workshop.

In order to revise the specifications and pavement catalogues, data on the materials, traffic and climate from existing LVSR research studies contained in the Database were grouped, combined with data from the field and laboratory study of Phase 3, and analysed. The data for analysis were taken from the Database developed in Phase 1 and Phase 2 of the Back Analysis Project. Data from the field and laboratory study of Phase 3 will be added into the Database by March 2020.

A scientific paper has been prepared for presentation/dissemination at the CAPSA 2019 conference in South Africa in October 2019. Another similar paper (utilising data gathered during the project) will be prepared and presented at the T2 conference in Maputo, Mozambique in May 2020.

## 6.2 Recommendations

The initiative of developing knowledge on the provision of LVSRs has come at a time when both the road authorities and road users recognise the importance of improving road networks in developing countries. The results and outputs of the Back Analysis Project have not only been an eye-opener in technical terms but are likely to influence a major paradigm shift in LVSR provision particularly the design and construction aspects. Key findings and recommendations based on the findings are given below.

1. It was found that most of the pavements studied carried much more traffic (5 MESA see Table 3) than what the existing LVSRs specifications suggested they would carry. This meant that a revision to the specifications and catalogue is possible. Based on this, the traffic loading category for LVSRs should be increased from a maximum of 1 MESA to 3 MESA while using the same design criteria for LVSRs. The initial Gourley-Greening LVSR catalogues went up to 3 MESA and data collected in the Back Analysis Project Phase 3 (see Fieldwork Report) and in the database (lvroadsdata.com) shows that locally available materials (natural gravels) are performing well on roads with traffic carried to date well in excess of 3 MESA. The scarcity of road building materials reinforces the need to make best use of locally available materials/gravels – exploiting any longevity in them to the utmost.
2. Some locally available materials which have previously been considered unsuitable have now been proven to be appropriate; the boundaries of plasticity characteristics and grading envelopes have been significantly widened. Based on the findings, the grading of bases has been extended to allow the use of very coarse materials such as macadam and Telford bases as well as very fine materials. These findings and the limits of the materials properties outlined below mean that the term 'standard materials and specifications for low volume roads', should replace terms such as 'marginal materials', 'non-standard materials', and 'non-traditional materials'.
3. The upper limits of plasticity should be increased from PI 6 -12 to 13-16 and PM 90 – 550 to 270 -700 for bases.
4. Similarly, the plasticity limits for sub-bases should be increased from PI 12–15 to 13-18. There is also a need to include upper limits for PM for sub-bases ranging from 420 – 920.

5. It is recommended where possible to design long-life pavements at relatively low cost and this includes the use of macadam and Telford bases where materials are locally available which can then be sealed with thin, amalgamated surfacings.
6. The use of CBR 60% material as a replacement for CBR 80% material used in the base layer, and CBR 25% material as replacement for CBR 30% material for sub-base layer should be adopted.
7. The specifications for surfacing materials remains unchanged.
8. Finally, roads authorities should consider incorporating the revisions proposed in this report into their country manuals and specifications.

These are very significant developments, which have positive impacts on LVSR engineering some of which are listed below:

1. The design of thinner pavements will enhance efficiency and increase outputs causing significant reduction in costs and conserve non-renewable resources.
2. A wider variety of materials is now available for road provision due to the widening of specification limits. This will significantly reduce the cost of acquiring materials, which in turn will reduce construction and maintenance costs.
3. The proposed change in the specifications of LVSRs in terms of their traffic loading is a significant and positive development. This change, which is based on LVSR performance evidence, means that the bulk of road networks in Africa including all tertiary and low to medium trafficked secondary roads can be categorised as LVSRs. This development will bring about viability and sustainability through reduction in the cost of road provision and increased economic rate of return thus attracting investment into the sector. Therefore, the proposed new definition of LVRs for pavement design purposes is: '*For pavement design purposes, a low-volume road is defined as one designed to carry a cumulative traffic loading of up to about 3 million equivalent standard axles per lane, constructed using locally available natural materials which may be modified to meet standards given in the LVR catalogues, and may be unsealed or surfaced with thin bituminous seals or discrete surfacings.*'. Roads designed for purposes of accessibility rather than mobility still fit in this definition since the design traffic loading will be less than 3 MESA.

# 7 Proposed Phase 4 Activities

During Phase 3 of the study, knowledge gaps were identified, which when filled would rapidly improve the design and performance of low volume sealed roads. The knowledge gaps and approaches to resolve them are outlined in the sections below.

## 7.1 The performance of low volume road surfacings

It was found (see Phase 3 Fieldwork Report) that most of the failures on the study roads are superficial and induced by failure of the surfacings. Therefore, a more detailed study is required with the aim of enhancing the life of surfacings.

### 7.1.1 Objective of the study

The performance of bituminous surfacings is largely affected by the quality of the bitumen – especially its ageing characteristics. Other factors that affect the performance include the quantity of bitumen used, the aggregate characteristics, and the substrate on which the surfacing is laid.

Concrete pavements also play a large part in the provision of low volume roads especially on steep slopes and in remote locations where the use of bitumen plant is prohibitive. There is a need to review the performance of some of the existing concrete sections. Therefore, the main objectives of the study are:

- To review the performance of bituminous surfacings used on low volume roads.
- Review the performance of concrete sections used on low volume roads with a view to estimating maintenance requirements and costs.

### 7.1.2 Methodology outline

A detailed study involving some advanced investigations into the performance of surfacings and specialised tests on materials (bituminous and non-bituminous) is required. A research study focusing only on the back-analysis of surfacings should be conducted in selected countries with existing low volume sealed roads. Preferably Mozambique (surfacings of AfCAP 1 sections including concrete ramps), Uganda (Matugga sections), Malawi (Cape Seals), and Tanzania (Morogoro Otta Seals). Surfacing materials from these roads would be sampled and subjected to various laboratory tests. The study would look at performance of the various sections in terms of cracking and potholing, characteristics of the bitumen and extent of ageing, characteristics of the aggregates used.

For the concrete roads, the approach would be to record all defects on the surfacing and estimate the cost of reinstating these defects. The maintenance costs of the sections would then be estimated for a chosen period of say 15 years. This will be compared with the cost of maintaining an equivalent bituminous seal on the same roads.

It is estimated that such a study could be conducted within 10 months and cost about £100,000.

### 7.1.3 Expected outcomes

A better understanding of the bitumen properties would lead to an improved method of specification of bitumen for thin bituminous surfacings. This would be a key breakthrough because it would potentially increase the performance of LVSRs from the 15 to 20 years as per the design standards to long-life pavements of about 30-40 years that can be provided at low life-cycle costs.

## 7.2 Specification of coarse aggregate bases

The fieldwork carried out in Phase 3 in Mozambique found that Telford and coarse Macadam bases were performing far beyond their design traffic. Due to the size of particles used in these bases, conventional or field tests are not applicable to these materials. This therefore poses a barrier to their use.

Additionally, appropriate construction techniques will need to be developed to encourage the wider use of these bases.

### 7.2.1 Objective of this study

The main objectives of this study are:

- To develop a method of specifying the use of coarse aggregate bases.
- To develop appropriate and rapid construction techniques for Telford bases.

### 7.2.2 Methodology outline

It is already known that these coarse bases exist on Boane – Moamba Road, Boane – Namaacha Road, and Macia – Chokwe Road in Mozambique. To achieve the objectives of the study, it would be necessary to convene a team of LVSR pavement experts, design consultants, contractors and roads agency staff for site visits and brainstorming sessions. This would be held in Mozambique where the team can visit the project roads prior to the brainstorming sessions. Following the brainstorming, a draft specification document will be produced. This document will be circulated to various countries to use to construct trial sections.

It is estimated that such a study could be conducted within 4 months and cost about £50,000.

### 7.2.1 Expected outcomes

The expected output of the project is a draft specification document. If successfully developed and applied, the use of such a document could significantly reduce LVSR provision costs in countries like Ethiopia and parts of Tanzania where coarse natural materials are abundant.

## 7.3 Damage on LVSR caused by heavy axles

The risk factor introduced for unique situations of high axle loading (excess of the 8 tonne standard axle) could be further refined (reduced). Research into the effect of high axle loading and more importantly high tyre inflation pressures, on the performance of LVSRs needs to be conducted to further refine the risk factor used in this case.

### 7.3.1 Objective of the study

A single pass of an axle whose mass exceeds the standard axle load of 8 tonnes has the potential to significantly damage LVSR constructed used natural gravels. The magnitude of this damage is proportional to the mass of the axle and the tyre inflation pressure/contact pressure. It is therefore necessary to determine the magnitude of damage that the overloaded axles would cause in order to add an appropriate factor of safety to the material strength.

The main objective of this study is to determine the magnitude of damage caused on LVSRs of various base strengths, by the passage of axles loaded to greater than the standard axle load (8 tonnes).

### 7.3.2 Methodology outline

The study would involve the construction of test sections of varying base materials and strengths. These sections would be trafficked using trucks with axles loaded to between 8 to 15 tonnes and differing tyre pressures in the wet season (when the pavement layers are at their weakest). The magnitude of damage on each test section would be measured. Using this a correlation between the base material strength and the critical damaging load and repetitions would be developed.

It is estimated that such a study could be conducted within 20 months. In order to achieve this, ReCAP should be willing to construct the trial sections. The cost of engaging a service provider to provide technical assistance to the study would be about £200,000.

### 7.3.3 Expected outcomes

If successful, the project would lead to the determination of the threshold base strength of road bases of LVSRs. In the long term, this would reduce wastage of road construction funds that is sometimes incurred by surfacing very weak bases.

# Annex 1 Structural Number Coefficients Used

The structural number is a measure of the total thickness of the road pavement weighted according to the 'strength' of each layer and calculated as follows:

$$SN = 0.0394 \sum a_i . h_i$$

where:

SN = structural number of the pavement,

$a_i$ = strength coefficient of the ith layer,

$h_i$ = thickness of the ith layer, in millimetres,

and the summation is over the number of pavement layers, n.

The structural numbers used in Chapter 2 were computed using the coefficients presented below. They are based on 4-day soaked laboratory CBR values. For the sections studied during the Back Analysis Phase 3, the layer strengths (including subgrade samples) were evaluated by moulding samples obtained from site, soaking for 4 days and testing the CBR. For studies other than Back Analysis Phase 3, the layer and subgrade strength values are soaked values obtained from the construction documents.

| Layer | Layer Type | Condition | Coefficient |
|---|---|---|---|
| Roadbase | Granular unbound | Default | $a_i$ = (29.14 CBR - 0.1977 $CBR^2$ + 0.00045 $CBR^3$) $10^{-4}$ |
| | | G100 (CBR > 100%)<br>G80 (CBR = 80%) | $a_i$ = 0.14 |
| | | With a stabilised layer underneath | $a_i$ =0.138 |
| | | With an unbound granular layer underneath | $a_i$ = 0.133 |
| | | G65 (CBR = 65%) | $a_i$ = 0.125 |
| | | G50 (CBR = 50%) | $a_i$ = 0.118 |
| | | G30 (CBR = 30%) | $a_i$ = 0.105 |
| | | G25 (CBR = 25%) | $a_i$ = 0.101 |
| | Cemented | Equation | $a_i$ = 0.075 + 0.039 UCS – 0.00088$(UCS)^2$ |
| | | CB 1 (UCS = 3.0 – 6.0 MPa) | $a_i$ = 0.18 |
| | | CB 2 (UCS = 1.5 – 3.0 MPa) | $a_i$ = 0.13 |
| | | (UCS = 0.7 – 1.5 MPa) | $a_i$ = 0.1 |
| Sub-base and capping | Granular unbound | Equation | $a_i$ = 0.01 + 0.065*$\log_{10}$ CBR |
| | | G30 (CBR = 30%) | $a_i$ = 0.105 |
| | | G15 (CBR = 15%) | $a_i$ = 0.09 |
| | | G10 (CBR = 10) | $a_i$ = 0.079 |
| | | G7 (CBR = 7) | $a_i$ = 0.065 |
| | | G5 (CBR = 5) | $a_i$ = 0.05 |

## Annex 2 List of Participants in the Regional Workshop in Tanzania

| Name | Country | Organisation | Job Title |
|---|---|---|---|
| Peter M Shirima | Tanzania | TARURA | Ag. Regional Coordinator |
| John Rolt | UK | TRL | Senior Researcher |
| Rubina Normahomed | Mozambique | ANE | Head of Department |
| Jerry Mends Kittoe | Ghana | DFR | Engineer |
| Vincent Lwanda | Tanzania | TARURA | Lab Manager |
| Steven Musumba | Uganda | UNRA | Lab Manager |
| Tran Thi Kim Dang | Vietnam | TP/SWG | Consultant |
| Tony Greening | UK | Consultant | Consultant |
| Fernando Dabo | Mozambique | ANE | Eng – Team Member |
| Mike Pinard | Botswana | Infra Africa | MD |
| Abdul Digaga | Tanzania | TARURA | Director Rural Roads |
| Ahsante Kamba | Tanzania | TARURA | Senior Technician |
| Olivia M Soli | Ghana | GHA | Research Manager |
| Christopher Ngwira | Zambia | RDA | Engineer – T&P |
| Joseline Kagombora | Tanzania | TARURA | Research Engineer |
| Meleck Y Silaa | Tanzania | TARURA | Regional Coordinator |
| Mawusi Joseph A | Ghana | DFR | Engineer |
| Eng. Tonny Mugenyi | Uganda | MoWT | Chief Materials Engineer |
| Dr. Patrick Amoah Bekoe | Ghana | DFR | National AfCAP Coordinator |
| Andrew C Mwale | Zambia | RDA | Materials Engineer |
| Carlos Cumbane | Mozambique | LEM/ANE | Engineer |
| Kenneth Mukura | UK | TRL | Senior Researcher |
| Andrew Otto | UK | TRL | BA Team Leader |
| Leah Musenero | UK | TRL | BA Research Engineer |
| Dr. Mark Henry Rubarenzya | Uganda | UNRA | Head – R&D |
| Presley Chilonda | Zambia | RDA | Principal Engineer |
| Mugume Rodgers B | Uganda | UNRA | Research Fellow |
| Dr. Jubily Musagasa | Tanzania | DIT | Lecturer |
| | | | |

## Annex 3 Detailed feedback on Regional Workshop Questionnaires

| Feedback Questions | Individual Responses : Scale 1 minimum (worst) and 5 maximum (best) | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | R1 | R2 | R3 | R4 | R5 | R6 | R7 | R8 | R9 | R10 | R11 | R12 | R13 | R14 | R15 | R16 | R17 | R18 | R19 | R20 | R21 | **Average** |
| How would you rate your knowledge of low volume roads materials Before the Back Analysis Project or this workshop? | 4 | 1 | 4 | 3 | 4 | 4 | 5 | 4 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 5 | 3 | 3 | 2 | 3 | 3 | **3** |
| How would you rate your knowledge of low volume roads materials After the activities and trainings carried out in the Back Analysis Project or this workshop? | 4 | 3 | 4 | 4 | 5 | 4 | 5 | 5 | 5 | 4 | 4 | 4 | 4 | 4 | 5 | 4 | 4 | 4 | 4 | 4 | 4 | **4** |
| How much have you learned from this training? | 4 | 5 | 3 | 4 | 5 | 4 | 5 | 5 | 4 | 4 | 4 | 4 | 4 | 5 | 4 | 4 | 5 | 4 | 4 | 4 | 4 | **4** |
| How do you rate this workshop overall? | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | 5 | **5** |
| How do you rate the facilities of the training? | 5 | 5 | 3 | 4 | 5 | 5 | 4 | 5 | 5 | 3 | | 5 | 4 | 3 | 5 | 5 | 5 | 4 | 5 | 4 | 5 | **4** |