Development of a Rural Road Note (RRN) on Pavement Design Methods for Low Volume Rural Roads

Final Scoping Report

TRL Limited

ReCAP Reference number: ***GEN 2166B***

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Cover photo: A low volume sealed road / Andrew Otto

Quality assurance and review table

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ReCAP Database Details: Development of a Rural Road Note (RRN) on Pavement Design Methods for Low Volume Rural Roads

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Abstract

Pavement design is a major part of the road provision process. The design of pavements has a major impact on the cost of the provision of low volume rural roads. There are three major empirical pavement design methods available for the design of low volume rural roads in Sub-Saharan Africa and South-East Asia. These include the CBR Method, the DCP-CBR-SN Method and the DCP-DN method. Many of these methods require different design inputs (data types). Consequently, the resulting design thicknesses and materials requirements are often different.

The designer must therefore consider a number of factors to evaluate the pavement options obtained from the different design methods. These factors include the life-cycle costs and benefits, the availability of materials and availability of construction technology, amongst other factors, before final selection of the preferred approach.

This project aims to develop a Rural Road Note (RRN) on pavement design methods for low volume rural roads. It will be developed in such a way that a designer will be able to compare design options using a systematic approach before final selection of the preferred option.

Key words

Low volume roads, Pavement design, Natural materials, Climate resilience, Geotechnical considerations, Uptake, Embedment

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The authors acknowledge the contribution of the Stakeholder Working Group (SWG) for their feedback on the Draft Scoping Report which has been incorporated into this Final Scoping Report.

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.

www.research4cap.org

Acronyms, Units and Currencies

£	Pound Sterling (£ 1.00 ≈ provide conversion to local currencies)
ΔSN	Difference between existing and required structural number
AADT	Annual Average Daily Traffic
ADT	Average Daily Traffic
AfCAP	Africa Community Access Partnership
AFCAP	Africa Community Access Programme
AsCAP	Asia Community Access Partnership
CBR	California Bearing Ratio
DCP-DN	Dynamic Cone Penetrometer – DCP Number
DfID	Department for International Development of the United Kingdom
EIRR	Economic Internal Rate of Return
Esa	Equivalent standard axles
HDM-4	Highway Development Model - 4
IRI	International Roughness Index
LVR	Low Volume Roads
LVRR	Low Volume Rural Roads
MESA	Million Equivalent Standard Axles
NPV	Net Present Value
ORN	Overseas Road Note
PMU	Programme Management Unit
ReCAP	Research for Community Access Partnership
RED	Road Economic Decision
RRCs	Road Research Centres
RRN	Rural Road Note
SEACAP	South East Asia Community Access Programme
SN	Structural Number
SWG	Stakeholder Working Group
ToC	Table of Contents
ToR	Terms of Reference
ToT	Training of Trainers
TRL	Transport Research Laboratory
UK	United Kingdom (of Great Britain and Northern Ireland)
UKAid	United Kingdom Aid (Department for International Development, UK)
VOC	Vehicle Operating Costs

Executive summary

The project was launched on the 15th May 2019 and is scheduled to be completed by 31st May 2020. The main aim of the project is to develop a concise Rural Road Note (RRN) on pavement design methods for low volume rural roads. This will draw on the strengths of the low volume roads manuals that have been developed for several ReCAP partner countries. It will also draw on several other manuals and design documents mentioned and referenced in the Inception Report, such as Overseas Road Note 31 (ORN31), Design Manual for Low Volume Sealed Roads Using DCP-DN for Malawi, and the Technical Recommendation for Highways 14 (TRH14). The outcomes of research studies, especially those conducted under ReCAP, will also be used in the development of the RRN. Examples of such studies include the Back Analysis Project (RAF2069A), the Climate Resilience Project (GEN2014C), the LTPP Monitoring Project (GEN2132A) and others from AFCAP 1 and SEACAP.

The inception phase of the project involved undertaking a desk study to identify reference documents, constitution of the Stakeholder Working Group (SWG) and development of Terms of Reference (ToR) for the SWG.

This report presents the proposed table of contents for the Rural Road Note (RRN) 01: A Guide on the Application of Pavement Design Methods for Low Volume Rural Roads. There are 8 chapters and 1 appendix proposed to form the RRN. This includes:

1. Introduction
2. Pavement Design Methods in General
3. Summary of the Design Methods for Paved Low Volume Rural Roads
4. Summary of the Design Methods for Unpaved Low Volume Rural Roads
5. Surfacings
6. Economic Analysis
7. Selection of Appropriate Pavement Design
8. Practical Considerations
9. Appendix A: Summary of the Design Methods and Major Differences

Given the importance of the RRN that is being developed, an Uptake and Embedment Plan will be developed to meet the objectives of the request from stakeholders.

1 Introduction

1.1 General

TRL is preparing a Rural Road Note (RRN) to guide practitioners on the application of pavement design methods for low volume rural roads (LVRR). This is an inter-regional project under the Research for Community Access Partnership (ReCAP) – a research programme managed by Cardno Emerging Markets (UK) Ltd on behalf of the UK Department for International Development (DFID).

The overall objective of this project is to develop a concise RRN on the Pavement Design Methods currently in the designers' "tool box" for LVRR.

The specific objectives include:

- Identifying and reviewing suitable reference documents for the development of the RRN;
- Outlining available methods that can be used for pavement design of LVRR;
- Demonstrating the limitations of each design method including the environment in which the methods are most suitable for application;
- Providing procedural guidance for application of the pavement design methods; and
- Assessing the current status of the reference documents and indicating any updates that need to be made in order to make them compatible with the RRN.

The project is divided into two phases.

Phase 1 is the scoping phase that deals with identifying the scope of the proposed RRN. A key activity in this Phase is the development of a plan for uptake and embedment of the RRN. The Uptake and Embedment Plan will be presented in a separate report.

Phase 2 is the document development stage. This involves production of the document to address the need for the RRN. A key activity of Phase 2 is implementation of the Uptake and Embedment Plan. This will involve activities geared at promoting the RRN for day-to-day use in the ReCAP partner countries and elsewhere.

1.2 Context of the Scoping Report

During the inception stage, the plan was to circulate a draft table of contents to stakeholders and get feedback prior to the SWG meeting; but this was altered as it was considered better to refine the proposed table of contents during the SWG meeting and then circulate that version to the broader stakeholders for feedback. This report presents the proposed table of contents for the RRN after addressing the resolutions of the first SWG meeting. The initial proposed scope has not been included in this report; it can be found in the Draft Scoping Report. This version will be circulated to stakeholders. The stakeholder feedback will be incorporated in the revised version of the scoping report. The Uptake and Embedment strategies previously included in the Draft Scoping Report have been developed into a separate standalone document and no longer form part of this Scoping Report.

1.3 Structure of this Document

Chapter 2 presents the feedback and resolutions that were agreed during the SWG Meeting. Chapter 3 presents the revised table of contents following the resolutions made at the SWG Meeting. An appendix of a summary of the key features of the main pavement design methods has also been included in this report.

2 Feedback from SWG Meeting

2.1 Attendance and opening remarks

The first Stakeholder Working Group Meeting was held on 28th August 2019 at the Holiday Inn in Dar Es Salaam, City Centre in Tanzania. It was attended by SWG members and the TRL team as shown in Table 1.

Table 1 Attendance for RRN 1st SWG Meeting

No.	Proposed individual to fill the position	Region/Role Represented
1	Joseph Haule	ReCAP PMU
2	Tony Greening	Technical Panel/Pavement design expert/Manual development
3	Patrick Bekoe	West Africa/Government representative/Practitioner/Academic
4	Dang Tran	Southeast Asia/Academic Institutions
5	Rubina Normahomed (ANE – Mozambique)	Southern Africa /Roads Agency Representative/Practitioner
6	Tonny Mugenyi (MoWT – Uganda)	Eastern Africa/ Government Representative
8	Mike Pinard	East and Southern Africa/LVR Pavement design expert/Manual development expert/consultant
9	Andrew Otto	TRL RRN Team Leader
10	John Rolt	TRL Lead Author
11	Kenneth Mukura	TRL Author
12	Leah Musenero	TRL Author

Mr. Joseph Haule (Team Leader - ReCAP PMU) opened and chaired the meeting. His main points were:

- This is a legacy project for ReCAP
- The RRN will go a long way in providing clarity to users
- It is good that the RRN will follow on from the Overseas Road Notes
- The RRN should be a document that is used and not simply filed
- The RRN needs to be well disseminated
- It is good that the next generation of research experts is being groomed; though RRCs are still facing challenges.

The TRL Team Leader presented the background to the project, objectives of the project, progress to date, and objectives of the SWG meeting. He stated that at the end of the meeting the team would like to be clear on the following issues:

- What ReCAP refers to as Pavement Design Methods – Manuals and documents or methods contained in them
- The extent to which associated topics, e.g. Climate Resilience, Drainage, Geotechnics should be covered
- Clarity on what is meant by "Rural Roads"
- The proposed revision to the definition of Low Volume Roads, in the context of the environments where the RRN will be mostly used, Asia and Africa
- The proposed new title of the RRN document.

2.2 Meeting Schedule

The meeting schedule is shown in Figure 1. Presentations on the various chapters contained in the Draft Scoping Report were made by the TRL Team and discussions were held around the proposed content of the RRN. Resolutions were made following these discussions.

Figure 1 Schedule of 1st SWG Meeting

	Item	Period	Activity	Lead
Wednesday 28th August 2019	1	10:00 - 10:15	Introductions and Registration	All
	2	10:15 - 10:30	Welcome Remarks and Task Briefing	ReCAP
	3	10:30 - 10:45	Overview of the project and Progress to date	TRL Team Leader
	4	10:45 - 12:00	Discussions on Chapters 1-4	TRL Lead Author
	5	12:00 - 13:00	Lunch Break	All
	6	13:00 - 13:45	Discussions on Chapters 5-8	TRL Team Leader
	7	13:45 - 14:30	Discussions on Chapters 9-12	TRL Lead Author
	8	14:30 - 15:00	Discussions on Uptake and Embedment Plan	TRL Author
	9	15:00 - 15:30	General Discussion & Summary of Resolutions/Next Steps	ReCAP
	10	15:30 - 16:00	Afternoon Tea/Coffee Break	All

2.3 General Comments

The following general comments were made regarding the Draft Scoping Report and the Project:

1. Will there be scope to comment on the other project documents such as the Inception Report?

   Response: The decision lies with the PMU on who to circulate documents for comments. The PMU believes there is scope to receive comments.

2. There are recent documents that represent new developments in the DCP-DN design method, and these have not been mentioned in the Inception Report.

   Response: This is noted and will be actioned upon by the Service Provider (SP), and the SP is open to receiving any documents that the SWG members identify as useful to the project.

3. Will other project documents be circulated to the SWG?

   Response: Project outputs going forward will be circulated.

2.4 Resolutions

The following resolutions were made:

1. Pavement Design Methods.

   From comments received, it appears that there is a misunderstanding between pavement design methods and pavement design documents/manuals.

   Resolution: The Inception Report and the Draft Scoping Report spell out the three main empirical pavement design methods commonly used for design of LVRs in Sub-Saharan Africa and South-East Asia to be considered. Several documents/manuals that contain these methods may have to be referred to in the RRN. The 3 pavement design methods that will be contained in the RRN are:

   - The California Bearing Ratio (CBR) Method,
   - The Dynamic Cone Penetrometer – California Bearing Ratio – Structural Number (DCP-CBR-SN) Method,
   - The Dynamic Cone Penetrometer (DCP)– DCP Number (DCP-DN) Method.

2. The extent to which associated topics, e.g. Climate Resilience, Drainage, Geotechnics, Compaction, Sealing Shoulders and Borrow-pit management, should be covered.

   Resolution: These are important topics which enable the RRN to be “stand-alone” and incorporate important findings coming out of other ReCAP projects. These should be included under a chapter called “Practical Considerations”.

3. The definition of “Rural Road”.

   Resolution: This should be left open and not constrained to a specific definition, since individual countries have different classifications of rural areas.

4. Definition of Low Volume Roads (LVRs).

   The SP proposed that an LVR should be defined as “one carrying up to 3000 ADT and cumulative traffic loading of up to 3 MESA 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.”

   This new definition was on the basis that the current geometric standards for LVR of > 300 ADT can carry thousands of vehicles per day without requiring any change in the geometry. Moreover, many countries, classify their roads on a functional basis, the lowest functional class of which permits for lower level of service (high passenger car units per hour) approximating to thousands of vehicles per day. Regarding pavement design, it has been shown that natural materials (gravels) can carry well in excess of 3 million equivalent standard axles (MESA). Indeed, the initial Gourley and Greening[1] catalogues went up to 3 MESA, and no scientific reason exists for lowering the definition of low volume roads to 1 MESA only.

   Resolution: The revision to 3000 ADT will not be adopted. For pavement design purposes however, the following definition will be adopted: “For pavement design purposes, a low-volume road is defined as one carrying a cumulative traffic loading of up to about 3 MESA 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.”

5. The proposed new title of the RRN.

   The ToR stipulates that the title of the RRN should be “Rural Road Note on Pavement Design Methods for Low Volume Rural Roads”.

   Resolution: The title proposed in the Inception Report shall be adopted, that is: “RRN 01: A Guide on the Application of Pavement Design Methods for Low Volume Rural Roads.”

6. Chapter 3 Subgrade Strength Assessment.

   Focuses on moisture condition for assessment and does not include other important aspects of subgrade strength assessment like test methods, and compaction levels.

   Resolution: Test methods, compaction levels and moisture condition will be covered as part of subgrade assessment.

7. In Chapter 6 Relaxation of Materials Requirements.

   The word “relaxation” has negative connotations and should be changed.

   Resolution: Before going on to relaxation of materials, first there should be a section on “selection of materials” and then a section on “choice of materials”; the word “choice” replaces “relaxation”.

   Concrete pavements should not be included in this section. It can be discussed briefly as a surfacing material in areas of steep gradients or high erosion.

8. Chapter 9 Slopes, Embankments and Cuttings.

   This issue does not affect only LVRs and there are several specific documents available that deal with these topics.

   Resolution: A brief outline of key aspects that should be considered will be presented under the proposed new chapter “Practical Considerations”.

9. Chapter 10: Economic Analysis.

   The determination of user costs is not easy. However, when upgrading a road from unpaved to paved standard, significant reductions in user costs occur and this has to be accounted for in economic analysis, in some way.

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[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

Resolution: The chapter should not be complicated to the extent of requiring the use of HDM-4 or RED. However, the chapter should include information on what types of data to collect, and how the data should be used in a simple economic analysis. The type of analysis should include both user costs and agency costs (construction and maintenance). Two cases should be considered, upgrading a road from unpaved to paved standard and comparison of two paved standard options. If possible, cost estimates of typical pavement structures should be given.

This resolution was later altered upon comments received from a reviewer. The RED Model is very important in that it was designed to be a simplified model in place of HDM-4. Moreover, financiers often require some form of economic justification for undertaking projects. Outputs of the RED Model meets the requirements of many financiers. Therefore, the chapter should discuss the input data required for the model and the outputs and interpretation of these outputs.

10. Chapter 11 Selection of Appropriate Pavement Design.

    It may not be possible to use a design example which is hypothetical, this could be misunderstood.

    Resolution: The chapter should include a methodology of comparing two or more designs that a designer may consider. The data needed for comparison and the steps for comparison should be included.

Key resolutions changing the structure of the proposed RRN (ToC)

11. Chapter 1 should include "Approach to Design" by the different pavement design methods.
12. Chapter 2 (now Chapter 3) should encompass key aspects of each of the design methods for paved (sealed roads). In discussing the methods, reasons should be given as to why a given design method may not require parameters required by other design methods. It should also include how each design method deals with design of new roads and upgrading existing roads.
13. There should be a Chapter 3 (now Chapter 4) that is similar to Chapter 2 (now Chapter 3) but focussing on key aspects of each of the design methods as related to the design of unpaved roads.
14. There is a need to include a chapter or section on "Surfacing Strategy to Minimise Lifecycle Costs". This will be highly beneficial to roads authorities in network management/maintenance. This chapter should contain guidance on how to select surfacings in relation to the pavement structure, and road environment.
15. There should be a chapter/section on "how using each pavement design method would influence other road pavement attributes e.g. source of materials, need to seal shoulders, quality control requirements, etc".

Resolutions on Uptake and Embedment Strategy

16. It was recognised that uptake and embedment is indeed a major challenge affecting a large number of outputs from projects/initiatives. In order to have an effective output uptake and embedment, the following are recommended:
    - Initiate implementation of the strategy as soon as possible
    - Target involvement of high-level government officials and champions – ReCAP country co-ordinators should assist with this and possibly DfID leads such as SRO for ReCAP
    - Involve engineering professional institutions, academia, regional and SSA associations (eg ASANRA, ARMFA) and development partners (eg World Bank, ADB, AfDB, KfW, EU)
    - Include consultants and contractors as trainees in Training of Trainers programmes
    - Prepare news items/alerts, blogs (topical advantages, impacts) of the RRN that can be used by champions/politicians to show the value of the RRN
    - Target conferences such as IRF (May 2020), T2 and FIDIC to raise awareness of the upcoming RRN.

Other comments

17. Further comments/suggestions should be emailed to the TRL RRN Team Leader or the Lead Author.

18. The proposal for the next RRN SWG Meeting to happen in December 2019 was considered problematic as it is a holiday season. It was proposed that the next meeting should take place around 10th January 2020.

3 Feedback from Stakeholders

The draft table of contents refined after the Stakeholder Working Group meeting was circulated to more than 130 stakeholders. Feedback that has led to a further alteration of the proposed Table of Contents is presented below, whilst detailed feedback is included in Annex 2.

- Consider treating internal drainage (sealing shoulders, achieving good crown height, permeability inversion, sub-surface drainage) as part of the pavement design process rather than as a "practical consideration".
- There should be a section before "Definition of LVRs and LVRRs" (currently section 1.1) that sets out the overall Design Philosophy for LVRs to put the three design method into context. This should cover things such as:
    - Environmentally Optimised Designs and the increased influence of the environment v traffic
    - Designing around the locally available materials which may be outside current specifications for optimal costing as opposed to finding materials to meet rigid specifications;
    - Using existing gravel roads in the pavement layer as sub-base as opposed to rip and re-compacting;
    - Definition of terminal condition for LVRs and acceptable levels of service. Surfaced LVRs with greater than 20 mm ruts and some cracking are still providing acceptable LoS which has impact on the maintenance and rehab strategies in terms of life cycle costing.
- Though it is not within the scope of the guidelines to discuss the surfacing in detail, it would be nice if the document could give some clear guidelines on the choice of surfacing type for low volume roads otherwise it looks like all the areas have been captured.
- Provide a background of the regions under focus i.e. Africa and South East Asia and consider including the following:
    - The regional setting and common features of LVRs in the countries within the regions, (common climatic conditions, economic factors, road network characteristics and classification)
    - A problem statement discussing the challenges faced in the design of pavements for LVRRs and reflect on the needs of the regions
    - a brief of knowledge and practical experience gained from pavement design in the regions/countries
- Write a note on the importance of carrying out engineering condition surveys before commencement of the pavement design. This is to assess the existing condition of the road and may inform on the pavement design approach.

4 Revised Scope/Table of Contents

Following the resolutions made during the SWG Meeting, the draft table of contents for the RRN was revised. The revised version presented in this chapter will be circulated to other ReCAP country stakeholders to solicit feedback as to whether it represents their requirements.

1 INTRODUCTION

1.1 DEFINITION OF LVRs and LVRRs

This section will provide a detailed description of low volume roads in general. Emphasis will be made on the definition as applied to pavement design.

Currently it has been common to define or classify Low Volume Roads (LVRs) by defining the traffic range that they represent and the traffic loading for which they are designed. It is the opinion of a growing number of road engineers that the current definitions are too rigid for the following reasons.

The natural break point from LVR to a higher standard in terms of geometric design quite naturally occurs when the road standard needs to be such that the required number of lanes changes. This occurs when one lane with passing places needs to become two lanes and when two lanes need to become four. Both are dependent on traffic level. However, these two transition points do not align with the current definition of LVRs. Except in a crowded and busy urban situation, a two-lane road can safely accommodate traffic levels of several thousand vehicles per day without congestion effects occurring and could be termed LVRs. However, a single carriageway with passing places is only satisfactory and acceptable at quite low traffic levels (hundreds of vehicles), thus the traffic range for a true LVR is effectively quite different to current nomenclature.

An alternative definition based on equivalent standard axles (esa) and therefore structural design may be more in keeping with current usage.

We are well aware that this debate has been going on for many years, but it seems appropriate to make some decisions at this time. Moreover, a clear distinction needs to be made between LVRs and Low Volume Rural Roads (LVRRs).

1.2 OVERVIEW OF LOW VOLUME ROADS IN SUB-SAHARAN AFRICA AND SOUTH EAST ASIA

This section will discuss:

- The regional setting and common features of LVRs in the countries within the regions. These features will include common climatic conditions, economic factors, and road network characteristics.
- The challenges faced in the design of pavements for LVRRs and reflect on the needs of the regions.

1.3 LOW VOLUME ROAD HIERARCHY

This section will describe where low volume roads fit in common road classification systems of various countries.

1.4 PURPOSE AND SCOPE OF THE DOCUMENT

This section will describe the purpose of the Rural Road Note pertaining to the common methods of pavement design for low volume roads, namely:

- The California Bearing Ratio (CBR) Method,
- The Dynamic Cone Penetrometer – California Bearing Ratio – Structural Number (DCP-CBR-SN) Method, and
- The Dynamic Cone Penetrometer (DCP)– DCP Number (DCP-DN) Method.

This does not mean that there are only three methods. For methods 1 and 2 there are alternatives based on the way that the designers of the methods analysed their original road performance data and specified how the strength of the subgrade should be assessed in the design process.

Also, these methods are not completely distinct because the DCP has a role to play in all of them. The primary difference is that in methods 1 and 2, the DCP is simply one tool amongst others to help select materials and carry out the structural design, whereas in method 3 it completely replaces the use of the CBR test

1.5 STRUCTURE OF THE DOCUMENT

The various pavement design methods for low volume roads include many aspects that are common to all methods. Such aspects common to all methods are not discussed in this guide, but only key facets required for sustainable road provision are emphasised. Other aspects are simply listed and cross referenced where necessary. The differences between the design methods arise in many places within the methods. These differences are identified in Chapter 2 and, the major differences for each design method are discussed in subsequent chapters, in turn, summarising their origins and discussing their effect and consequences on structural design.

In addition to this, certain aspects that affect the design and performance of pavements, but which are not dealt with in all the key manuals for LVR design, will be discussed in a more general context. This includes ground and material improvements, drainage, slope stability for cuttings and embankments, climate resilience, and life-cycle costing.

Recommendations will also be provided to assist the pavement design engineer wherever a decision is required.

2 PRINCIPLES OF PAVEMENT DESIGN FOR LOW VOLUME ROADS

2.1 THE ROAD ENVIRONMENT

This section will discuss the road environment in context of the many engineering and operational factors that have to be considered in the provision of low volume roads. Critical factors will be discussed in greater detail.

2.2 ENVIRONMENTALLY OPTIMISED PAVEMENT DESIGN

Environmentally Optimised Design (EOD), approach provides a pragmatic way forward in constrained resource situations. EOD covers a spectrum of solutions for improving or creating low volume rural access – from dealing with individual critical areas on a road link (Spot Improvements) to providing a total whole rural link design (Whole Length Improvement). EOD provides a framework for the effective application of the recent research outcomes, particularly for the common situation where aspirations of local communities have to be balanced with very limited budgets.

2.3 PAVEMENT DRAINAGE

This section will discuss considerations of both internal and external drainage. The importance and impact of sealing shoulders and of achieving good crown height, culvert sizing, permeability inversion and sub-surface drainage in pavement layers

2.4 APPROPRIATE USE OF LOCALLY AVAILABLE MATERIALS

The appropriate use of locally available materials is a fundamental issue in the design and construction of sustainable LVRR pavements and surfacings. This section will discuss the factors to be considered in the selection of suitable locally available materials for road provision.

2.5 DECISION ON PAVEMENT AND SURFACING OPTIONS

This section will discuss the consideration of pavement and surfacing options that optimise the use of local labour, introduce intermediate equipment techniques and increase opportunities for the local private sector to participate in road construction and maintenance.

It will also discuss the selection of options between paved and unpaved, and flexible and rigid pavement options whilst taking account of the road environment.

3 PAVEMENT DESIGN METHODS IN GENERAL

3.1 METHOD OF USE

Several pavement design methods have been developed and published by many authors. For a specific set of conditions, the various methods do not give the same solutions. As a result, there is often some element of confusion and uncertainty amongst road designers concerning which method to choose and how to use it.

The first and most important point is that each method must be used in the way that the developers intended. Unfortunately, this is not always made clear, with the consequence that methods can easily be used incorrectly. An example of this is if the worst-case moisture condition does not necessarily mean soaked but many designers base subgrade strength on soaked conditions whereas the worst case may be drier than soaked or only equivalent to 2 days soaking and not 4 days soaking. One way that this problem can be avoided is if the analysis of the source data that the authors have used to develop their design method is known and understood by the design engineer. However, it is unreasonable to expect the road designer to investigate the research on which the design method is based and so the onus should be on the authors to provide sufficient information to satisfy the road designer.

This Note will therefore discuss key facets and the contexts in which each of the design methods should be used.

3.2 METHODS OF MEASUREMENT AND DATA ANALYSIS

This section will discuss the various methods by which input data for each of the design methods is measured and analysed.

The input data required for any pavement design method are well known in general terms. They are primarily:

1. The key environmental factors affecting each particular road
2. The design period and how it is defined. Though many ways exist for evaluating this, the same approach can be applied to any pavement design method.
3. Information about the expected traffic; numbers and types of vehicle, their loading, etc. Likewise, though many ways exist for evaluating this, the same approach can be applied to any pavement design method.
4. Details concerning the properties of the materials available for construction, especially the subgrade and road base,
5. Selection of the materials including the surfacing layer.

Despite the apparent simplicity of these elements there are different methods of obtaining the required information and each can influence the values obtained for the pavement design and subsequently the final design.

Most importantly the choices made by the designer are critically influenced by the risks that are perceived and the risks that are considered reasonable and therefore acceptable.

3.3 ANOMALIES AND INCONSISTENCIES

There are also anomalies and inconsistencies in some of the methods that often arise because of inadequate original data and sometimes through technical disagreements between experts.

It is the purpose of this Guideline to guide the user through all of these issues by:

- Reminding users of the key features of the principal methods of designing low volume roads;
- Ensuring that the methods are used as the authors intended;
- Highlighting discrepancies and technical uncertainties that contribute to risk and that will require engineering judgement of the designer;
- Providing unbiased advice on the methods to be recommended.

4 SUMMARY OF THE DESIGN METHODS FOR PAVED LOW VOLUME RURAL ROADS

The methods are arranged in alphabetical order.

4.1 TRAFFIC ASSESSMENT

A brief discussion on how to collect traffic and axle load data. An additional discussion on how to compute the vehicle equivalence factor and the effect and choice of the damage exponent to use.

4.2 COMPARISON OF THE PAVEMENT DESIGN METHODS

This section will compare the key aspects of the three pavement design methods for designing low volume rural roads. This is intended to give the RRN user an overview of the key similarities and differences between the methods.

It will also describe how each of the methods deals with design of new roads versus upgrading of existing roads.

4.3 THE CALIFORNIA BEARING RATIO (CBR) METHOD

4.3.1 Assessment of subgrade strength

This section will cover the key facets in:

- sampling subgrade material,
- sampling depth,
- laboratory preparation of the samples,
- compaction levels,
- moisture conditioning,
- testing, and
- classifying the subgrade.

4.3.2 Determination of pavement layer requirements

This section will discuss how to:

- divide the road length into uniform sections.
- determine the pavement layer thicknesses and materials requirements based on the traffic evaluation and subgrade assessment and classification.

4.3.3 Selection of pavement materials

This section will cover the key facets in the:

- sampling,
- preparation and laboratory testing of materials,
- comparison of the materials characteristics determined in the laboratory with materials specifications required for the pavement layers, and
- selection of the appropriate materials.

It will also discuss how to select marginal materials that do not fully meet the materials specifications.

4.4 THE DYNAMIC CONE PENETROMETER – CALIFORNIA BEARING RATIO – STRUCTURAL NUMBER (DCP-CBR-SN) METHOD

4.4.1 Assessment of subgrade strength

This section will cover the key facets in:

- in situ subgrade assessment,
- the data types collected and how they are interpreted,
- how moisture is accounted for in subgrade assessment, and
- classifying the subgrade.

4.4.2 Determination of pavement layer requirements

This section will discuss how to:

- divide the road length into uniform sections.
- determine the pavement layer thicknesses and materials requirements based on the traffic evaluation, and subgrade assessment and classification.

4.4.3 Selection of pavement materials

This section will cover the key facets in the:

- sampling,
- preparation and laboratory testing of materials,
- comparison of the materials characteristics determined in the laboratory with materials specifications required for the pavement layers, and
- selection of the appropriate materials.

It will also discuss how to select appropriate materials that do not fully meet the specifications.

4.5 THE DYNAMIC CONE PENETROMETER (DCP)– DCP NUMBER (DCP-DN) METHOD

4.5.1 Assessment of subgrade strength

This section will cover the key facets in:

- in situ subgrade assessment,
- the data types collected and how they are interpreted,
- estimation of equilibrium moisture content (EMC) and the subgrade strength at that EMC, and
- classifying the subgrade.
- divide the road length into uniform sections

4.5.2 Selection of pavement materials

This section will cover the key facets in the:

- sampling,
- preparation and laboratory testing of materials,
- comparison of the materials characteristics determined in the laboratory with materials specifications required for the pavement layers, and
- selection of the appropriate materials.

It will also discuss how to select materials that do not fully meet the materials specifications

4.5.3 Determination of pavement layer requirements

This section will discuss how to compare the layers strength profile with that specified in the catalogue and how to make up for any additional material requirements or existing deficiencies.

4.6 CONSEQUENCES OF THE DIFFERENCES

This section will discuss the differences that can result from using the three different pavement design methods.

5 SUMMARY OF THE DESIGN METHODS FOR UNPAVED LOW VOLUME RURAL ROADS

The methods are arranged in alphabetical order.

This section will be devoted to the design of unpaved low volume rural roads.

5.1 COMPARISON OF THE PAVEMENT DESIGN METHODS

This section will compare the key aspects of the three pavement design methods for designing unpaved low volume rural roads. This is intended to give the RRN user an overview of the key similarities and differences between the methods.

5.2 THE CALIFORNIA BEARING RATIO (CBR) METHOD

5.2.1 Assessment of subgrade strength

This section will cover the key facets in:

- sampling subgrade material,
- sampling depth,
- laboratory preparation of the samples,
- compaction levels,
- moisture conditioning,
- testing, and
- classifying the subgrade.

5.2.2 Determination of pavement layer requirements

This section will discuss how to:

- divide the road length into uniform sections.
- determine the pavement layer thicknesses and materials requirements based on the traffic evaluation and subgrade assessment and classification.

5.2.3 Selection of pavement materials

This section will cover the key facets in the:

- sampling,
- preparation and laboratory testing of materials,
- comparison of the materials characteristics determined in the laboratory with materials specifications required for the pavement layers,
- selection of the appropriate pavement materials, and
- selection of appropriate wearing course materials.

It will also discuss how to select marginal materials that do not fully meet the materials specifications.

5.3 THE DYNAMIC CONE PENETROMETER – CALIFORNIA BEARING RATIO – STRUCTURAL NUMBER (DCP-CBR-SN) METHOD

5.3.1 Assessment of subgrade strength

This section will cover the key facets in:

- in situ subgrade assessment,
- the data types collected and how they are interpreted,
- how moisture is accounted for in subgrade assessment, and
- classifying the subgrade.

5.3.2 Determination of pavement layer requirements

This section will discuss how to:

- divide the road length into uniform sections.
- determine the pavement layer thicknesses and materials requirements based on the traffic evaluation, and subgrade assessment and classification.

5.3.3 Selection of pavement materials

This section will cover the key facets in the:

- sampling,
- preparation and laboratory testing of materials,
- comparison of the materials characteristics determined in the laboratory with materials specifications required for the pavement layers,

- selection of the appropriate materials, and
- selection of appropriate wearing course materials.

It will also discuss how to select marginal materials that do not fully meet the materials specifications.

5.4 THE DYNAMIC CONE PENETROMETER (DCP)– DCP NUMBER (DCP-DN) METHOD

5.4.1 Assessment of subgrade strength

This section will cover the key facets in:

- In situ subgrade assessment,
- the data types collected and how they are interpreted,
- estimation of equilibrium moisture content (EMC) and the subgrade strength at that EMC,
- classifying the subgrade, and
- divide the road length into uniform sections

5.4.2 Selection of pavement materials

This section will cover the key facets in the:

- sampling,
- preparation and laboratory testing of materials,
- comparison of the materials characteristics determined in the laboratory with materials specifications required for the pavement layers,
- selection of the appropriate pavement layer materials, and
- selection of appropriate wearing course materials.

It will also discuss how to select marginal materials that do not fully meet the materials specifications.

5.4.3 Determination of pavement layer requirements

This section will discuss how to compare the layers strength profile with that specified in the catalogue and how to make up for any additional material requirements or existing deficiencies.

5.5 CONSEQUENCES OF THE DIFFERENCES

This section will discuss the differences that can result from using the three different pavement design methods as regards unpaved roads.

6 SURFACINGS

The design of thin bituminous surfacings is similar for all pavement design methods. It is not within the scope of the guide to discuss these in detail, but summaries and recommendations will be made as to the advantages and disadvantages of each surfacing type. The RRN will provide guidance on:

- factors to be considered in the selection of appropriate surfacings for any given pavement
- the potential life of different surfacings and the factors that affect these, for example the skill of the contractor
- surfacing construction and maintenance strategy to minimise lifecycle costs, and ultimately minimise moisture ingress into the lower pavement layers

In addition to thin surfacings, structural surfaces including 'discrete element' surfacings (e.g. concrete blocks, cobble stones, and hand-packed stone), have a place for use on LVRs. Initial cost is usually a constraining factor, but because of the structural value of such surfacing, overall pavement thickness can be reduced and the whole life costs may sometimes make these options favourable. The most common use is for semi-urban areas where marketing and trading takes place and where vehicle movements are unpredictable, and on sections that are very steep or otherwise difficult from an engineering point of view.

The RRN will discuss how the different pavement design methods recognise the strength contribution and account for it.

The use of concrete pavements will be included in this section. It will be discussed briefly as a surfacing material in areas of steep gradients, low-lying flood areas, where regular maintenance is not likely, high erosion, or as a spot improvement measure.

7 ECONOMIC ANALYSIS

When a comparison is being made between two or more designs that have little or no effect on the riding quality of the road, then the costs of operating vehicles will not be a major factor unless the length of the options is different. The associated maintenance costs of the different approaches will be the deciding factor in the choice of design; that is, a simple 'life-cycle cost analysis' can be carried out to determine the long-term minimum cost solution of meeting a specified standard for the forecast traffic.

However, where a marked change in riding quality and driving speed is being considered, as for example when paving an existing gravel road, then consideration of total transport costs (including benefits) is required. This takes into account not only the costs of construction and maintenance but also variations in road user costs associated with the different road surfaces. The difficulty in estimating road user costs is understood since it includes many factors, but at a minimum VoCs should be estimated and used – RED assists in this. In this case the different road surfaces will have different roughness values, measured by the international roughness index, (IRI). Vehicle operating costs are principally determined by road roughness, driving speed and road gradient. Road roughness, in turn, is dependent upon the surface material and maintenance policy.

In this chapter guidance will be given on:

1. The data inputs required to carry out a basic transport economic analysis. This will cover:
    a. Traffic counts
    b. Traffic growth rates
    c. vehicle operating costs,
    d. construction and maintenance costs,
    e. inflation,
    f. economic discount rates,
    g. adjustment of 'market prices' to 'economic prices', and
    h. other data required for estimating costs and benefits.
2. Lifecycle cost analysis.
3. Estimating road roughness (IRI).
4. Calculating vehicle operating costs using the World Bank's spreadsheet-based Road Economic Decision Model (RED).
5. Estimating construction and maintenance costs of pavement design options.
6. Calculation of key economic decision criteria such as the Net Present Value (NPV) and Economic Internal Rates of Return (EIRR) using a 'stand-alone' spreadsheet.
7. Estimation of socio-economic benefits, non-motorised traffic benefits, accidents reduction and environmental benefits/costs.
8. Ranking/multi-criteria analysis of options.

8 SELECTION OF APPROPRIATE PAVEMENT DESIGN

This section will describe a methodology of comparing two or more designs that a designer may consider. The data needed for comparison and the steps for comparison will be included. This will be presented using either a flow chart or tables.

9 PRACTICAL CONSIDERATIONS

There are several factors that influence successful provision of low volume rural roads. These factors affect the life of any pavement structure regardless of the design method. This chapter will discuss these pertinent topics and also incorporate results of other ReCAP projects. The following will be considered under this chapter:

- .
- Climate resilience considerations. How to identify risk, identify and assess vulnerable areas, prioritise vulnerable areas, evaluate and choose intervention options. This in view of protecting the pavement and drainage structures from events that would otherwise cut off communities. Reference will be made to the Climate Resilience Handbook and associated Guidelines produced under ReCAP.
- The importance of good compaction and its associated quality control requirements.
- Borrow-pit management. This section will discuss the proper management of how to extract only just the right quality of material required for any project without over exploiting higher specification materials. In addition, corrective actions to be taken to minimise environmental damage or nuisance caused by extraction of materials from borrow-pits will be covered. The correct procedure for reinstating borrow-pits, and minimising water ponding (unless the planned road pond to retain water for community use), will be provided.
- Ground improvement. This sub-section will give an outline of the geotechnical investigation techniques for identification of soils requiring improvement, and how to treat such problem soils (compressible, expansive, dispersive, and collapsible soils).
- Slopes, Embankments and Cuttings. Under this sub-section, a summary of the approach to geotechnical surveys, slope stability assessment and geotechnical analysis shall be presented. Additionally, a brief outline of design considerations for embankments and cuttings; slope protection and geo-disaster mitigation will be provided

APPENDIX A SUMMARY OF THE DESIGN METHODS AND MAJOR DIFFERENCES

This will include flow charts for each method and tables identifying where differences occur, plus explanations and advice.

A sample of this is presented in the Annex 1 of this report. It is proposed that this annex will be included in the final RRN, albeit with more additions.

Annex 1 Table of Stakeholder Feedback

No.	Chapter/Section	Feedback	Action to be taken by Authors
1	General Comment	Perhaps you should consider providing more details on the surfacings; if not in this version then maybe in the future version. That way, the designer is able to make a more informed pavement designs.	This will be for consideration in future editions.
2	General	It is good starting point; however, I believe it will significantly change through the process of preparation of the Note. As you are aware and also indicated it, there are many issues with the LVR roads. The definition and concepts are varied among professionals in different countries and also depends on the level of development of each country. Therefore, one of the challenges will be how it will be defined and for whom this Note is to be prepared. I also have the opinion that use of locally available materials shall be addressed in the interest of economic and environmental aspects in developing countries. The other issue to be considered is also the LVR Manuals prepared through the AFCAP initiatives as there are many important ideas and approaches are raised. The DCP method for design of pavements shall also be taken with care as there are different concepts among professionals before we start promoting it as a design standard.	The RRN is a first of its kind so it is intended that should allow stakeholders and practitioners to use the first edition and assess its usefulness and propose improvements thereafter. Again, the DCP-DN method is not being promoted but presented as an alternative, considering the significant investment already ploughed in its development and application in a number of countries. That is why the RRN aims to outline the benefits and limitations of each method.
3	General	Consider treating internal drainage (sealing shoulders, achieving good crown height, permeability inversion, sub-surface drainage) as part of the pavement design process rather than as a "practical consideration".	This has been noted and will be taken on board in this edition.
4	General	My only comment is that (in my opinion) in the proposed Table of Contents there should be a section before "Definition of LVRs and LVRRs" (currently section 1.1) that sets out the overall Design Philosophy for LVRs to put the three design method into context. This should cover things such as:	This has been noted and will be taken on board in this edition. However, the section will come

		• Environmentally Optimised Designs and the increased influence of the environment v traffic • Designing around the locally available materials which may be outside current specifications for optimal costing as opposed to finding materials to meet rigid specifications; • Using existing gravel roads in the pavement layer as sub-base as opposed to rip and re-compacting; • Definition of terminal condition for LVRs and acceptable levels of service. Surfaced LVRs with greater than 20 mm ruts and some cracking are still providing acceptable LoS which has impact on the maintenance and rehab strategies in terms of life cycle costing. I seem to remember an article by Phil P-G related to this. I also realise that this may have been discussed by the SWG and there may be good reasons for not including this. However, for future generations, I think this is important to have a section up front that puts the three design methods into the overall context of the LVR design philosophy/approach.	after the definition of LVRs and LVRRs. Ripping and re-compacting of existing gravel roads is important for obtaining a stable foundation for upper layers. Terminal condition is a complex issue since the pavement design methods have already incorporated a terminal condition in developing their respective catalogues. Brief discussion will be provided for to highlight the fact that roads with ruts greater than 20 mm are continuing to provide good service.
5	General	Maintenance as a standalone topic may be better since after the construction of every road, pavement, maintenance becomes the subsequent woks onwards.	Road maintenance is beyond the scope of this RRN that focusses on Pavement Design.
6	General	Though it is not within the scope of the guidelines to discuss the surfacing in detail, It would be nice if the document could give some clear guidelines on the choice of surfacing type for low volume roads otherwise it looks like all the areas have been captured.	A flow-chart on selection of surfacings will be provided.
7	General	1. Provide a background of the regions under focus i.e. Africa and South East Asia and consider including the following • The regional setting and common features of LVRs in the countries within the regions, (common climatic conditions, economic factors, road network characteristics and classification)	A brief description of the features of LVRs in the different continents will be provided. Engineering condition surveys will be discussed albeit briefly.

		• A problem statement discussing the challenges faced in the design of pavements for LVRRs and reflect on the needs of the regions • a brief of knowledge and practical experience gained from pavement design in the regions/countries 2. Write a note on the importance of carrying out engineering condition surveys before commencement of the pavement design. This is to assess the existing condition of the road and may inform on the pavement design approach. 3. Most LVRs start as earth/gravel roads while a totally new pavement design may be required for a new road/alignment. Consider discussing the design of these roads separately. Also write a note on rehabilitation design for both the paved and unpaved roads. 4. Include a section for definitions, descriptions, use and application of the DCP and CBR tests prior to discussing the design methods (The outline of the three design methods is well detailed and will achieve the intended purpose of the guide) 5. Include a section for discussion of general material characteristics and specifications for the regions under focus including natural occurring soils and gravels, crushed rock, stabilized/improved materials etc. A brief or References for prospecting and testing of the materials should be provided. These can help the designer to assess material availability and provide an economic pavement structure in terms of material types and thicknesses to accommodate the expected traffic loading. 6. Appendices to include the catalogues and data collection forms	Rehabilitation and test methods is beyond the scope of this RRN. All the methods will be discussed in the context of upgrading a road as well as in the context of new road constructions. Appendices of design catalogues and data collection forms are beyond the scope of this RRN. Materials prospecting utilises several techniques based on local knowledge and is beyond the scope of this RRN.
8	1.3 Purpose and Scope of The Document	DCP is a well-practiced and familiar field test equipment in many developing countries. It is easy to carryout in the field and represent in-situ conditions. However, its reliability particularly on coarse grained materials is quite questionable. A quite repeated tests even with the experienced field technicians highly varies and results a completely different levels of outputs in a relatively stronger existing old gravel surface or coarse-grained materials. DCP can be a good indicative only for very weak subgrade layers or fined grained materials.	These limitations will be discussed under the respective limitations of the different design methods.

9	2.2 Methods of Measurement and Data Analysis	Defining design period and traffic predictions, especially traffic growth factors are the most influencing parameter in pavement design and need a very strong emphasis and more detail guide on the approaches. Adopting with simple assumptions on the economic/GDP growth or elasticity factor is highly varying the assumptions and predictions by various experts.	Design periods, growth rates and estimation will be discussed under the economic analysis chapter.
10	3.1 Traffic Assessment	Is it possible to include here the ways of assessing traffic growth rates based on some statistical analysis?	Design periods, growth rates and estimation will be discussed under the economic analysis chapter. However statistical analysis will not be used for this.
11	3.1 Traffic Assessment	It is preferred if factors that affect damage exponent can be explicitly illustrate along with typical values of the factors instead of only the value of the damage exponent, considering the old nature of this factor visa vis the current vehicle technology development, how much is this damage exponent factors reasonably representing the current pavement nature as well as vehicle technology (its reliability)	This is a good topic but requires extensive research in order to address. The time scale and budget do not permit for this unfortunately.
12	3.3.2 Determination of pavement layer requirements	If the pavement layer thicknesses are to be presented in catalogue form or thickness sizes just numbers, It is highly recommended that the RRN guideline to include the very foundation or theoretical/empirical relationship behind the input parameters discussed (say subgrade strength and traffic loading) the layer determination (i.e. how these thickness are researched) so that any variation on the users input can be analysed effect on the thicknesses.	This is fundamental to pavement design and the design methods used in LVRs are based on empirical studies – Trial sections. This means there is no sophisticated theory behind the catalogues. The thickness and materials used will have worked for a given traffic level and subgrade class.
13	3.3.2 Determination of pavement layer requirements	Is it possible to include in detail about obtaining the designed CBR value from the CBR test data on the selected section of the road.	This will be discussed. It is based on percentiles of measured values.

14	3.3.3 Selection of pavement materials	And possibly discuss some recommendations of improving the engineering properties of selected marginal materials at inexpensive cost. Could a sub-section 3.3.4 be included following here that discusses the advantages and limitations of the traditional CBR method. Similar sub-sections 3.4.4 and 3.5.4 spelling the advantages and limitations of the Could a sub-section 3.4.4 be included following here that discusses the advantages and limitations of the DCP-CBR-SN and DCP-DN methods respectively are suggested. This I believe would make the clear distinctions between the various methods.	Improving materials will be discussed under 'Selection of pavement materials' sub-chapters. Advantages and limitations of all methods will be discussed.
15	3.4.3 Selection of pavement materials	Could a sub-section 3.4.4 be included following here that discusses the advantages and limitations of the DCP-CBR-SN	Advantages and limitations of all methods will be discussed.
16	3.5.3 Determination of pavement layer requirements	Could a sub-section 3.5.4 be included following here that discusses the advantages and limitations of the DCP-DN method	Advantages and limitations of all methods will be discussed.
17	3.6 Consequences of the Differences	The sub-sections 3.3.4; 3.4.4; and 3.5.4 would make this section 3.6 more easily to comprehend	Noted
18	4.5 Consequences of the Differences	Is it possible to include the design real design example by all the design methods and compare the results?	Design examples will be included for each method. However, comparing different designs for the same road would require a practical exercise. Moreover, this would vary from road to road. It cannot be included as part of the RRN as it could lead to wrong perception of a method. The RRN will give guidance that can allow the user to select the

			right method from the onset for any particular scenario.
19	6 Economic Analysis	Is the RED model reliable? many have reservations on this model effectiveness/reliability. will it be improved or will be adopt as it is?	RED is reliable and give results close to reality once good data is used.
20	Proposed new Chapter 9	9. LVR & LVRRS SHOULDER CONSTRUCTION & PRESERVATION; In practice, we noticed that the shoulder of LVR or LVRRS which are important for the roads, do not get much attention neither during construction nor maintenance period. As most of the LVRR is single lane (3.5m) lane width with (600mm-1800mm) design shoulder. Due to scarcity of land some time the design shoulder is not constructed as per design, slope is not maintained. So when wheel of vehicle passed, the load transmit in 45 degree angle, if the shoulder slope does not exist it crushes the hard portion of the pavement. This propagates the damage of the pavement. In a country like Bangladesh, which is low lying & require earthen embankment on an average 4.5m, instigates damage instantly. In my opinion, special attention should be paid in designing LVR & LVRRs	This will be addressed as part of slope stability analysis.

Annex 2 Summary of the Design Methods and Major Differences

Table A1: Flow Chart for DCP-CBR-SN design method

Step	Procedure	Comments	Concerns
1	Select design period, collect and analyse traffic data, determine traffic class	Traffic may not be treated the same way in each method. For example classification, 4th power damage law.	Probably not a serious problem provided that the same damage law is used.
2	Undertake a DCP survey plus a sampling survey for moisture and strength measurements in the laboratory. The frequency of the DCP measurements will depend on the variability in road conditions and level of confidence required.	A DCP survey to identify subgrade strengths may not always be appropriate if the alignment requires extensive cut and fill. Generally the survey is not design method dependant, although the analysis of the data is very different and is discussed in detail in the chapters for each method	Used primarily for upgrading design where little or no realignment is required. The DCP data is used to determine in situ CBRs and SN so that thickness and strength deficiencies can be calculated and corrected.
3	For each test point determine the layer strength diagram (DN in mm/blow versus depth and CBR versus depth) and the layer boundaries, preferably using the computer program**.**	This is very specific to the method and is discussed and compared for each method	The DCP analysis defines the actual thickness and strength of each pavement layer. No weighted averages are required or arbitrary thicknesses as in the DCP-DN method.
4	Determine the in situ SN values for each layer and the total SN (and SNP) for the pavement at each test point using the DCP program (	The SN approach is specific to this method and discussed below. The method of analysing DCP data also differs in important ways.	A method of defining the overall strength of the pavement is required. The SN method gives appropriate weight to each layer based on its strength. The DCP-DN method uses just the total depth that 800 blows will reach and is not weighted. It serves a similar purpose to SN but is not used directly in the thickness design process and so is not so critical
5	The design method is based on the value of the soaked CBR of the layers, therefore the CBR values (and hence the SN values) must be converted from in situ to soaked conditions for comparison with the design catalogue. To convert from the in situ values to the soaked values requires a measurement of the in situ moisture condition, expressed as the ratio of in situ moisture content divided by the optimum moisture content, and the use of **Error! Reference source not found.**. The in situ moisture condition is obtained from the samples collected	The design method for pavement layer strength is specific to each method and the differences and consequences discussed in chapters 5 and 6. The design charts are based on the interpretation of data from different studies, hence different results arise for two reasons; namely different data and different analyses comprising different assumptions	All methods require ways of calculating strengths of layers at different moisture contents. It is in this process that different degrees of risk are assumed as discussed in chapter 5 and 6. The structural designs produced by the different methods for the same set of conditions will vary and are often not strictly comparable because some of the assumptions/risks will be different, depending as they do on the designer's assessment of them. These are discussed in more detail in Chapters C and D. However,

	for laboratory analysis during the DCP survey. A minimum of three samples per kilometre is recommended. It is often more useful to obtain the samples once the DCP survey has been analysed and the most appropriate sampling points identified to ensure that maximum benefit is obtained from the sampling and testing.		in broad terms the DCP-DN method produces thinner and weaker pavements (less expensive) at low traffic levels, but pavements that are fairly similar at the higher end. A concern is that although heavy vehicle traffic s will not be excessive, because deformation of the roadbase is dependent on tyre pressures, a relatively small number could cause roadbase failures.
6	Determine the required SN_r values at each test point from the catalogue appropriate to the climate, traffic and subgrade strength		From a statistical point of view it is important to first calculate the structures required at each testing point first and then to determine the statistical values to be used. This is because the physical relationships in road engineering are very nonlinear so any averaging or statistical manipulation must be the final step. [Don't forget that the mean of x^2 is not the same as (mean of $x)^2$, this is something that is often forgotten or ignored.
7	Compare the in situ SN_i with the required SN_r to determine the structural deficiency at each test point (SN_r - SN_i).		The structural deficiency is computed in different ways in all methods, but the point by point analysis described above for the DCP_SN and SN-CBR method is the most accurate because of the statistical principle mentioned above
8	Identify areas (a) where the structural deficiency is large and (b) areas where layers are very weak and unlikely to meet the specifications for the layer that they will become in the upgraded design. Such areas will require individual treatment and should be removed from the main analysis.	This step is not specified in the DCP-DN method	Removing the weak sections from the main analysis will save on costs and should always be done but a value judgement is required to decide whether an area is too weak or not. A statistical method based on relative costs could easily be devised and would be an improvement
9	Identify uniform sections based on the structural deficiencies at each test point using a 'CUSUM' method.	The Cumulative Sums (CUSUM) method of identifying uniform sections similar for all methods, but can be based on different parameters	
10	Bulk samples from each uniform section are collected for laboratory testing		
11	Determine the appropriate percentile of the structural deficiencies for each uniform section and design the upgrading requirements in terms of additional layers and/or layer processing.		

Table A2: Flow Chart for The CBR Method

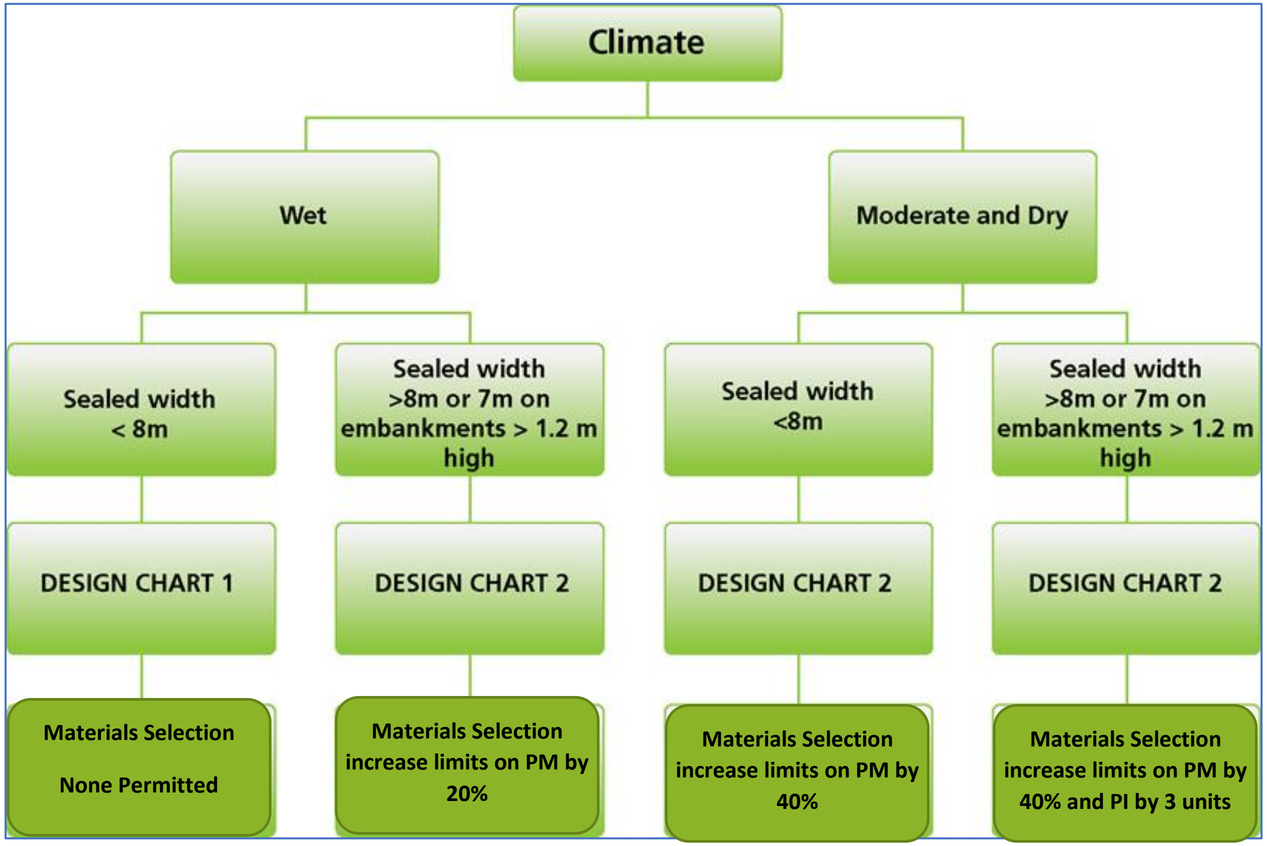

Table A3: DCP-DN Method

Step	Procedure	Comments	Concerns
1	Select design period, collect and analyse traffic data, determine traffic class.	Traffic may not be treated the same way in each method. For example classification, 4th power damage law.	Probably not a serious problem provided that the same damage law is used.
2	Undertake a DCP survey plus a sampling survey for moisture and strength measurements in the laboratory. The frequency of the DCP measurements will depend on the variability in road conditions and level of confidence required.	A DCP survey to identify subgrade strengths may not always be appropriate if the alignment requires extensive cut and fill. Generally survey is not design method dependant although the analysis of the data is very different and is discussed in detail in the chapters for each method.	Used primarily for upgrading design where little or no realignment is required. The DCP data is used to determine in situ CBRs and Structural Number so that thickness and strength deficiencies can be calculated and corrected.
3	For each test point determine the layer strength diagram (DN in mm/blow versus depth) and the DSN_{800} and DSN_{450} values.	In this method the DCP analysis shows the actual strength with depth but does not define each layer.	In some analyses (the main option) the road is assumed to comprise layers of 150 mm. If this does not agree with the DCP test then a weighted average DN value is computed for each 150mm layer. It is assumed that this is a linear weighting based on the thickness at each strength and, because of non-linearity, may not be the best average to use to define the layer strength.
4	Determine the uniform sections.	A CUSUM method is used on the DN values.	A method of defining the overall strength of the pavement is required. The SN method gives appropriate weight to each layer based on its strength. The DCP-DN method uses just the total depth that 800 or 450 blows will reach and is not weighted. It serves a similar purpose to SN but is not used directly in the thickness design process and so is not so critical.
5	Bulk samples are collected from each uniform section for testing in the laboratory.		
6	For each uniform section a representative layer strength profile is determined.	This is the weighted average DN for all layers per uniform section using the AfCAP program.	From a statistical point of view the weighting is not strictly correct, but probably makes little difference in the next step because percentiles can be selected that reduce risks of under design
7	Compare the layer strength profiles with the specified profiles from the design charts and determine where the deficiencies are and the upgrading requirements.		The structural deficiency is computed in different ways in all methods but the point by point analysis described above for the DCP_SN and SN-CBR method is the most accurate because of the statistical principle mentioned above.

8	Specifications for the layers – the design charts.	Strength very dependent on traffic level The structural designs produced by the different methods for the same set of conditions will vary and are often not strictly comparable because some of the assumptions/risks will be different, depending, as they do, on the designer's assessment of them. These are discussed in more detail in the main text.	In broad terms the DCP-DN method produces thinner and weaker pavements (less expensive) at low traffic levels but pavements that are fairly similar at the higher end. A concern is that although heavy vehicle traffic will not be excessive, because deformation of the roadbase is dependent on tyre pressures, a relatively small number could cause roadbase failures.

Table A4: Additional differences between the DCP-DN Method and the DCP-CBR -SN Method

Property	DCP-DN method	DCP-SN/CBR method	Comment
Strength	Uses DCP to assess in situ conditions. Uses DCP penetration rate (DN in mm/blow) directly (in situ strength). No modifications required.	Uses DCP to assess in situ conditions. Requires conversion of DN to CBR. CBR converted to soaked values. Soaked CBR converted to layer strength coefficients for SN.	
Uniform Sections	CUSUM based on actual DN and DSN_{800} values of each point.	CUSUM based on ΔSN or ΔSNC required for new design of each individual point or based on any of the parameters obtained from the DCP test, e.g. subgrade strength, subgrade thickness, subbase strength etc.	
Layers	150 mm layers with weighted average strength analysed.	Exact layer thicknesses with actual average strength. Analyses for multiple layers (bases, subbases and subgrade(s).	
sign	Subgrade strength assessed at anticipated long-term moisture condition. Variable strength for base / subbase depending on traffic load class.	Requires minimum soaked CBR of 45% for base. For upgrading requirement, the 10^{th}, 25^{th} or 50^{th} percentile of the SN required is used, depending on traffic.	