South Africa

COTO

Committee of Transport Officials

TRH 24

UPGRADING OF UNPAVED ROADS

Draft Standard (DS)

October 2024

Committee of Transport Officials

TECHNICAL RECOMMENDATIONS
FOR HIGHWAYS

TRH 24

UPGRADING OF UNPAVED ROADS

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Compiled under auspices of the:

Roads Coordinating Body (RCB)

Committee of Transport Officials (COTO)

Road Asset Management Systems Subcommittee

Published by:

The South African National Roads Agency SOC Limited

PO Box 415, Pretoria, 0001

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Synopsis:

TMH24 provides guidelines to most major aspects regarding the upgrading of unpaved roads. These include economic evaluations and warrants, geometric design, drainage design, road pavement structure evaluation and design, surfacing design, recommended procurement procedures and proposed future maintenance actions. The emphasis is on the application of applicable and appropriate standards and the optimum use of Naturally Available Granular Materials (NAGMs). The latter is achieved through the incorporation of scientifically proven Material Compatible New (Nano) Modified Emulsions (MC-NME) technologies, which enables NAGMs to be utilised in all road pavement layers. These technologies are also ideally suitable for the improved labour-intensive maintenance of roads. The use of inferior products are largely prevented through the recommendations of “End Product Specifications” where the use of any MC-NME product must result in processed materials meeting basic engineering properties in terms of stresses, strains and durability. Many of the recommendations incorporated into the TRH24 not only applies to lower order roads but are also applicable to higher order roads. The applicability of the various recommendations are addressed within the introduction to each chapter.

Withdrawal of previous publication:

Not Applicable

Technical Recommendations for Highways:

The Technical Recommendations for Highways consists of a series of publications that describe recommended practice for various aspects related to highway engineering. The documents are based on South African research and experience and have the support and approval of the Committee of Transport Officials (COTO). The documents are primarily aimed at ensuring uniform practice throughout South Africa.

Users of the documents must ensure that the latest editions or versions of the document are used. When a document is referred to in other documents, the reference should be to the latest edition or version of the document.

Any comments on the document will be welcomed and should be forwarded to coto@nra.co.za for consideration in future revisions.

Document Versions

Working Draft (WD). When a COTO subcommittee identifies the need for the revision of existing, or the drafting of new Technical Recommendations for Highways (TRH) or Technical Methods for Highways (TMH) documents, a workgroup of experts is appointed by the COTO subcommittee to develop the document. This document is referred to as a Working Draft (WD). Successive working drafts may be generated, with the last being referred to as Working Draft Final (WDF). Working Drafts (WD) have no legal standing.

Committee Draft (CD). The Working Draft Final (WDF) document is converted to a Committee Draft (CD) and is submitted to the COTO subcommittee for consensus building and comments. Successive committee drafts may be generated during the process. When approved by the subcommittee, the document is submitted to the Roads Coordinating Body (RCB) members for further consensus building and comments. Additional committee drafts may be generated, with the last being referred to as Committee Draft Final (CDF). Committee Drafts (CD) have no legal standing.

Draft Standard (DS). The Committee Draft Final (CDF) document is converted to a Draft Standard (DS) and submitted by the Roads Coordinating Body (RCB) to COTO for approval as a draft standard. This Draft Standard is implemented in Industry for a period of two (2) years, during which written comments may be submitted to the COTO subcommittee. Draft Standards (DS) have full legal standing.

Final Standard (FS). After the two-year period, comments received are reviewed and where appropriate, incorporated by the COTO subcommittee. The document is converted to a Final Standard (FS) and submitted by the Roads Coordinating Body (RCB) to COTO for approval as a final standard. This Final Standard is implemented in industry for a period of five (5) years, after which it may again be reviewed. Final Standards (FS) have full legal standing.

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Preface

The objective of this document is to provide applicable design guidelines for the cost-effective upgrading of unpaved roads. To this regard recommendations and guidelines are provided for:

- geometric design standards;
- drainage standards;
- pavement structural evaluation and design methods;
- material design for the optimisation of the use of NAGM using proven and available Material Compatible New (Nano) Modified Emulsions (MC-NME) technologies;
- Surfacing selection and design;
- Maintenance, and
- Implementation of method of contract incorporating "End product specifications" to which the use MC-NME products must adhere to during design and construction in a "proof of concept" evaluation process.

The implementation of applicable standards and optimisation of the use of naturally available materials aim to provide for the cost-effective upgrading of unpaved roads without compromising the safety of the road user as well as the integrity of the road pavement structure. The design also aims to maximise opportunities for SMME and labour development.

Overview of this Manual

A reliable road network is a pre-requisite for economic development. However, the provision of all-weather transportation infrastructure (roads) in developing areas, using traditional design approaches, currently comes at a considerable cost. The construction of a low-volume two-lane road in rural and urban areas in South Africa currently costs varying between R 12 to 17 million/km (2024 costs), depending on various local factors such as terrain with few challenges in terms of terrain variables (e.g., steep gradients, flat, etc.),drainage, logistics, safety, etc., carrying less than 300 vehicles per day. These high costs can be attributed largely to the use of dated documents, the application of inappropriate standards and a general lack of comprehension of the need to optimise the use of available resources in the face of dwindling available funds to provide basic infrastructure facilities.

The high unit costs can be significantly reduced through selection of appropriate geometric standards and the implementation of proven new technologies. Material Compatible New Modified Emulsion (MC-NME) stabilising agents have been proven to have the ability to improve and enhance the use of materials traditionally considered to be of inferior quality to meet the structural engineering requirements for all road pavement layers, addressing the need for sustainable, climate resilient road infrastructure.

This document provides a comprehensive approach towards the upgrading of unpaved roads with an emphasis on socio-economic warrants for upgrading of unpaved roads (not currently fully addressed), appropriate standards for design (geometric and drainage) and optimising the use of Naturally Available Granular Materials (NAGM). The aim is to provide all-weather surfaced roads at an affordable cost without compromising the integrity of the road pavement structure and/or the safety of road users. A comprehensive study to enable user to compare alternate options (i.e., conventional design versus a design optimising NAGM through NME technology is provided.

The recommended approach to contract management, incorporating the concept of “End product Specifications” aims to ensure that evaluation procedures are in place for the use of “new technologies” and not misused by suppliers to introduce inferior products or reintroduce so-called “snake-oils” or “wonder-products” under the umbrella of scientifically proven products.

Recommendations contained in the various chapters should be implemented by design engineers to optimise opportunities for the development of Small, Medium and Micro Enterprises (SMMEs) in the construction and maintenance of these roads in line with the requirements of various implementation agencies. The aim is to eventually also include guidelines for the inclusion of socio-economic criteria such as poverty alleviation within communities by improving accessibility to work opportunities, markets and social facilities, as well as all exogenous benefits to improve models to include these benefits in the assessment of roads as warrants for the upgrading of roads. Currently, not sufficient details are provided to give clear guidelines, However, Chapter 2 contains guidance as to the gathering of such information in order to provided more clear guidance for the incorporation of such analysis.

Although the design approach is based on simplified investigations, the designer is still required to compare various options against a “do minimum” option as a basis for cost-comparisons, ensuring that any recommendation can economically be warranted based on meeting of the recommended Level of Service (LOS) throughout the service life of the road.

These recommendations are divided into typical phases of design currently used by major road authorities in South Africa to ensure that the recommendations are implemented without major institutional changes. Reference is made to various chapters containing the details of the various aspects referred to. These include:

- **Chapter 2**: **Road network evaluation and prioritisation (Cost-Effective Analysis (CEA) - based)**. Economic factors to be applied for the economic evaluation, identification and prioritisation of unpaved Low Volume Roads (LVRs) earmarked for surfacing. Only data that should be gathered are currently being addressed. Due to a lack of real data this aspect cannot be addressed in full. This model must aim to also provide for the scheduling of projects over sustainable periods, with the specific objective of avoiding scattershot approaches that simply respond to emergencies but block progression toward an optimised network
- **Chapter 3**: **Geometric standards and side drainage requirements.** Recommendations towards applicable Levels of Service (LOS), Geometric standards as a function of the Category of Road within the broader concept of LVRs, also allowing for the effect of the introduction of new technologies to be considered in the reduction of additional imported materials;
- **Chapter 4**: **Standards for low-level river crossings**. Recommendations towards applicable cross-drainage facilities as a function of the road category as defined by traffic volumes;
- **Chapter 5**: **Pavement and materials investigations and design: Assessment of in-situ bearing capacity and recommended structural design approaches.** Recommendations towards design methods for the assessment of the in-situ bearing capacity of existing routes, materials testing applicable to LVRs, incorporating of new (MC-NME) technologies, providing climate resilient layers while also addressing the requirements in terms of design traffic loadings, environmental influences and the optimum use of naturally available materials. The DCVP-DN recommended approach allows for the identification of several options to consider for the design traffic loading, a final recommendation of which should be based on a Present Worth of Cost of applicable options;
- **Chapter 6: Pavement and materials investigations and design: Optimisation of materials utilisation using Material Compatible New Modified Emulsion (MC-NME) technologies.** Provide guidelines for the use of naturally available materials based on the mineralogy of the materials, neutralising the presence of problematic minerals in the granular material while also negating the influence of environmental factors while also addressing the requirements of design traffic loadings.
- **Chapter 7**: **Surfacing selection and design.** Selection and design of applicable protective surfacings, with an emphasis on environmental resistance, labour-intensive applications and cost-effectiveness. Specific reference is also made for the incorporation of NME slurries as an alternative surfacing option;
- **Chapter 8**: **Road maintenance.** Recommendations towards required maintenance actions for surfaced roads, incorporating new technologies (NME) with shown benefits, and
- **Chapter 9**: **Construction contractual guidelines**. Recommended End Product Specifications to ensure that engineering and durability requirements are met.

Keywords

appropriate standards, basic engineering requirements, climatic adjusted DCP design, cost-effective design, design based on materials science, Dynamic Cone Penetrometer, end product specifications, engineering specifications, labour-intensive construction, low-volume road pavement design, material mineralogy, material stabilisation, measurement and payment, nanotechnologies, naturally available materials, surfacings, Nano Modified Emulsions (MC-NME), soil improvement, stabilisation, unpaved road, upgrading of unpaved roads, NME slurry surfacings

Definitions

Accessibility - The ease with which a destination can be reached. A concept more closely related to mobility than to access.

The difference between "access" and "accessibility" in the context of road classification is often not well understood. Accessibility defines the ease with which a destination can be reached and is therefore a concept more closely related to mobility rather than to access. Access is the physical connection that allows traffic to enter or cross a public road. The more access to a road is allowed, the higher the accident risks and increased travel time.

The terms “Accessibility” and “Trafficability” are often used in documents related to low-volume roads as the ability to cross obstructions/barriers/obstacles on a road due to washaways, water overflowing, potholes, rock outcrops etc. In this document, the term “Accessibility” is used for this purpose.

Access management - The equitable provision of a safe and efficient road network through the systematic control of access on mobility roads and mobility on access streets**.**

Appliable standards and Appropriate standards – Design standards applicable and/or appropriate to different categories of roads as a function of the traffic volumes and traffic loading and an associated risk profile of the road in terms of the road user and road structure with the aim to optimise facility, user and impact costs on the national and regional economies of a country. Applicable standards and materials utilisation could be influenced by affordability in terms of national priorities and economic realities within any region.

Blading – (Also referred to as grading) - Activity performed with a motor grader or towed grader to maintain or improve the riding quality/roughness and shape of an unpaved road.

Clear-seals – similar to a rejuvenator, consisting of mixture of proven Nano-Polymers and Nano-Silanes (NPNS) with a potential high degree of penetration (due to smaller particle sizes) with water-repellent (waterproofing) characteristics, providing improved protection of existing surfaced roads against water ingress and subsequent pot-hole formation. Clear-seals can also be used in the upgrading of gravel roads to protect the integrity of the base material without providing a black surfacing layer to limit the attraction of heavy vehicles to lower order roads. The use of clears seals as a cost-effective protection of shoulder materials could prove to be a viable option. The application of clear seals is an ideal way for labour intensive operations and the development of SMMEs.

EPS – End Product Specification.

High Pressure Permeability (HPP) test – Test developed to measure the water permeability of a 20 mm thick compacted slurry briquette at a pressure of 150 kPa. The aim is to determine and design slurry seals that are water impermeable.

International Roughness Index (IRI) - Measurement in mm/m to indicate the roughness/riding quality of pavements with a direct influence on road user costs and damage to any products that are being transported.

Level of Service (LOS) – (I) parameters or combination of parameters that reflect social, environmental and economic outcomes that the organisation has agreed to deliver (ISO 55000); (ii) a statement of the performance of the asset in terms that the customer can understand. Levels of Service typically cover road condition, availability, accessibility, capacity, amenity, safety, environmental impact and social equity. It covers the condition of the asset and non-condition-related demand aspirations, i.e., a representation of how the asset is performing in terms of both delivering the service to customers and maintaining its physical integrity at an appropriate level (Roads Liaison Group, UK).

Mobility - the ease with which traffic can move at relatively high speeds with the minimum of interruptions or delays. On LVRs in the rural environmental, interruptions such as traffic lights and congestion are minimal. Delays or slower speed of travel is mainly due to the geometry, surface condition, climatic conditions, non-motorised traffic and (important) as required by pedestrian use and the presence of stray animals/game.

Material Compatible Nano Modified Emulsion (MC-NME) - where an emulsion is defined as any additive in the form of a solution, including any additive added to the construction water, including (but not limited to):

- Bitumen emulsions with/without a Material Compatible modified emulsifying agent (e.g., aggregate adhesive, water-repellent agents (e.g., organo-functional-silanes) and/or with the addition of polymers (micro- and or nano-polymers);
- Polymers (micro- and/or nano-polymers) with/without a Material Compatible modified emulsifying agent (e.g., aggregate adhesive, water-repellent agents (e.g., organo-functional-silanes), or
- Any “alternative” rock/aggregate/soil Material Compatible stabilising agent.

The quality of any MC-NME is ensured through the implementation of a recommended method of contract incorporating a “proof of concept” with the implementation of an “End Product Specification” (EPS). Reference to an NME stabilising agent will be considered to be a MC-NME.

Nano Modified Emulsion (NME) slurries – the design of surfacing and maintenance slurries without the addition of cement, with improved characteristics, including higher tensile strengths and zero permeability at 150 kPa pressure.

Periodic maintenance – Planned maintenance that happens at frequencies from annually up to 15 years, depending on the condition of the asset. This includes reseals, regravelling and may also include activities such as planned cleaning of pipe culverts and side drains that could influence the road structural and functional design over time.

Regravel - Periodic maintenance by replacing the gravel wearing course of an unpaved road.

Rehabilitation – Rehabilitation involves the improvement, strengthening or salvaging of existing, de-efficient road pavements (that have reached a terminal level of serviceability) so that they can continue to carry traffic at adequate speed, safety and comfort in a cost-effective way. This could involve treatment of exiting layers with binders and additional layers as well as a new surfacing, either chip seals or asphalt as determined through a detailed project level investigation involving various phases to ensure that rehabilitation is done in the most cost-effective way (TRH 12). Rehabilitation of roads is ideally performed when a road has reached a “end of optimal functionality”, at which stage it can still carry traffic, but now by compromising the safety of the road user and an increase in road user costs, costs to transportation of sensitive produce (such as certain food supplies) and future agency costs in terms of maintenance costs and deferred rehabilitation costs.

Rejuvenation spray – The application of a rejuvenator to soften old, oxidised binder, extending the effective life of the existing bituminous surfacing. Products currently used for this purpose are diluted anionic stable grade emulsion or invert cutback emulsion.

Resurfacing - Resurfacing is a periodic maintenance treatment consisting of a chip seal or an asphalt surface layer.

Riding Quality - Term used to describe the relative degree of comfort or discomfort a road user experiences when using a road and the relative damage that can be associated with the riding quality. The terms riding quality and roughness are often used interchangeably. In this guideline, the term roughness is preferred.

Roughness: Term used to describe the relative degree of comfort or discomfort a road user experiences when using a road.

Routine maintenance - Routine maintenance is the day-to-day maintenance of the road surface, the drainage and the road reserve.

Rural Area - any area not defined as an Urban Area. Typically, an area of sparse development, mainly given over to nature or farming activities (TRH 26).

Rural Roads - any roads located in a rural area and include Throughways and Bypasses passing through urban areas (TRH 26).

Surfaced roads - any road provided with a permanent all-weather surfacing.

Surfacing – the uppermost part of a pavement specifically designed to resist abrasion from traffic and to minimise the entry of water into the underlying pavement layers. Surfacings include bituminous surfacings, concrete and segmented block surfacings

Unpaved roads – (unsurfaced roads) any road not provided with a permanent all-weather surface. Unpaved roads include earth- and sand tracks, engineered natural surfaced (ENS) roads or earth graded roads and engineered gravel surfaced (EGS) roads, often referred to as gravel roads.

Upgrading – refers to the improvement of a facility (road) to a higher (applicable) standard or level of service. Unless stated differently, upgrading in the context of this document refers to the upgrading of an unpaved road to applicable surfaced standards.

Urban Area – for the purpose of this TRH, an urban area is an area that has been subdivided into erven, whether formal or informal. It includes formal and informal rural settlements of one hectare or less (TRH 26).

Urban Roads - any roads located in an urban area, excluding throughways and bypasses (TRH 26).

Abbreviations

AADT	Annual Average Daily Traffic
AC	Asphalt Concrete (USA); Asphalt
ACV	Aggregate Crushing Value
AIV	Aggregate Impact Value
AFCAP	Africa Community Access Partnership
ALD	Average Least Dimension
CBR	California Bearing Ratio
BMS	Bridge Management System
BoQ	Bill of Quantities
BP	Ball Penetration
CB	Concrete Blocks (Non-interlocking)
CBP	Corrected Ball Penetration
CEA	Cost-Effective Analysis
COLTO :	Committee of Land and Transport Officials
COTO	Committee of Transport Officials
DCP	Dynamic Cone Penetrometer
DN-value	DCP number value in mm/blow (also referred to as DCP-DN-value)
ELV	Equivalent Light Vehicles per lane per day
EMC	Equilibrium Moisture Condition
EPS	End Product Specification
FMC	Field Moisture Condition
GRMS	Gravel Road Management System
GVA	Gross Value Added
HPP	High Pressure Permeability
HCT	Hydroxy Conversion Treatment
ICSM	Intergovernmental Committee on Surveying and Mapping
ICB	Interlocking Concrete Blocks
IDF	Intensity-Duration-Frequency
IRI	International Roughness Index
IRR	Internal Rate of Return
ITC	Indirect Tensile Strength
KPI	Key performance indicator
LAA	Los Angeles Abrasion
LCCA	Life-Cycle Cost Analysis
LFS	Low flashpoint solvent
LL	Liquid Limit

LLRC	Low-Level River Crossing
LOS	Level of Service
LVR	Low Volume Road
LVSR	Low Volume Sealed Road
MESA	Million Equivalent Standard Axels
MC-NME	Material Compatible Nano Modified Emulsion
MDD	Maximum Dry Density
MMS	Maintenance Management System
MPNS	Micro-Polymer Nano-Silane
NAGM	Naturally Available Granular Materials
NDP	National Development Plan
NME	New (Nano) Modified Emulsion
NMT	Non-motorised traffic
NPNS	Nano-Polymer Nano-Silane
OMC	Optimum Moisture Condition
PBC	Performance-Based Contract
PI	Plasticity Index
PL	Plasticity Limit
PMS	Pavement Management System
PNS	Polymer Nano-Silane
PSV	Polished Stone Value
RAI	Rural Access Index
RAMS	Road Asset Management Systems
RIAMP :	Road Infrastructure Asset Management Policy
RCS	Retained Compressive Strength
RTS	Retained Tensile Strength
SABITA	Southern Africa Bitumen Association
SADC	Southern Africa Development Communities
SANRAL	South African National Roads Agency SOC Ltd
SB	Slurry Bound
SMME :	Small Medium and Micro Enterprises
TMH	Technical Methods for Highways
TRH	Technical Recommendations for Highways
TSR	Tensile Strength Ratio
UCS	Unconfined Compressive Strength
URMS	Unpaved Road Management System
Vpd	Vehicles per day
VTD	Volumetric texture depth

XRD	X-Ray Diffraction

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1. Introduction

1.1 General

This document must be seen in the context of a considerable need that exists in South Africa for the upgrading of unsurfaced roads. Many of these roads already exceed by some margin, the traffic volumes traditionally considered as benchmarks (economic warrants) for the upgrading of unsurfaced roads to that of a surfaced standard. The fact is, that similar backlogs exist in the provision of preventative maintenance, road rehabilitation and road congestion alleviation through the provision of new roads in major economics hubs in the country. It follows that the funding requirements for transportation infrastructure far exceed the currents allocations. This situation is not expected to improve in the foreseeable future.

Hence, the transportation fraternity must ensure that the available funds are optimally utilised in providing and maintaining the required road infrastructure in the most cost-effective manner. This TRH 24 aims to provide the necessary guidelines to prioritise upgrading projects, to select appropriate levels of service, to apply applicable design criteria and to maximise available resources, incorporating the most cost-effective proven technologies in materials utilisation. These guidelines will not impede in any way road user safety and/or compromise the structural integrity and long-term durability of the facilities designed and constructed.

The “Upgrading of Unpaved roads” may be applicable to a considerable range of traffic volumes and different design traffic loadings. Each chapter within the document provides details as to the applicable recommendations provided for within that chapter and the application thereof within the framework of various road classes and definitions. No recommendation is set in stone and depending on socio-economic and fiscal factors these guidelines may require adjustments to account for changes over time, ensuring that user needs are addressed within the limits of available resources.

Retaining traditional South African standards in terms of levels of service and design and maintenance methodologies, require funding levels that cannot be sustained in a developing environment (Refer Funding level A in Figure 1). The reality with current funding levels and applied methodologies, is that very little of the road infrastructure can be maintained at the traditional standards, leading to a collapse of road networks and significant lowering of the overall level of service (Refer red Funding level B).

Significant reduction in the funding requirements can be achieved through setting applicable or appropriate levels of service (Refer Funding level C). This is particularly relevant to geometric standards, use of local materials and provision of low-level river crossings without compromising safety. It should be noted that legal opinions obtained from various sources confirmed that this practice is generally acceptable provided that adequate safety measures be put in place, such as speed limits, line markings and warning signs. Maintaining the condition of any such safety measures must be a primary objective of any future planned routine maintenance actions to be undertaken on the road network.

Through continuous research, experience and documented good practice, locally and world-wide, knowledge exists to provide an acceptable overall level of service with the current available funding levels. This requires a paradigm shift in road asset management to develop longer-term turnaround strategies, implementing more appropriate testing, design, construction and maintenance methodologies and, improving local Naturally Available Granular Materials (NAGM) through new technologies e.g., nano technology (Refer yellow line in Figure 1).

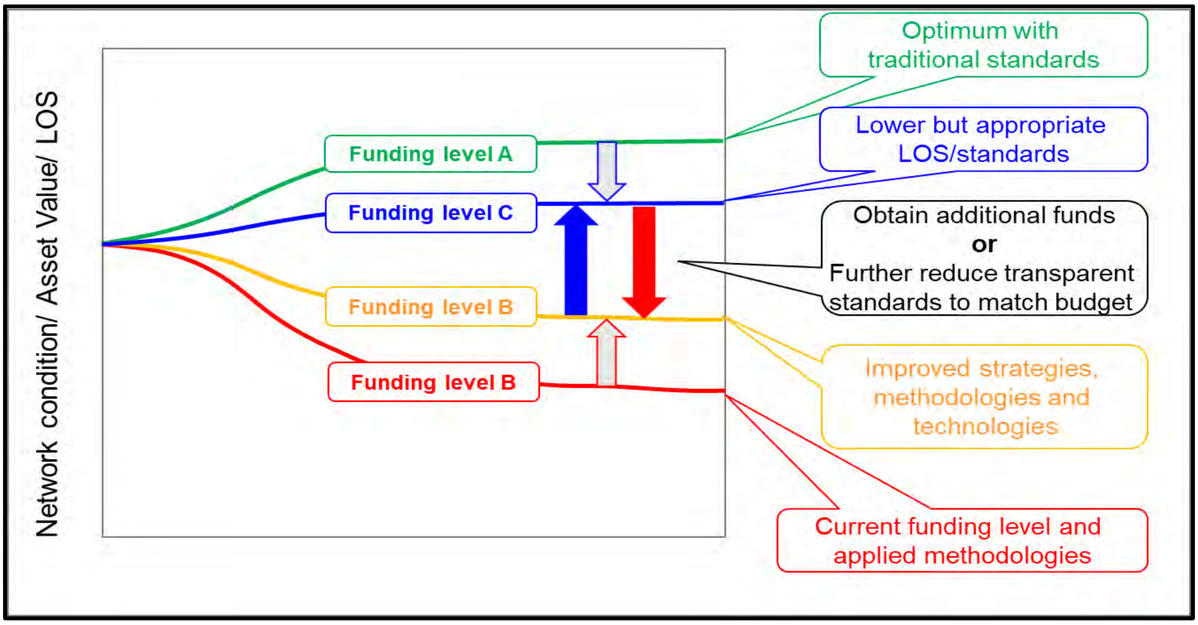


Figure 1 Principles for establishing applicable and appropriate standards

If target adjusted levels of service cannot be achieved with improved strategies, methodologies and technologies, either additional funds must be obtained, or standards must be reconsidered and reduced with the required safety measures in place.

1.2 Road Construction Costs

1.2.1 Cost comparisons

The main factors contributing to the cost of upgrading an existing unpaved road to a surfaced standard, in terms of the formation, pavement, surfacing, structures and road-side furniture are:

- Standard of current facility versus selected level of service, influencing:
  - Horizontal and vertical alignment required
  - Formation and surfaced width required
- Project size and remoteness
- Traffic accommodation
- Topography (Flat, Rolling, Mountainous) influencing:
  - Earthworks (Cut & Fill)
  - Provision of lined drains and sub-surfaced drains
  - Number and size of culverts, inlets and outlets, scour protection
  - Retaining structures/walls required
  - Need for bridges/ low level river crossings
- Urban (Additional costs)
  - Walkways and Bus bays
  - Kerbs
  - Street lighting and Traffic lights

- o Services
- o Stormwater drains/ Lined drains
- o Additional road signs
- o Traffic calming e.g. speedhumps, raised pedestrian crossings, minicircles

Figure 2 highlights different situations as starting points, resulting in significant differences in the cost of the upgraded facility.

Figure 2 Variability in existing level of service

Following an investigation into the cost of different components, Table 1, Table 2 and Table 3 were developed assuming a "greenfield situation" e.g. upgrading from a track in flat (F), rolling (R) and mountainous (M) terrain for design loads of 0,3, 1,0 and 3,0 million standard axles (MISA) to three different standards, using conventional materials i.e.:

- AS (Applicable Standards) Design speed (60 – 80 km/h) Surfaced width (7,4 m)
- MS (Medium Standards) Design speed (80 – 100 km/h) Surfaced width (8,0 m)
- HS (High Standards) Design speed (100 – 120 km/h) Surfaced width (8,6 m)

Figure 3 displays the results of the tabled data, highlighting the high possible cost variation.

Note: Increases in unit rates for different components vary between 6% and 14% per annum.

Table 1 Costs per scenario – Applicable Standards (AS) (ZAR, Excluding VAT)

Component (Cost/km)	AS/0,3/F	AS/1,0/F	AS/3,0/F
Surfacing	1 145 709	1 145 709	1 145 709
Pavement	3 819 031	4 773 789	5 728 547
Formation including drainage	954 758	954 758	954 758
Structures	124 751	124 751	124 751
Road furniture/ Ancillary	541 890	541 890	541 890
Training & Development	605 925	693 762	781 600
Total	**7 192 063**	**8 234 659**	**9 277 254**
Component (Cost/km)	**AS/0,3/R**	**AS/1,0/R**	**AS/3,0/R**
Surfacing	1 145 709	1 145 709	1 145 709
Pavement	3 819 031	4 773 789	5 728 547
Formation including drainage	1 909 516	1 909 516	1 909 516
Structures	365 541	365 541	365 541
Road furniture/ Ancillary	554 792	554 792	554 792
Training & Development	717 102	804 940	892 778
Total	**8 511 691**	**9 554 286**	**10 596 882**
Component (Cost/km)	**AS/0,3/M**	**AS/1,0/M**	**AS/3,0/M**
Surfacing	1 145 709	1 145 709	1 145 709
Pavement	3 819 031	4 773 789	5 728 547
Formation including drainage	3 819 031	3 819 031	3 819 031
Structures	847 121	847 121	847 121
Road furniture/ Ancillary	593 498	593 498	593 498
Training & Development	940 644	1 028 482	1 116 319
Total	**11 165 034**	**12 207 630**	**13 250 225**

Table 2 Costs per scenario – Medium Standards (MS) (ZAR, Excluding VAT)

Component (Cost/km)	MS/0,3/F	MS/1,0/F	MS/3,0/F
Surfacing	1 238 605	1 238 605	1 238 605
Pavement	4 128 682	5 160 853	6 193 023
Formation including drainage	2 064 341	2 064 341	2 064 341
Structures	221 067	221 067	221 067
Road furniture/ Ancillary	541 890	541 890	541 890
Training & Development	753 902	848 861	943 821
Total	**8 948 486**	**10 075 617**	**11 202 747**
Component (Cost/km)	**MS/0,3/R**	**MS/1,0/R**	**MS/3,0/R**
Surfacing	1 238 605	1 238 605	1 238 605
Pavement	4 128 682	5 160 853	6 193 023
Formation including drainage	4 128 682	4 128 682	4 128 682
Structures	461 857	461 857	461 857
Road furniture/ Ancillary	554 792	554 792	554 792
Training & Development	967 161	1 062 121	1 157 080
Total	**11 479 779**	**12 606 909**	**13 734 039**
Component (Cost/km)	**MS/0,3/M**	**MS/1,0/M**	**MS/3,0/M**
Surfacing	1 238 605	1 238 605	1 238 605
Pavement	4 128 682	5 160 853	6 193 023
Formation including drainage	8 257 364	8 257 364	8 257 364
Structures	1 328 701	1 328 701	1 328 701
Road furniture/ Ancillary	593 498	593 498	593 498
Training & Development	1 430 310	1 525 270	1 620 230
Total	**16 977 161**	**18 104 291**	**19 231 421**

Table 3 Costs per scenario – High Standards (HS) (ZAR, Excluding VAT)

Component (Cost/km)	**HS/0,3/F**	**HS/1,0/F**	**HS/3,0/F**
Surfacing	1 331 500	1 331 500	1 331 500
Pavement	4 438 333	5 547 917	6 657 500
Formation including drainage	4 438 333	4 438 333	4 438 333
Structures	221 067	221 067	221 067
Road furniture/ Ancillary	580 596	580 596	580 596
Training & Development	1 012 904	1 114 986	1 217 068
Total	**12 022 734**	**13 234 399**	**14 446 064**
Component (Cost/km)	**HS/0,3/R**	**HS/1,0/R**	**HS/3,0/R**
Surfacing	1 331 500	1 331 500	1 331 500
Pavement	2 219 167	3 328 750	6 657 500
Formation including drainage	6 657 500	6 657 500	6 657 500
Structures	461 857	461 857	461 857
Road furniture/ Ancillary	606 400	606 400	606 400
Training & Development	1 241 594	1 343 676	1 445 758
Total	**12 518 018**	**13 729 683**	**17 160 515**
Component (Cost/km)	**HS/0,3/M**	**HS/1,0/M**	**HS/3,0/M**
Surfacing	1 331 500	1 331 500	1 331 500
Pavement	4 438 333	5 547 917	6 657 500
Formation including drainage	13 315 000	13 315 000	13 315 000
Structures	1 328 701	1 328 701	1 328 701
Road furniture/ Ancillary	709 617	709 617	709 617
Training & Development	1 943 330	2 045 412	2 147 493
Total	**23 066 482**	**24 278 147**	**25 489 812**

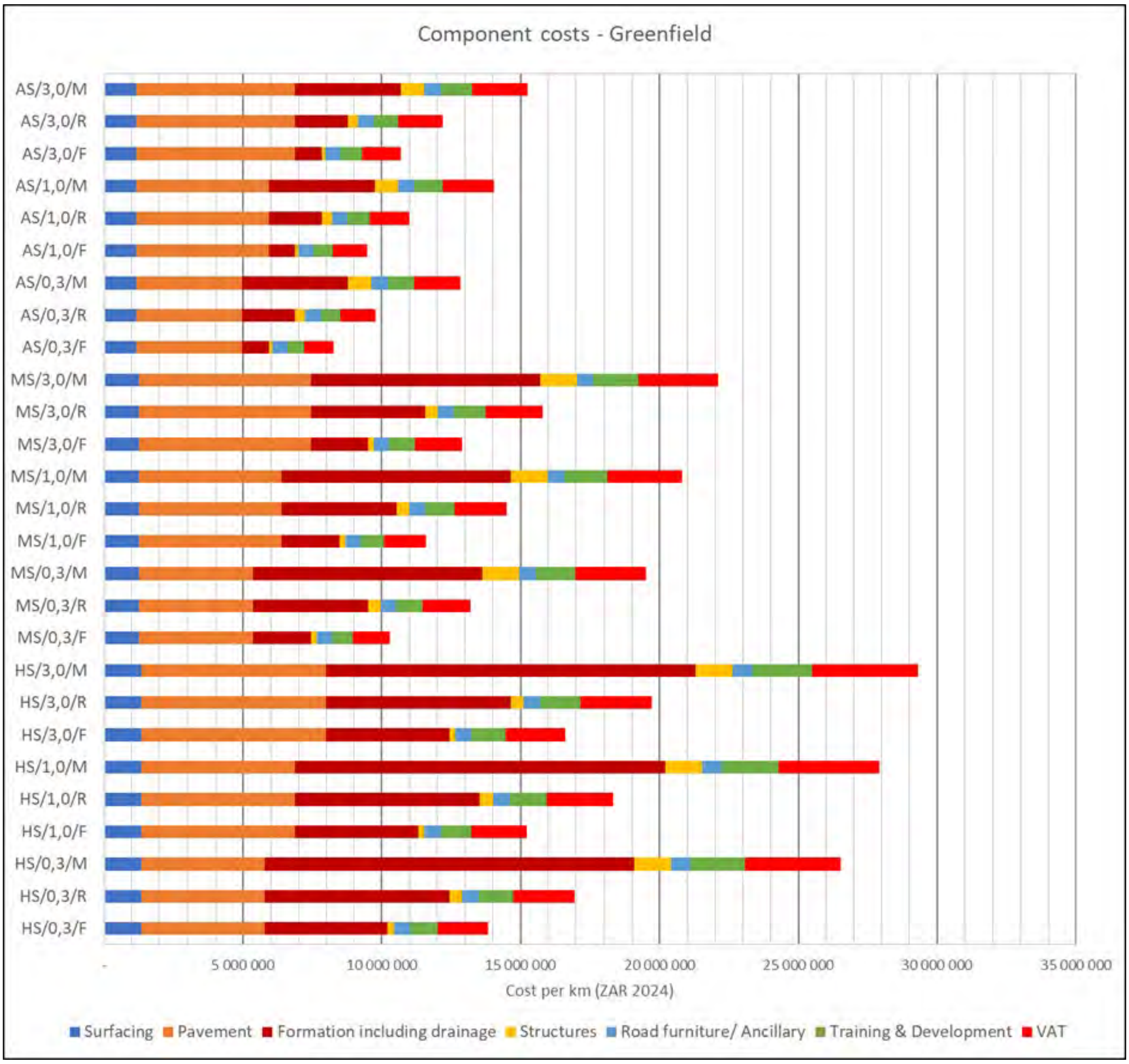


Figure 3 Variation in component and total costs for greenfield construction

Utilising available, but limited information, Table 4 has been developed to make adjustments to "greenfield" costs allowing for the use of NME, incorporating project size (km), state of existing formation and drainage, adequacy of existing structures and distance in urban environments.

Table 4 Provisional adjustment factors

Select situation			
MISA	**3**	**1**	**0,3**
NME- Apply to pavement only	70%	60%	50%
Project size (km)	**10**	**20**	**30**
Apply to all items	118%	0%	91%
Existing formation & drainage	**Poor**	**Average**	**Good**
Apply to formation only	100%	50%	20%
Existing structures	**None**	**50%**	**Adequate**
Apply to structures only	100%	50%	10%
Urban settlements urban km	1		
Add to ancillary works 300k/km	300000		

Two examples of application are provided in Scenarios A and B with selected situations highlighted in green:

Scenario A

Table 5 Selected situation for scenario A

Selected situation			
MISA	**3**	**1**	**0,3**
NME- Apply to pavement only	70%	60%	50%
Project size (km)	**10**	**20**	**30**
Apply to all items	118%	0%	91%
Existing formation & drainage	**Poor**	**Average**	**Good**
Apply to formation only	100%	50%	20%
Existing structures	**None**	**50%**	**Adequate**
Apply to structures only	100%	50%	10%
Urban settlements urban km	1		
Add to ancillary works 300k/km	300000		

Table 6 Impact of adjustment to scenario A

Example Scenario A	AS/0,3/F	Adjust Item	Adjust All	Applied	Urban addition	Total
Component (Cost/km)	**Greenfield**					
Surfacing	1 145 709	100%	91%	1 042 595		1 042 595
Pavement	3 819 031	50%	91%	1 737 659		1 737 659
Formation including drainage	954 758	50%	91%	434 415		434 415
Structures	124 751	10%	91%	11 352		11 352
Road furniture/ Ancillary	541 890	100%	91%	493 119	300 000	793 119
Training & Development	605 925	100%	91%	551 392		551 392
VAT	1 078 810					685 580
Total	**8 270 873**					**5 256 113**

Scenario B

Table 7 Selected situation for scenario b

Selected situation			
MISA	**3**	**1**	**0,3**
NME- Apply to pavement only	70%	60%	50%
Project size (km)	**10**	**20**	**30**
Apply to all items	118%	0%	91%
Existing formation & drainage	**Poor**	**Average**	**Good**
Apply to formation only	100%	50%	20%
Existing structures	**None**	**50%**	**Adequate**
Apply to structures only	100%	50%	10%
Urban settlements urban km	2		
Add to ancillary works 300k/km	600000		

Table 8 Impact of adjustment to scenario B

Example	AS/1,0/R	Adjust Item	Adjust Proj Size	Applied	Urban addition	Total
Component (Cost/km)	**Greenfield**					
Surfacing	1 145 709	100%	118%	1 353 083		1 353 083
Pavement	4 773 789	60%	118%	3 382 707		3 382 707
Formation including drainage	1 909 516	100%	118%	2 255 138		2 255 138
Structures	365 541	50%	118%	215 852		215 852
Road furniture/ Ancillary	554 792	100%	118%	655 209	600 000	1 255 209
Training $ Development	804 940	100%	118%	950 634		950 634
VAT	1 433 143					1 411 893
Total	**10 987 429**					**10 824 516**

The modelling of the performance of a road with a pavement structure containing an NME is currently under investigation in available HDM-4 models. Comparative work done has shown that the expected behaviour of a pavement containing an NME stabilised base is currently (2024) best simulated using the model for a stabilised base. The NME stabilised layer will have a considerably longer life to crack initiation (will not be the critical layer in any simulation) and will not progress to develop deep potholes with surface deterioration due to the specification of a minimum required UCS$_{wet}$ (refer Chapter 6). Work will continue to develop NME specific models for the simulation of NME stabilised layers within the HDM-4 software.

1.2.2 Pilot projects

Tendered rates for six pilot projects were evaluated in 2024. A comparison of total costs per km and distribution per relevant items are displayed in Figure 4.

Note: Design axle loadings on all projects were 1,0 MISA or more.

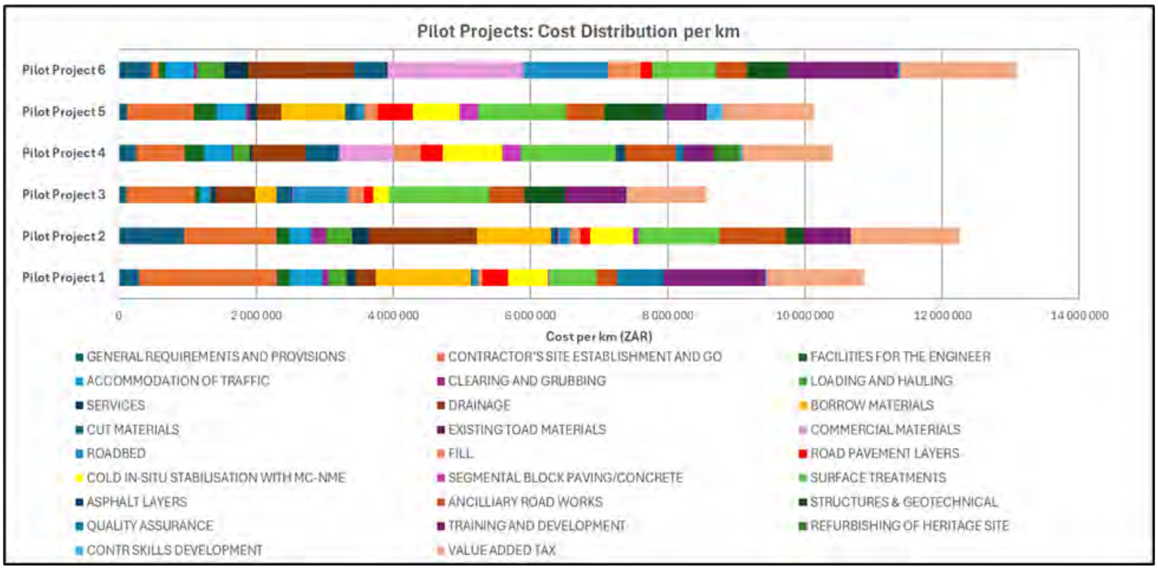


Figure 4 Pilot projects cost comparison

Although each project is different, as evident from Figure 4, the average proportional cost per item, as shown in Figure 5 is informative.

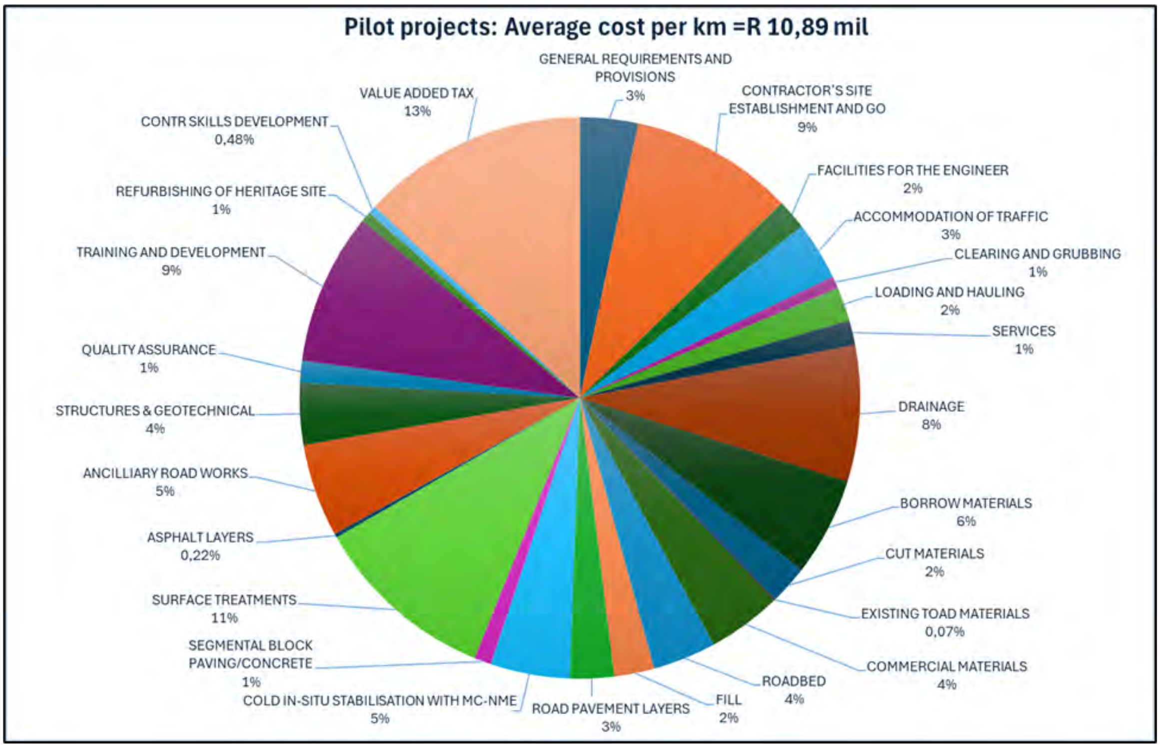


Figure 5 Average proportional cost per item

1.3 Basic principles towards applicable and appropriate design standards

Figure 6 demonstrates the basic principles involved in establishing applicable and appropriate design standards to be applied within any Implementing Agency (e.g., Road Authority or Agency), taking local specific conditions into account.

The objective of this document is to establish the basic principles for the cost-effective upgrading of unpaved roads. The emphasis of the recommended procedures is on the enhancement of labour-intensive construction and the empowerment and development of small enterprises, allowing for different approaches, depending on the various policies of different Implementing Authorities. Labour-intensive construction methods are covered in detail in various documents and should be taken into consideration in conjunction with the basic design concepts covered in this TRH24. A comprehensive approach to the upgrading of gravel roads, including the various phases of design investigation, testing, construction and quality control to be addressed is summarised in the flow diagram in Figure 7.

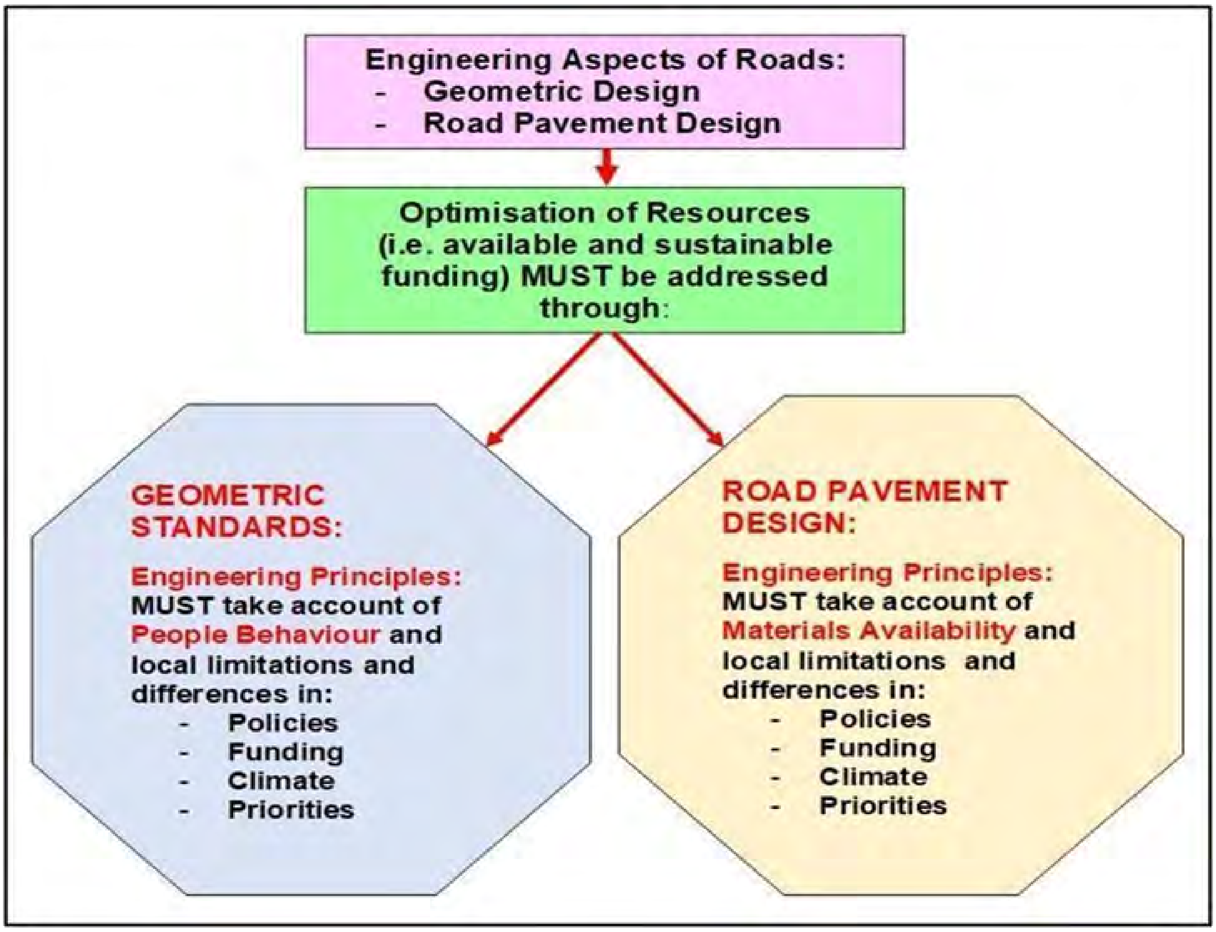


Figure 6 Principles for establishing applicable and appropriate standards

As shown in Figure 6, the engineering technical design and investigations are strongly driven by external objectives with socio-economic implications in terms of larger economic and development objectives at national and regional scales, including:

- Managerial considerations;
- Social and environmental considerations, and
- Practical and functional consideration.

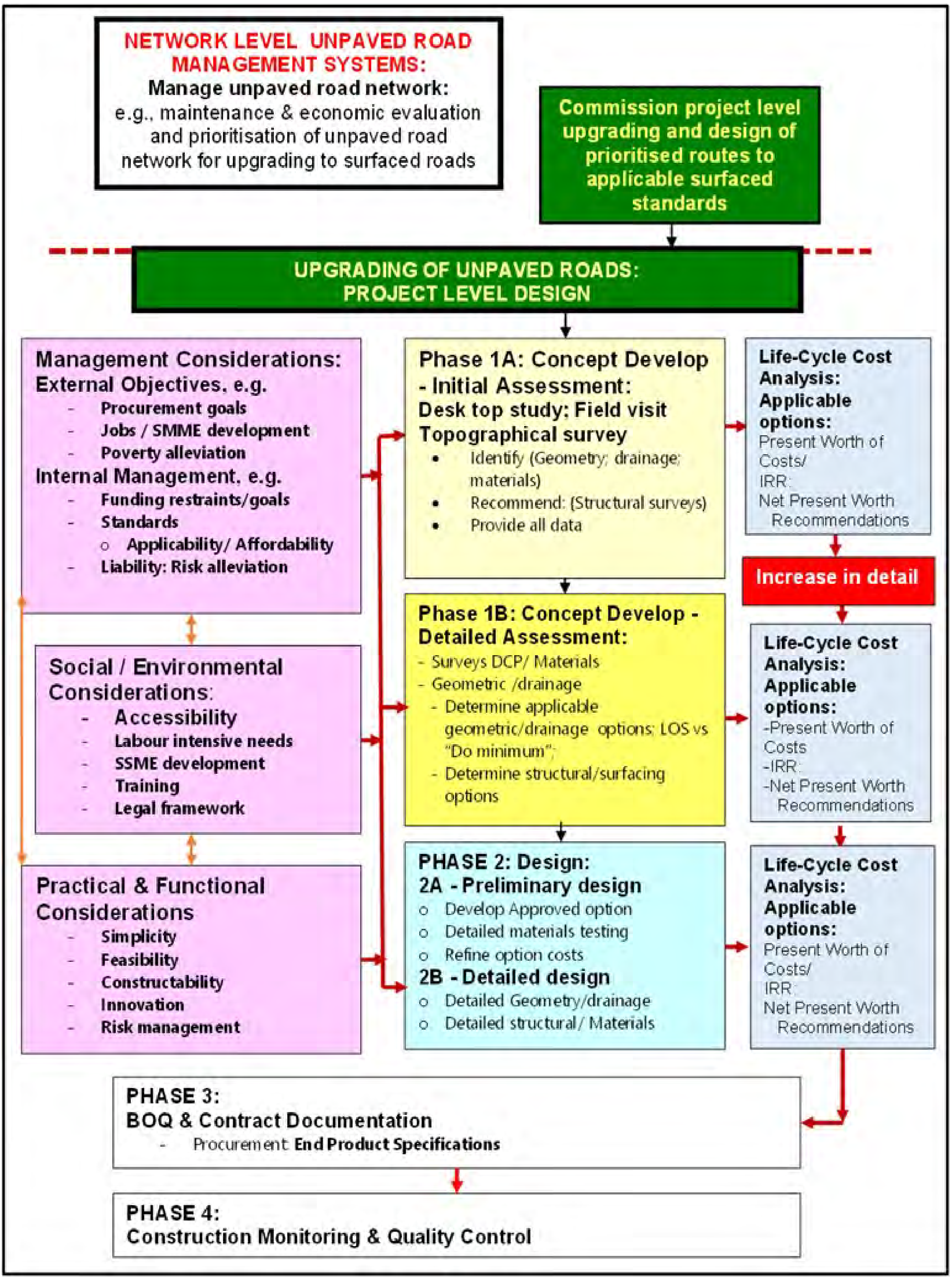


Figure 7 Flow-diagram of a comprehensive approach to the upgrading of unpaved roads

1.4 Recommended design approach

1.4.1 Network level management

Projects must be identified and managed through a sound economic evaluation as part of a broad network-level assessment to determine needs. Economic evaluations must include socio-economic benefits over and above standard engineering principles. The provision of adequate transportation facilities is a major avenue to pursue in achieving general development objectives.

In a broader sense, development objectives must be addressed and included in an economic evaluation for the identification of feasible projects for upgrading within a Network Level Management System of the unpaved road network. These principles are addressed in detail in Chapter 2 of this document.

Typical aspects of a management system that have been developed to a stage which generates information that enables management to address policy and standards, as well as assessing the impact or broader policy, are shown in Figure 8.

For roads identified for upgrading, the same principles are applied to evaluate, in increasingly more detail, the economic impact of various design options applicable to a specific road. The principles of these project level investigations are addressed in detail in Chapter 2.

1.4.2 Non-technical influences

It is not the intention of the document to discuss the non-technical aspects influencing the technical implementation of the upgrading of unpaved roads in detail. Figure 8 contains the main elements of the non-technical aspects that must be considered during all design phases as indicated.

1.4.3 Technical design approach

a. General

The recommended approach includes the identification of applicable Levels of Service (LOS), applicable design methods, testing requirements, the use of naturally available materials and the implementation of proven, applicable new technologies. All applicable options are identified in order to recommend the most cost-effective solution for the upgrading of any unpaved road, without compromising the integrity and durability of the end product.

The overall approach to the design for the upgrading of unpaved roads follows the general principles of any good road design. However, there are several important differences from the traditional approaches that need to be appreciated by the designer to provide designs that will meet the social, economic and environmental requirements in terms of sustainably and cost-effectiveness. Conventional engineering design approaches are often challenged by the unique characteristics associated with the upgrading of unpaved roads. These challenges relate specifically to the application of applicable criteria and the use of naturally available materials to design the most cost-effective solutions.

The following specific characteristics for the upgrading of unpaved roads affect the design approach:

- The alignment may not necessarily be fully “engineered,” especially at very low traffic levels, with most sections following the existing alignment and for which special attention must be paid to road safety;
- A need to cater for non-motorised traffic, especially in urban/peri-urban areas, coupled with a focus on the adoption of a range of appropriate road safety measures;
- Variable travelling speeds that will seldom exceed about 60 to 80 km/h, as dictated by local vehicle characteristics and prevailing topography;

- These roads are constructed mostly from local naturally occurring, often "non-standard", moisture-sensitive materials, and
- Pavement deterioration in these low-volume roads is driven primarily by environmental factors, particularly moisture, with traffic loading being a relatively lesser influential factor, and drainage being of paramount importance.

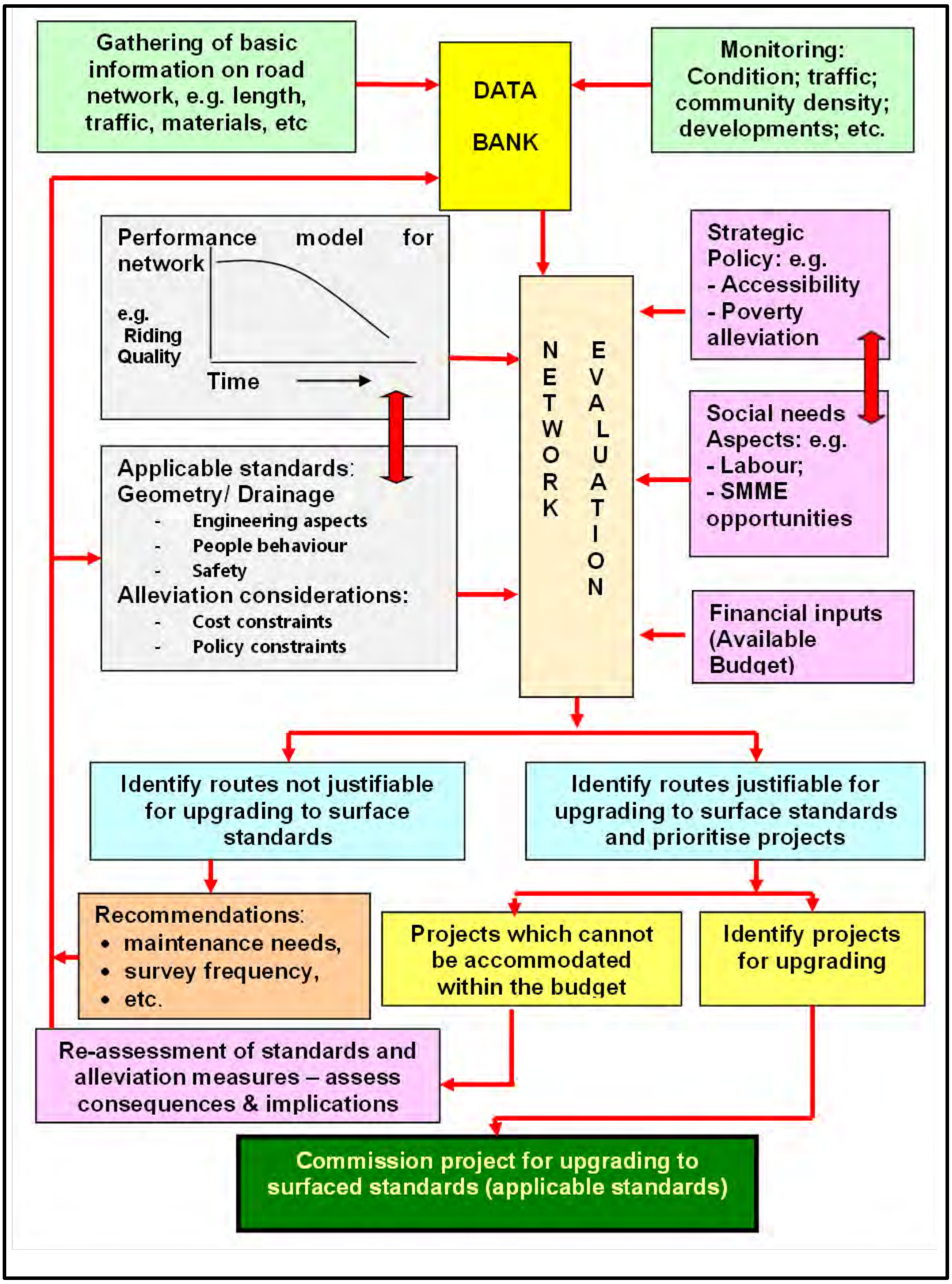


Figure 8 Typical aspects to be contained in a road Network Level Management system

b. Phase 1A: Concept Development – Initial Assessment

The typical investigation and design approach to be followed at the project initiation phase is summarised in Figure 9. The sequence of required surveys to be followed during the investigation process is specifically highlighted as shown in Figure 9. It is of importance to conduct the topographical survey to finalise the geometric design before any Dynamic Cone Penetrometer (DCP) survey or materials testing is done to ensure that all testing is relevant and applicable to the alignment of the road and all testing can be fully utilised in the design.

The applicable standard and Level of Service (LOS) and side drainage is discussed in detail in Chapter 3 and cross-drainage in Chapter 4. The pavement design method, material utilisation and surfacing are discussed in detail in Chapters 5,6 and 7.

c. Phase 1B: Concept Development – Detailed Assessment

The same principles discussed in detail in the preceding sections also apply to the Detailed Assessment Phase of Concept Development. The aim is to increase the relevant information to enable the designer to more accurately determine and identify applicable upgrading options to proceed to the design phase with confidence. The main aspects to be addressed during this phase of the design include:

- Geometric design options (e.g., alignment, etc.), drainage (detailed needs for calculated flows) and all related aspects such as traffic signs, road markings, traffic calming actions, etc., and
- Pavement structural design options, including material utilisation and surfacing options.

The details for this phase of the investigation are discussed in the following chapters:

- **Chapter 3:** Geometric and side drainage design, identify applicable standards and LOS;
- **Chapter 4:** Standards for low-level river crossings;
- **Chapter 5:** Material investigations and design: Assessment in the in-situ bearing capacity and recommended material structural design. Identifying applicable tests and design methods for the assessment of the in-situ bearing capacity of existing routes. This chapter is not applicable only to LVRs, but applicable to and recommended for design traffic loadings up to 10 million E80s;
- **Chapter 6:** Material investigations and design: Optimisation of material utilisation using Material Compatible New Modified Emulsions (MC-NME). This chapter is applicable for the design of lower-order roads as well as higher-order roads with traffic loadings exceeding 30 m E80s, and
- **Chapter 7:** Surfacing selection and design.

A flow diagram with the recommended approach is given in Figure 10 for Phase 1B: Concept Development – Detailed Assessment.

d. Phase 2: Design

The detailed design phase is aimed at developing more detailed concepts of the design for implementation purposes. During the Concept Development Phase of the Investigation, various options regarding geometric design and drainage, meeting the recommended LOS and applicable standards in terms of Ch.4 in comparison with a “do minimum” option would have been fully investigated and analysed. The in-situ bearing capacity of the existing structure would have been determined with confidence. Structural pavement needs and surfacing alternatives would have been identified and economically evaluated. Based on the Life cycle cost comparison of applicable options identified during the Concept Development Phase of the investigation, a decision would have been taken together with the Implementing Agency, on the preferred Design Option that should be developed in more detail during the Design Phase of the investigation. During the design phase, all the detailed designs will be finalised with any outstanding details to enable accurate drawings to be produced and a detailed Bill of Quantities (BOQ) compiled with the necessary tender documents ready to allow for open tender and implementation of the project to proceed.

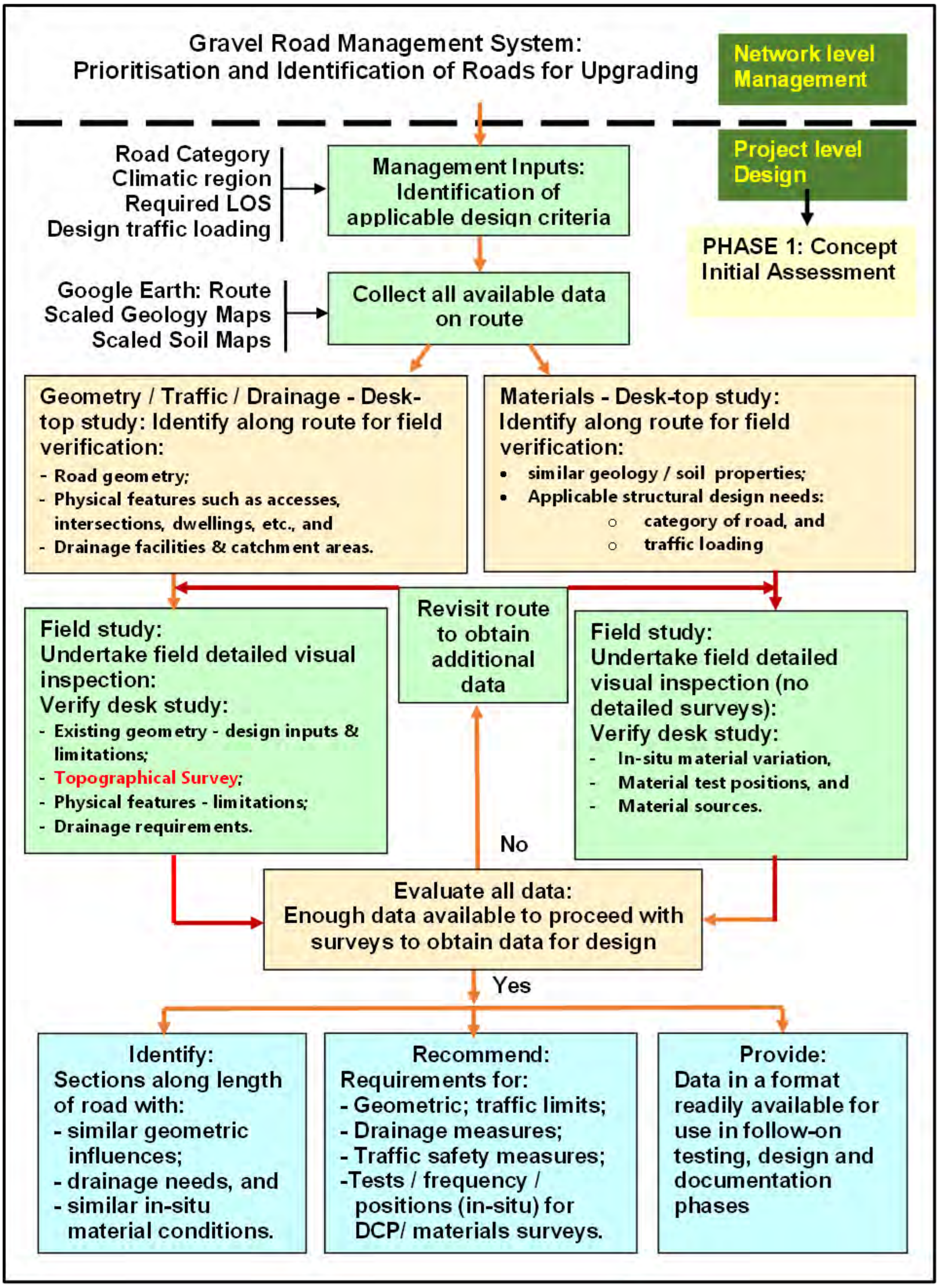


Figure 9 Flow diagram of Phase 1A: Concept - Initial Assessment

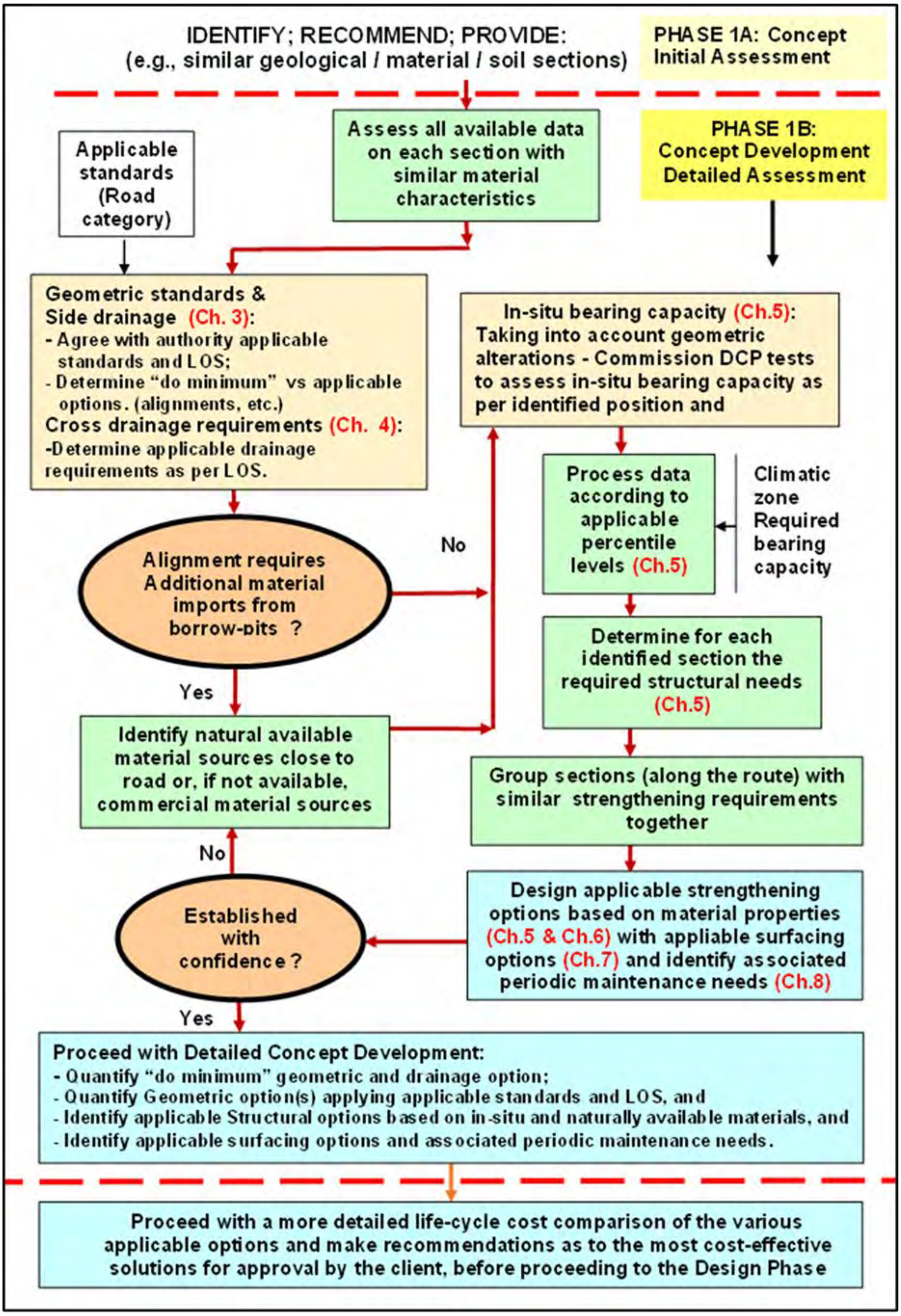


Figure 10 Flow diagram of Phase 1B: Concept Development – Detailed Design

The design phase is sub-dived into:

- **Phase 2A:** Preliminary design that addresses both details with regard to:
    - o Pavement materials design, sampling and appropriate basic testing of naturally available materials plus additional specialised testing if the option of new technologies is to be investigated in detail, and
    - o Surfacing material sourcing, sampling and testing, and
- **Phase 2B:** Detailed design which will involve detailed:
    - o Geometric drawings to be produced based on the approved preliminary design that will enable the accurate determination of quantities for the compilation of a BOQ needed for the tender process, and
    - o Materials testing: testing of borrow-pit materials to be utilised where necessary for both untreated and MC-NME stabilisation to. These tests will provide more accurate information on the need for MC-NME stabilisation and the associated cost implications.

The applicable standards and Level of Service (LOS), geometric standards and side drainage are discussed in detail in **Chapter 3** and cross-drainage in **Chapter 4**. The pavement design method and material utilisation are discussed in detail in **Chapter 5** and Chapter 6 and pavement surfacing selection and design in **Chapter 7**.

1.5 Scope and layout

The whole objective of this TRH24 is to ensure that available resources are optimally utilised. This is in main achieved through the:

- Provision of the Cost-effective Analyses (CEA) based method to assist with identification and prioritisation of upgrading projects on an unpaved road network as part of an authority's Road Asset Management System (RAMS);
- Recommendation of applicable Levels of Services (LOS) for geometric standards and Low-level River Crossings (LLRC) in a safe and responsible manner, bridging the gap between unpaved roads and traditional high standard roads, carrying high volumes of traffic;
- Applying a comprehensive approach to design as required in South Africa incorporating initial assessment, detailed assessment preliminary and detailed design phases combined with more detailed, life-cycle strategy analyses;
- Utilisation of the Dynamic Cone Penetrometer (DCP) as the pavement structural evaluation tool and the DCP design method to provide an optimised pavement design at minimum costs;
- Optimising the use of naturally available materials incorporating new material technologies in terms of New Modified Emulsion (MC-NME) stabilisation options;
- Providing guidelines for maintenance and the management of the road network, and
- Providing end-product specifications and project specifications for the use of NME stabilising agents.

The document is structured in accordance with Figure 11 and includes a number of Appendices providing details on specific actions.

1	Introduction
2	Road Network Evaluation and Prioritisation (CEA-BASED)
3	Geometric Standards and Side Drainage
4	Cross Drainage Standards for LVRs
5	Pavement Structural Evaluations and Design:
6	Material Design Method using (MC-NME) Technologies
7	Selection and Design of Applicable Surfacings
8	Required Maintenance Actions
9	Method of Contract for Upgrading of Unpaved Roads

APPENDICES

APPENDIX A	Key Data and Sources for Economic Prioritisation
APPENDIX B	Guidelines for pre- and post-project assessments
APPENDIX C	Physical Environment
APPENDIX D	Laboratory DN Testing and Selection of a Moisture Regime
APPENDIX E	Project Specifications
APPENDIX F	Examples of MC-NME Stabilising Agents Tested in Practice
APPENDIX G	Surfacings for Low Volume Roads
APPENDIX H	Maintenance Concepts

Figure 11 Document layout

2. Road Network Evaluation and Prioritisation (CEA-BASED)

2.1 Purpose of these recommendations

These recommendations are intended to assist road departments to firstly identify and prioritise unpaved roads for upgrading to Low Volume Sealed Roads (LVSR), followed by an economic evaluations of the selected road upgrade projects. The starting point is to understand the unpaved road network - notably its extent, condition, traffic characteristics, etc., for authorities to identify roads to be upgraded to LVSR as projects from within this network. The next step is to provide the economic rationale for upgrading unpaved roads to surfaced standard, often at traffic volumes below the traditional guideline of 200 vehicles per day. This economic rationale is provided by combining a Life-Cycle Cost Analysis (LCCA) of alternative road surfaces with a summary of the welfare benefits generated by upgrading unpaved roads to LVSR. Having established a sound rationale to upgrade unpaved roads to LVSR in the South African context, a Cost-effective Analysis (CEA)-based Road Classification System is introduced as the means by which to prioritise roads within the unpaved road network for upgrading to LVSR. The CEA-based Road Classification System is then applied for demonstration purposes at the network level, as well as at a project level using one of the case studies attached to the development of this Manual. The last section of this chapter details the approach that road departments should follow in order to effectively evaluate their road upgrade projects.

Some users of this manual will be disappointed to discover that it does not provide an algorithmic tool into which they can simply plug variables relevant to a specific prioritisation decision and see a clear decision pop out. (Note that HDM-4 is often presented as having this characteristic, but this impression is illusory. HDM-4, rightly, allows discretionary economic values to be weighted in varying ways that drive specific applications. That this scope for discretion is often not taken up by users is a bug in current practice, not a feature.) There are, of course, reasons why such an algorithm cannot be provided.

If one set out to construct such a discretion-free instrument, one would need quantitative data of two kinds that are not available.

First, one would require a complete specification of the national road network outside the major metropoles. This is because, for reasons explained below, a road's relative economic priority is highly sensitive to its marginal contribution to the efficiency of the network as a whole. Thanks to a recent project funded by the World Bank

https://www.dbsa.org/sites/default/files/media/documents/2023-08/Beyond%20the%20Gap%20-%20Transport%20Sector%20Report%20-%202022.pdf and

https://www.polity.org.za/article/going-beyond-the-infrastructure-funding-gap---a-south-african-perspective-2024-02-01),

A complete map of the South African rural network is provided. This map can be integrated with evolving updates of the geography of the most important assets that roads serve schools, health clinics, and sites of productive enterprise. These are major steps toward the needed full-network specification. Unfortunately, one crucial element of information remains missing, i.e., traffic use data. National government does not have an accurate base of such data. Some provinces have relatively reliable and comprehensive data bases of their road networks, though almost all have important gaps, and some provinces have almost no such records. An urgent need in South African roads policy is a scientifically designed and conducted traffic data census, which would be carried out no less frequently than every decade. This has been urged by transport economists for many years, but institutional resources have yet to be marshalled for its provision.

Second, one would require a range of microeconomic assessments of specific projects, of the kind illustrated in the case study furnished in Appendix B, in order to infer quantitative parameters around local benefits and costs of different forms of surface upgrade. The methodology for conducting such assessments is described in detail below. However, due again to institutional infrastructure gaps in the current national environment, such assessments could not be carried out under the terms of the project that generated TRH-24. Provision of the substantial funding (see detailed estimates below) required for such assessments is another important priority for future work.

These limitations duly noted, the discussion below does inform road authorities how to qualitatively frame prioritisation decisions, in a way that is applicable at all problem scales. It does so by indicating a new road classification logic, intended to be complementary to existing classifications designed for engineering and jurisdictional purposes, that planners can use to identify the local variables they need to attend to in order to incorporate microeconomic and social factors into their prioritisation decisions.

Note that the need for varying local data is an inevitable aspect of any economic prioritisation instrument, which will persist even when the limitations discussed above have been addressed at some future time. No one document can ever be a “one-stop shop” for the planner, which could be used without the need for consulting any additional sources. This is simply because the economic value of a road project always depends on local variables, such as locations and sizes of clinics and schools, that vary across project sites and over time. These data are normally accessible, but any general manual that set out to include them would be out of date within months of being distributed. Optimising local projects always depends upon local variations, and nothing, in principle, can make that need for project-specific research go away. We have aimed to serve a general practical purpose, however, in closely specifying how such research can be planned and conducted, and (approximately) how much it can be expected to cost.

2.2 Identifying characteristics of rural road network unpaved roads

The starting point is to identify and review the pool of unpaved roads from which surface upgrade projects will be selected. This determines the demand base for road upgrade projects, as well as the budget parameters given that the cost to upgrade a gravel road to surfaced standards depends on the specific characteristics of the roads (e.g., location, condition, traffic volume, etc.). This requires a comprehensive situation analysis of this road network.

The proclaimed South African rural road network was approximately 328 550 km in 2020. This equates to 43.8 per cent of the total road network. The ownership of these rural roads was shared by SANRAL, which managed (17 912 km), of national roads in rural areas, the 9 provincial road departments, which collectively managed (247 830 km) of provincial roads in rural areas, and the 44 District Municipality Road departments, which collectively managed (62 808 km) of municipal roads in rural areas. The provincial road departments are therefore the most important agents, as they currently have 75.4 per cent of the rural road network under their management.

Figure 12 presents the recorded surface composition for most of South Africa with paved roads comprising only 18.8 per cent of the rural road network. The remaining 81.2 per cent of the rural road network is unpaved, consisting of a combination of gravel and track/earth roads. Based on available data, the proportion of unpaved roads that are track/earth roads ranges from 33.0 per cent in the Eastern Cape Province to 4.9 per cent in the Western Cape Province. This extensive volume of unpaved roads scattered across jurisdictions presents planners with a significant – and practically unrealistic - demand base for potential road upgrade projects, which necessitates a robust formal project selection methodology.

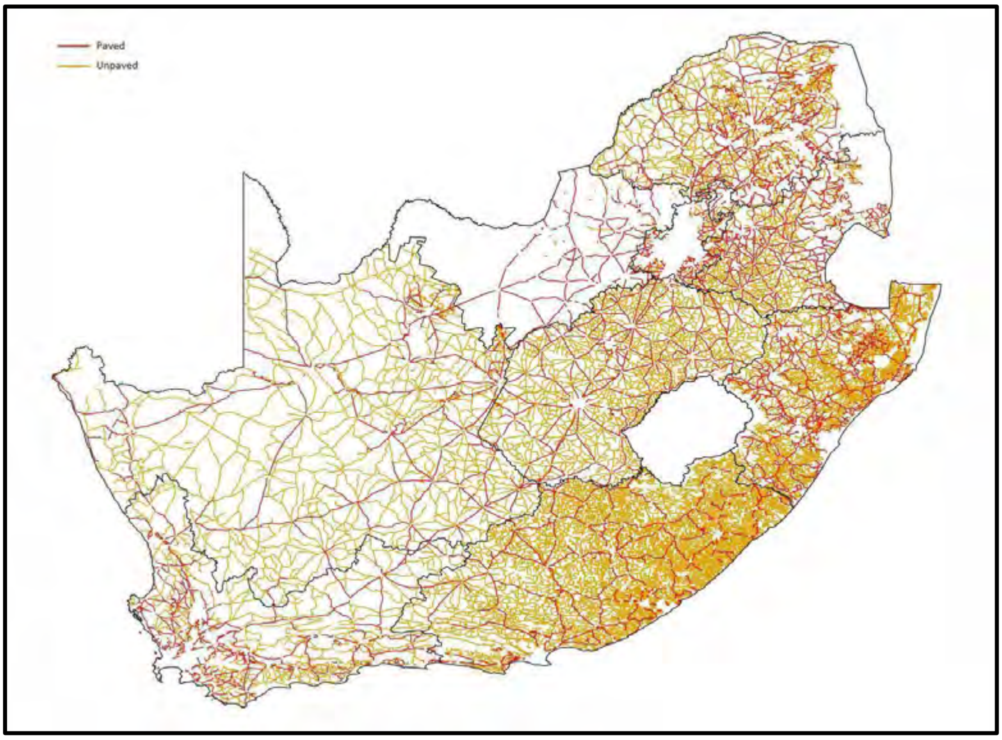


Figure 12 Surface composition of the rural road network, 2020

Moreover, the budgets available for unpaved road upgrades will be constrained by the upward cost pressures imposed by the prevailing road network conditions. The rural road network is in a generally poor condition, with only 9.7 per cent in good or very good condition. The overwhelming majority of unpaved rural roads are in a heavily deteriorated state.

In light of the extent and condition of the unpaved rural road network, it follows that what South Africa must prioritise is more, and more systematically scheduled, road maintenance, along with surface upgrades to more heavily trafficked and economically important unpaved roads.

From available traffic data the distribution in terms of Annual Average Daily Traffic (AADT) is as follows:

Table 9 Traffic distribution on the unpaved rural road network

AADT	Distribution
Less than 100	32.7%
100 - 300	54.3%
More than 300	13.0%

The following section therefore offers a set of South African specific motivations to justify the policy to upgrade some low-volume unpaved roads to surfaced standards, which involves relaxing the traditional rule of thumb.

2.3 General economic analysis of surfacing decisions

Several road departments have based their surfacing strategies on the HDM-4 derived guideline, without regard to marginal or dynamic efficiencies, that AADT must exceed 200 vehicles to justify upgrading an unpaved road to a surfaced standard. Because the practice has not generally met this standard due largely to budget constraints, many unpaved roads are only upgraded to a surfaced standard once AADT exceeds 500 or even 1 000 vehicles. This strategy is aligned with Rozenberg and Fay's (2019) suggestion that many developing countries should maintain unpaved networks due to the excessive opportunity cost of large-scale upgrading to surfaced standard sealed status. Such reasoning might apply to South Africa if a large part of its unpaved network were in good condition. However, most unpaved roads are in a deteriorated condition and those in good condition are concentrated amongst those roads with AADT above 300 vehicles. Hence, the relevant comparison is between maintaining thousands of kilometres of unpaved roads and upgrading them to surfaced standards. Although the latter option requires higher capital expenditure per rehabilitated kilometre, this section shows that these costs are offset by lower maintenance costs over life cycles, less reduced environmental harm, and realisation of gains from employing local low-skilled labour that has a modal shadow cost of zero.

2.3.1 Life-cycle cost analysis

A LCCA uses initial and discounted future costs to evaluate the overall long-term economic efficiency of alternative investment options. This analysis provides critical information to inform investment decisions. The LCCA will be used in this Manual to compare the whole-life cost of the following road surface options for AADT up to 400 vehicles: Gravel road with minimum maintenance; Gravel road with required maintenance; gravel road upgrade to surfaced standard (14mm Cape Seal).

The reviewed road authority costs include the differential construction, maintenance, rehabilitation, and salvage costs. Salvage costs refer to the serviceable life of a road at the end of the analysis period, which is calculated as the remaining serviceable life as a prorated share of the last rehabilitation cost less any repair and restoration works and are netted from other costs to estimate the total life-cycle cost for each alternative road surface. Road user costs are also included in the analysis based on an assumed 80/20 per cent split between light and heavy vehicles, respectively.

The analysis period is set at 20 years to cover the longest design life, incorporate at least one major rehabilitation activity for each road surface, and reflect long-term cost differences associated with the alternative road surfaces. The discount rate is set at 10.0%, in line with the typical working rate applied by road departments in South Africa.

a. Unit costs and event frequencies

Values for the cost variables could not be determined probabilistically due to data limitations. A deterministic approach is therefore adopted in which fixed, discrete costs are applied for each variable based on evidence and professional judgement of what value is likely to occur. These fixed costs are then collectively applied to estimate the life-cycle cost of the alternate road surfacings.

The roadwork unit cost data shown in Table 10 reflect the use of no commercially sourced materials. Although borrow pits are used for more than 90 per cent of rural unpaved roads, some public authorities can only obtain the needed materials by relying on commercial sources,. The use of commercially sourced materials increases the costs for structural layers and regravelling by approximately 30 per cent and 75 per cent, respectively. The costs for structural layers are also 15 per cent higher in wet areas.

b. Life-cycle cost analysis simulations

Based on the cost data from Table 10, a range of simulations has been conducted to compare the relative costs of the alternative surface options under climatic conditions common across South Africa. In addition to the above specifications, the levels of service were set at a steady state IRI of 8 for gravel roads receiving normal maintenance and an IRI of 2.5 for the LVSR options.

Table 10 Road maintenance unit costs, 2024 (Including VAT)

Unit costs 2024 (VAT inclusive)					
Unpaved road blading and periodic maintenance					
Maintenance activity/ Upgrade scenario		**Unit**	**Low**	**Average**	**High**
Tyre dragging		km (7m wide)	R195	R273	R362
Towed grader blading		km (7m wide)	R265	R361	R401
Light dry blading		km (7m wide)	R951	R1 093	R1 766
Hard blading (in-situ moisture)		km (7m wide)	R1 109	R1 298	R2 018
Wet hard blading with Water bowser		km (7m wide)	R3 881	R4 812	R6 468
Wet hard blading, Water bowser, PTR rolling		km (7m wide)	R8 074	R9 609	R13 457
Full Reshaping (Side Dr + Full depth)		km (7m wide)	R96 640	R128 853	R166 298
Clearing, forming and shaping (Track - Engineered Natural Earth)		km (7m wide)	R112 720	R210 581	R284 739
Spot gravelling		m^3	R345	R553	R761
Chemical treatment		km (7m wide)	R82 566	R197 240	R311 915
Reclaiming from shoulder and reserve (100 - 150mm)		km (7m wide)	R99 076	R158 428	R170 895
In-line crushing, reshape		km (7m wide)	R151 686	R174 717	R283 827
Regravelling (150mm) Borrow pit		km (7m wide)	R517 864	R586 519	R741 576
Regravelling (150mm) Commercial		km (7m wide)	R906 261	R1 026 409	R1 297 758
Track to Gravel (Engineered Imported Gravel Surface) using Borrow Pits		km (7m wide)	R630 584	R797 101	R1 026 315
Upgrading to Low Volume Surfaced Road					
Refer Table 1					
Surfacing	**Surfacing Type**	**Unit**	**Low**	**Average**	**High**
Surfacing alone but as part of upgrading contract	14/7 Double Seal	km (7,4m wide)	R1 363 840	R1 500 224	R1 636 608
	14 mm Cape seal	km (7,4m wide)	R1 363 840	R1 568 416	R1 772 992
	20 mm Cape Seal	km (7,4m wide)	R1 772 992	R2 393 539	R3 014 086
	Slurry-bound MacAdam	km (7,4m wide)	R2 182 144	R2 829 968	R3 477 792
	Otta seal+sand (16mm)	km (7,4m wide)	R1 636 608	R1 923 014	R2 209 421
	40 mm Asphalt overlay	km (7,4m wide)	R3 136 832	R4 227 903	R5 318 975
Paved periodic maintenance and rehabilitation on LVSRs					
Activity for LVSR				**Average**	
Resurfacing	Sand/Grit seal	km (7,4m wide)		R539 710	
	Slurry seal (6mm)	km (7,4m wide)		R975 914	
	10mm Single seal	km (7,4m wide)		R680 182	
	14mm Single seal	km (7,4m wide)		R739 329	
	Rejuvenation	km (7,4m wide)		R160 113	
	30 mm Asphalt overlay	km (7,4m wide)		R2 454 572	
Shape correction plus 14 mm Single seal		km (7,4m wide)		R1 278 056	
Light rehabilitation (Significant repairs and Double seal)		km (7,4m wide)		R3 296 767	
Medium Rehabilitation (Insitu recycling and Double seal)		km (7,4m wide)		R5 315 477	
Heavy Rehabilitation/ Reconstruction to higher standard		km (7,4m wide)		R9 623 988	
Routine maintenance (Annual)					
			Low	**Average**	**High**
Annual routine maintenance unpaved (excluding blading)		km (7m wide)	R7 620	R9 860	R12 100
Annual routine maintenance two lane paved		km (7,4m wide)	R27 455	R31 573	R35 692

Figure 13 presents the LCCA simulations for the alternative road surface under a moderate climate using a 14 mm Cape seal as initial seal. The results clearly indicate the very high relative cost of the do minimum maintenance strategy on gravel roads, which is currently the predominant maintenance strategy across the unpaved road network. Before the welfare benefits from surfacing unpaved roads identified in Section 3.4 have been introduced, the LCCA indicates that maintained gravel roads are the most cost-effective alternative for very low volume roads with AADT of approximately 100 vehicles. However, due to the ability to upgrade roads to appropriate standards, at lower costs, the results of the LCCA shift in favour of the LVSR alternatives at around AADT of 150-180 vehicles. Once AADT reaches 200 vehicles, the LCCA demonstrates that all of the modelled LVSR options except for a 40mm asphalt overlay are more cost-effective surface options than gravel. This overall finding that LVSR options, except for a 40mm asphalt overlay (Figure 14), are more cost-effective than gravel is maintained with a rising relative cost differential as traffic volumes increase.

The findings identified above are confirmed in all climatic areas of South Africa, namely that the LVSR alternatives are in many instances cost-effective substitutes for gravel roads, even at less than 150 vehicles per day.

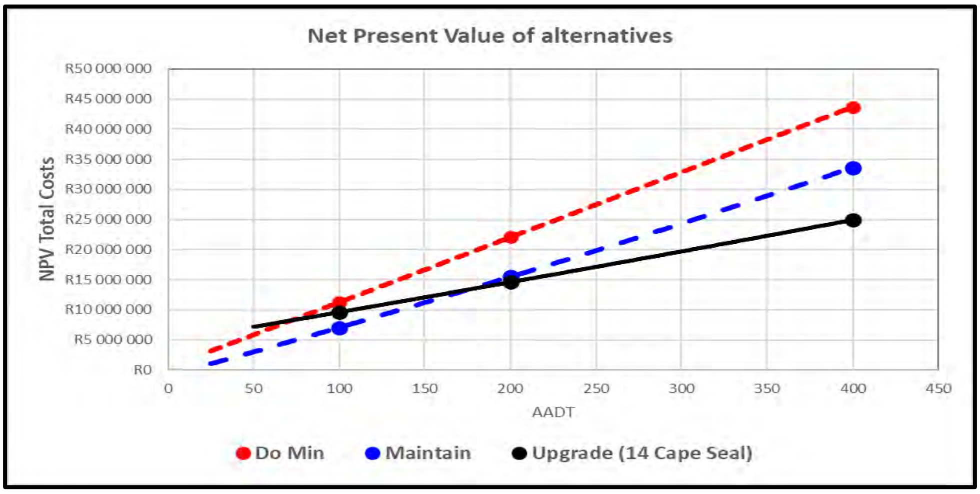


Figure 13 LCCA in moderate climates of South Africa (Upgrade 14 Cape seal)

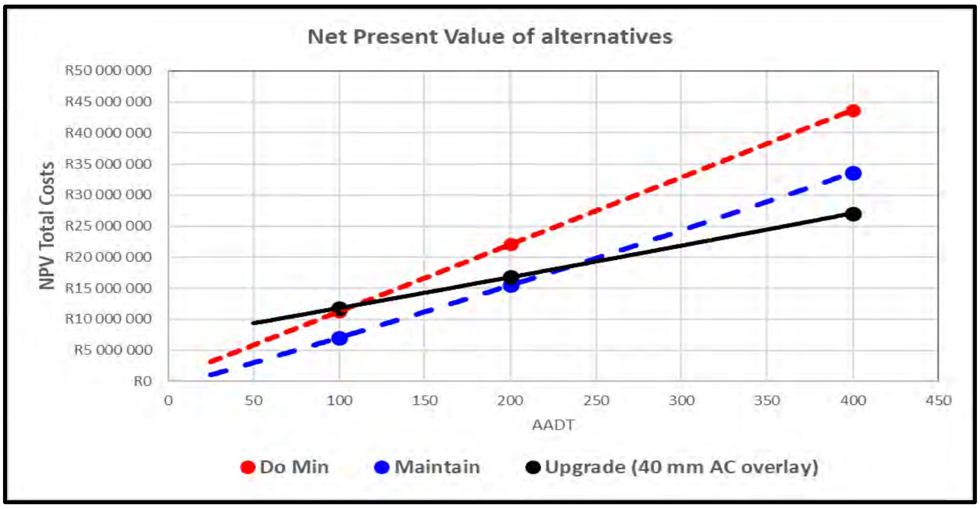


Figure 14 LCCA in moderate climates of South Africa (Upgrade 40mm AC)

The consistent conclusion from this limited LCCA, focusing only on road agency and vehicle operating costs, is that LVSR alternatives are indeed more cost-effective than gravel roads at traffic volumes well below the traditional threshold of 200 vehicles per day. Moreover, this finding holds across the general climatic conditions in South Africa. This means that all road departments will be responsible for at least some, but often many, unpaved roads that meet these simple criteria under which it is cost-effective to upgrade them to LVSR. The LCCA can be deepened to include the welfare benefits introduced in the subsequent section, which add further weight to the rationale to upgrade unpaved roads to surfaced standard and lower the traffic threshold at which departments should schedule upgrades of unpaved roads to LVSR.

2.4 Welfare benefits from paving unpaved roads

In addition to allowing road departments to accommodate more kilometres of road with the available maintenance budgets, which allows the road network to support higher levels of economic activity, a policy of surfacing unpaved roads would create further welfare benefits. These benefits to seal low-volume roads offer other potential welfare benefits, namely:

- Employment opportunities:
    - Surfacing unpaved roads is an effective mechanism to absorb and upskill unskilled workers with very low, and frequently (in the specific context of rural SA), if not almost zero shadow opportunity cost;
- Substitution of inefficient welfare transfers for productive labour:
    - Because of inefficiencies within the redistributive social welfare system, a policy to surface unpaved roads must not be viewed simply as a labour creation scheme. The unemployed workers absorbed through a policy to surface unpaved roads would lower the state's social welfare burden at the same time as developing productive road infrastructure. This trade-off of inefficient, indirect transfers to unemployed workers for asset creation is therefore not a rand-for-rand swap. Rather, surfacing unpaved roads could generate large macroeconomic efficiency gains – with multipliers in the range of 0.2 to 0.4 - that stand as a point of clarification for further research;
- Substitution of local resources for imports:
    - Petts (2002) contends that the imported, heavy equipment used to construct and maintain gravel roads is suited to countries with high-wage, low-investment-cost environments. The cost of imported capital equipment tends to be more expensive when interest rates are high and the exchange rate is volatile, conditions that both apply structurally in South Africa, and local resources for imports – outcomes that could be achieved by upgrading gravel roads to surfaced standard rather than maintaining them as gravel roads;
- Reduced short-term rural-urban migration pressures:
    - Inadequate rural incomes and few job opportunities are among the factors that have forced people to relocate from rural areas to settle in urban centres or along transport corridors (National Planning Commission, 2012). Between 2001 and 2011 the urban population grew from 57.0 per cent to 63.0 per cent of the population (Statistics South Africa, 2011). Based on current migration rates the United Nations (2010) estimates that South Africa's urban population will grow to 71.3 per cent by 2030 and 80.0 per cent by 2050.
    - A policy to surface unpaved roads could generate significant rural non-farm employment as well as promote rural diversification, which renders it an important tool to help create more balanced growth and thereby moderate the rate of the prevailing structural tendency for population to migrate to metropoles. In this regard, widescale surfacing of unpaved roads reflects the National Development Plan (NDP) objectives to increase the rural employment rate from 29.0 per cent to 40.0 per cent, promote rural infrastructure investment that incentivises citizens to remain in rural areas, and ensure that citizens in rural areas are not locked into poverty (National Planning Commission, 2012);
- Supply-side infrastructure and human capital development:
    - Gravel roads typically preclude local communities, small enterprises, and poor citizens from having an ownership stake in roadworks because of the high cost of capital and the large

capital investment requirements in terms of specialist equipment to construct and maintain gravel roads. Petts (2002) argues that haulage and gravelling by tractors and trailers involve high equipment provision and operation costs, compared with light bituminous seals, for which the capital investment is significantly lower and much of the required equipment is available for hire on the local market.
    - The inclusion of small contractors in road construction and maintenance works enhances human capital in the form of management, tendering, investment skills, and on-the-job training. The sector has developed programmes, for which sealed roads offer more learnership opportunities than gravel roads, to incentivise labour-intensive works on low-volume roads and grow capacity among emerging contractors (Department of Public Works, 2018);
- Dust emissions:
    - Dust can travel hundreds of metres from a gravel road and is released from the surface under the wheels of moving vehicles, the turbulence caused by vehicles, and through the wind.
    - Dust generated from gravel roads has a variety of potential negative effects on the health of road users, pedestrians, and adjacent communities. The largest effect is on human and animal respiratory systems, with 10.0 μm and 2.5 μm particles small enough to pass through the nose and throat and enter the lungs (Greening, 2011). Certain gravels also contain undesirable materials such as asbestos and silica (Department of Transport, 2013).
    - Dust generated from unpaved roads has further negative effects on agricultural yields. Among other effects, dust coatings on crop foliage: reduce spray contact of pesticides, fungicides, and fertilisers; hinder pollination; reduce the efficacy of the transpiration and photosynthesis process; and cause leaf and fruit scorch and discolouration (Jones, 2000). These effects reduce agricultural yields and prices.
    - While dust palliatives are available to limit dust emissions from unpaved roads, these products add further costs to the provision of gravel roads – further undermining their life-cycle cost-effectiveness relative to surfaced alternatives CSIR (2003), and Tanzanian Roads Authority (2016).
- Water consumption and vulnerability:
    - Declining water availability in some parts of the country, and the rising frequency of highly concentrated rainfall that can destroy unpaved roads, are among the most important dynamic factors that increasingly favour surfacing roads.
    - The construction and maintenance of gravel roads require large volumes of water. The CIDB (2007) prescribe 150 to 170 l of water per m^3 of gravel for compaction. Although rainfall eases water requirements, many parts of the country where gravel roads are prevalent are water scarce and experience long dry seasons.
    - Combining the road network data with the climate data in the CSIR’s (2023) Greenbook indicates that 33 140 km of unpaved roads are in water-stressed parts of the country, defined as areas that receive low annual rainfall and/or are at risk of groundwater depletion.

2.5 Prioritisation methodology

2.5.1 CEA-based road classification system

Section 2.1 identifies the urgent need for a network-level road investment prioritisation model for South Africa that reflects the policy priorities set for the roads sector to satisfy citizens' constitutional right to access basic services and to maximise potential economic growth. Without such a model, road departments risk prioritising a sub-optimal set of unpaved roads for surfacing.

The first step in the development of this road investment prioritisation model is to ensure that roads are classified according to whether they serve basic access or economic growth function, or a combination of these functions. The recommended CEA-based road classification system, therefore, moves away from the focus of current road classification systems on factors such as road traffic, design, function, and ownership to account for the type and relative value of the economic service provided by a road. This does not mean that these more familiar classification systems should be abandoned. Anticipating traffic volume is, after all, crucial to deciding which of various sealing options is correct from an engineering perspective, as discussed throughout this document. The point is rather that different classifications are appropriate for addressing different questions. In prioritising projects for national welfare optimisation, a classification that is driven by technically correct welfare economics is required. The innovative road classification system described below separates the network into tiers that represent lexicographical priorities based on the network mandate. This information enables road departments to plan their maintenance schedules in descending order of importance and to focus on cost-effectively satisfying the maintenance demands within each tier of road to maximise the funding available for subsequent tiers.

2.5.2 Adherence to fundamental classification criteria

The fundamental criteria for an effective road classification are covered in a seminal report on road classification developments by the Intergovernmental Committee on Surveying and Mapping (ICSM) (2006). The CEA-based road classification system must comply with these criteria for the system to fulfil the minimum requirements for acceptance by South African road departments and related public agencies.

A first criterion is a small number of road classes. The ICSM note the need for trade-offs between simplicity and accommodation of all road classes. However, while officials should be able to effectively manage and work with the classification system, no practically relevant road classes can be excluded when rationalising the theoretically possible classes.

The second criterion is that classification systems use unambiguous descriptive terminology for the road classes. The definitions should be distinct, clear, and concise to ensure a simple and objective application of the classification system. Broad definitions of classes allow more scope for interpretation and thus impair the consistent application of a classification system.

The third criterion is that road classes are scale independent and ubiquitous across the network. The entire road network must be consistently classified with respect to the relevant objective the system aims to serve – in the present instance, welfare optimisation objectives. Because modifications to classes that account for regional significance detract from the countrywide effectiveness of a classification system, all distinguishing variables must be applicable across the whole spectrum of roads.

The final criterion is hierarchical contiguity, which requires that the roads in the same class connect to form a continuous network. The rationale is that network integrity is improved if authorities are responsible for the maintenance of seamless road networks. However, this criterion undermines efficiencies obtainable from prioritising across the South African road network as a whole. It could enjoin maintaining or upgrading a road of Class A because it connects two other Class A roads, even in a case where these roads are already connected by an adequate Class B road. Therefore, the CEA-based road classification system deliberately removes this criterion from consideration.

2.5.3 The applied prioritisation rules

The prioritisation model classifies rural roads as either:

1. Basic Access: roads that connect households to essential services (schools and clinics) but do not make a net positive contribution to South Africa's GDP;
2. Strategic: roads that support the highest contribution to economic growth independently of fluctuations in business and commodity price cycles and may or may not also provide access to essential services for rural populations;
3. Tactical: roads that make positive contributions to economic growth under some (but not all) market conditions but do not provide access to essential services for rural populations, or
4. Surplus: roads that, if unproclaimed, would generate a net saving to the economy and would not deprive any community access to essential services. Some Strategic and Tactical roads are multi-functional, meaning that they also connect communities to basic services.

The prioritisation rule for the road classes is shown in Figure 15 and reflects the above Rawlsian normative reasoning. Basic Access Roads, by definition, provide the only viable means for a community to access basic service centres. In their absence, citizens in the community in question fall outside the prescribed norms and standards that regulate the roads sector as a whole. Basic Access Roads are thus set as the first lexical priority to ensure that all South Africans enjoy at least the minimum prescribed level of access to constitutionally protected primary and secondary schools and healthcare facilities.

However, there is often a false dichotomy between these basic access and economic growth functions, with some roads, which are termed 'multi-functional', essential for basic access whilst contributing to economic growth as per 1a in Figure 15. These multi-functional roads are prioritised before Basic Access Roads (1b in Figure 15) due to this dual function. The South African road network presents many opportunities to create multi-functionality by moving schools and clinics in such a way that no community loses basic access, but the number of roads needed to maintain the constitutional commitment while making negative net contributions to national GDP is reduced. Such redistribution will be an essential part of any optimisation of overall expenditure on roads. In effect, the prospects for rationalisation signal that the country currently has more roads than it needs, or than its fiscal resources allow it to adequately maintain.

However, because the governments constitutional obligation prevents it from being able to trade off basic access for contribution to economic growth, Basic Access Roads that cannot be rationalised by relocation of basic service centres must still be prioritised as the final call on resources within the top priority tier regardless of their negative contribution to growth.

Strategic Roads must in turn be prioritised over Tactical Roads as the former support higher levels of structural economic activity. This point is of merely formal significance. Given the relatively high levels of economic activity associated with Strategic Roads, there are no Strategic Roads within the set of unpaved roads that an authority would consider for prospective resurfacing.

Figure 15 Prioritisation rules

Surplus Roads are the last priority. These roads fulfil no essential basic access function and make negative economic contributions, as the cost to maintain them exceeds the value of the economic activity they facilitate. Road authorities should consider de-proclaiming Surplus Roads, thereby removing the risk that authorities might misdirect resources, including complementary non-road infrastructure, to these roads instead of more efficient allocation to points linked by higher priority roads.

Once roads are placed within the classes as defined above, the subsequent within-class prioritisation exercise is based on the relative contribution of the roads to economic growth. This determination should be based on a structural growth model that has two main arguments: the expected cost of the road, and the road's contribution to economic growth. The latter is difficult to estimate in South Africa given the data. Given these constraints, a **proxy ranking for the economic contribution of roads can be estimated based on their associated:**

- Heavy vehicle traffic, sourced from freight companies and/or tax authorities, to measure support for potential export products, and
- Gross Value Added (GVA) at the mesozone level to measure supported output. Heavy vehicle traffic supersedes GVA as the primary proxy given that it is a direct measure of freight, and thus possible export-supporting activity on a road. GVA is an important second-best proxy because these data are currently available for all regions of South Africa.

The primary strategy to increase economic growth is therefore to prioritise road links in areas with comparatively higher output that boost export performance for the highest volume of goods by efficiently connecting the local producers with export-orientated infrastructure, specifically ports and airports.

2.6 Integration of the CEA-based road classification system within RAMS

The CEA-based road classification can be easily added as a decision variable in the existing departmental Road Asset Management Systems (RAMS) by pairing the road IDs with the relevant road class. As emphasised previously, the recommendation is not to overwrite any of the existing classification data as these serve specific purposes distinct from economic prioritisation, but rather to complement the engineering variables in the asset management systems which currently include visual condition, roughness, rut depth, macro texture, deflections, and traffic. These technical variables prescribe remedial works, which budget allocation systems reference to allocate the limited resources in a way that minimises the whole life cost of the network. This often means that roads in better condition are prioritised for maintenance, as delayed routine and periodic maintenance exponentially increases project costs, and deteriorated roads are ignored. While the same strategy might still apply, the CEA-based classification system ensures that authorities set their works schedules with full information about which roads they have a constitutional obligation to maintain, which roads support high levels of economic activity, which roads support lower levels of merely cyclical economic activity, and which roads make a negative economic contribution.

2.7 Application of the CEA-based road classification system

This section details a network level application of the CEA-based road classification system to the unpaved road network, accompanied by step-by-step instructions concerning procedures and data sources to guide future network-level and sub-national applications of the classification system.

The exercise disaggregates the road network into baskets of roads within each class. Road departments can then begin scheduling surfacing of unpaved roads according to the stated prioritisation rule, beginning only with multi-functional roads. Given the combination of budget constraints and the high volume of roads that satisfy this criterion, the road departments will be focused exclusively on multi-functional roads for the medium- to long-term.

By individually applying the CEA-based road classification system, road departments can generate their specific prioritisation schedules at a granular level with economic values assigned to each road according to its specific heavy vehicle traffic load or mesozone-level GVA. Missing traffic data for many parts of the unpaved road network entail that this analysis must currently be regarded as incomplete. Going forward, road departments should re-run the existing simulation using freshly available traffic data to deepen the accuracy of the prioritisation schedule. In the meantime, the prioritisation results are based on the second-best approach of grouping multi-functional and tactical roads into GVA quartiles for presentation purposes.

Key data sources used for mapping and simulation include:

- Population data;
- Land use data;
- Basic service facilities data;
- Gross Value-Added data;
- Basic access and multi-functional road networks;
- Strategic networks, and
- Tactical road networks.

These identified data sources are described in more detail in Appendix A together with a typical case study of the application there-off.

2.8 Guidelines for effective economic assessment of LVSR projects

2.8.1 Background

The programme to upgrade many unpaved roads across South Africa to LVSR will require very large public budget allocations and a long-term investment timeframe. As such, this programme should include comprehensive economic project assessments. These assessments will provide evidence to inform the economic benefits that result from the expenditures, which can then be added to the LCCA to further motivate upgrade decisions. Depending on the assessment results, especially the employment and skills development benefits from surfacing unpaved roads, the findings could be used to advocate for additional public funds for this programme as part of ongoing national efforts to boost employment and the country's capital base. Moreover, the individual project assessments (based on before-after comparisons) should provide road departments with important insights into community responses to surfacing unpaved roads, thereby enabling them to enhance project impacts as the LVSR programme matures.

For the purposes of this document, guidance is provided on the form and process to conduct appropriate economic assessments of LVSR projects. This guidance is based on good practice with due consideration given to the South African context, highlighting critical deficiencies that were identified during undertaking economic assessments of the pilot projects linked to the development of this Manual.

2.8.2 Shortfalls associated with desktop assessments

Economic analyses of infrastructure provision in SA have often been based on desktop work that manipulates national averages for key variables such as the cost of labour. Therefore, it is important to stress that averages taken across large scales discard massive amounts of information that can be obtained by more granular scrutiny. Where the economic impact of rural roads is concerned, this discarded information is typically what is most important. Consider, for example, efforts to estimate the extent of Basic Access Roads. The key determinant for that is household geographical dispersal, since this drives the proportion of people who continue to live outside feeder zones for basic services as roads are progressively upgraded to surfaced standard. Because of historical settlement patterns, this density is far lower in rural KZN Province than in other parts of rural SA. Estimates of the total kilometres of Basic Access Roads based on the national average rural household dispersion would therefore hugely underestimate the extent of that high-priority part of the network in KZN. But this still only scratches the surface of the issue. In relatively flat parts of the country, feeder zone boundaries can be readily adjusted as effective access routes change through network upgrades. In areas characterised by gorges and wetland areas – again, most of KZN Province, and the southern zone of the Eastern Cape – feeder zone boundaries are relatively inflexible, because (for example) children cannot climb cliffs to walk to school. A person's house might be 2 km from their job, but 8 km by shortest road distance if the road must go around a steep kopje. In addition, it is not enough for the analyst to know the average income in a community where a project is planned; they must know the distribution of household income strata relative to the geography of the target road. Calculation of impacts of road upgrades that are insensitive to these local variations can lead to community rejection of plans when desktop-derived models meet reality at ground level. Sound economic assessment of projects requires site-level data gathering and parameter adjustment.

2.8.3 Pre- and post-project assessments

Pre-project assessments must be conducted before the implementation of a LVSR project to establish the situation or conditions in the project area. Through this exercise the evaluation team can estimate local parameters associated with the variables discussed in Section 2.8. This information informs the design of the assessment tool and its implementation, ensuring it is sensitive to pressing issues in the community and addresses all relevant project impacts.

Pre-project assessments gather important data on the indicators (identified variables) related to a project's objectives. The data provide baseline reference points against which a road project's impacts can be measured in the post-project evaluation. It is important to note that the pre-project assessment should be conducted prior to any roadworks beginning as this work and its expected impacts might distort road user activity and stakeholders' perceptions regarding certain survey questions. The post-project assessment should be conducted at least 6 months after the project completion to allow road use patterns to adapt to the presence of the upgraded LVSR.

More information is provided in Appendix B.

3. Geometric Standards

3.1 Focus of this chapter

Warrants for the upgrading of unpaved roads to surface standards are dependent on the standards applied and cost to achieve and to maintain the target standard in a specific environment, incorporating society benefits. The focus of this chapter is to select reduced but still appropriate standards can result in significant cost reductions.

3.2 Sub-classification of Low-Volume Roads (LVRs)

3.2.1 General

Several methods could be and have been used for road network classification. Each classification system fulfils or fulfilled a specific purpose and could be accommodated in the inventory of a Road Asset Management System as an attribute for each defined road segment. This allows reporting of statistics, conditions, asset value etc. per selected class or sub class.

The TRH 26 functional classification system has been adopted for South Africa. However, the need was identified to incorporate an "Economic Classification System" to assist with the prioritisation of upgrading projects (Chapter 2).

These road classification systems do not necessarily define the standards to which the road must be constructed and maintained. This is particularly true for unsealed roads and low-volume sealed roads with a high range of traffic volumes, which could serve different purposes of importance.

A "Level of Service Classification System", incorporating traffic and exogenous benefits to provide appropriate safe standards on the low-volume road network is recommended (Figure 17). Four LOS design classes define recommended standards for road geometry and drainage requirements. Accessibility or lack thereof due to cross drainage structures overtopping is defined for each of the four LOS design classes in Chapter 4.

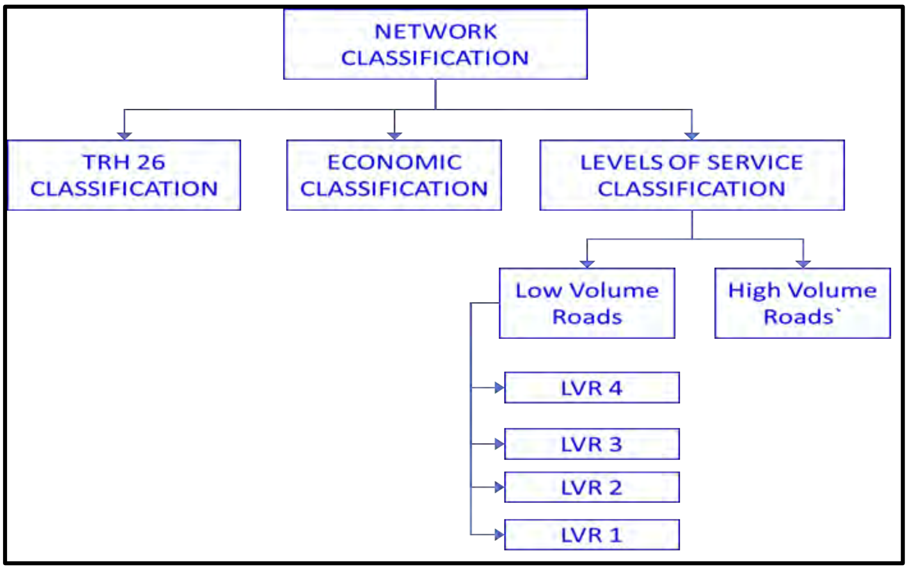


Figure 16 Relevant classification systems for LVRs

3.2.2 Level of service classification standards and specification framework

Level of service is defined as:

- Parameters or combinations of parameters that reflect social, environmental and economic outcomes that the organisation has agreed to deliver (ISO 55000), and
- A statement of the performance of the asset in terms that the customer can understand. Levels of Service typically cover condition, availability, accessibility, capacity, amenity, safety, environmental impact, and social equity. They cover the condition of the asset and non-condition-related demand aspirations, i.e. a representation of how the asset is performing in terms of both delivering the service to customers and maintaining its physical integrity at an appropriate level.

An appropriate rural road design approach requires a framework comprising important technical elements:

- Level of service classification;
- Standards;
- Specifications, and
- Design guidelines.

Fundamentally, standards fit the needs of a working classification. There are then sets of LVR Technical Specifications that define how the roads and associated structures and earthworks must be built to comply with these Standards. Finally, there is usually an overarching document or manual, such as this document defining the application of the standards and specifications, parts of which will be included in any required contract information or Terms of Reference.

The Classification-Standards-Specification framework aims to ensure that roads within the LVR road network adhere to the following key strategic principles:

- Consistent with the South African Rural Development Strategy;
- Compatible with the various road environments in South Africa;
- Fit for Purpose, and
- Sustainable.

3.2.3 LOS classification

A LOS Classification system enables effective management and delegation of responsibilities and provides important outcomes that relate to the class assigned to each road, including:

- Establishment of road design criteria and construction specifications;
- Implementation of road management systems to prioritise needs and to determine funding requirements to maintain the selected levels of service;
- Planning and scheduling of road construction and maintenance, and
- Guidance to the public.

Four LOS classes are adopted based on the expected Average Annual Daily Traffic (AADT) at the midpoint of the design life. However, exogenous factors have been incorporated to increase the level of accessibility, safety and mobility of roads fulfilling important social functions and to compensate for losses that are difficult to quantify (Table 11 and Table 12)

Table 11 Level of service design classes

LOS Design Class	Design Traffic Flow (AADT) with Low – Medium Exogenous Benefits (Mid-life)	Design Traffic Flow (AADT) with High Exogenous Benefits (Mid-life)
LVR 4	150 - 300	75 - 150
LVR 3	75 - 150	25 - 75
LVR 2	25 - 75	< 25
LVR 1	< 25	

As a guide, the three levels of potential exogenous benefits are provided in Table 12.

Table 12 Aspects leading to different levels of potential exogenous benefits

Potential benefits	Description
High	Direct access to hospital/ clinic or education centre. Highly sensitive agricultural produce. Dangerous dust particles in densely populated environments, in the case of unsealed roads
Medium	Access to tourism attractions, high dust levels affecting human comfort, crops and animals
Low	Low population density, non-sensitive agricultural produce

3.2.4 Standards

A network road ‘standard’ defines a minimum level of service and performance that should always be achieved. This translates to a set of agreed norms, uniformly applied in the design, construction, and maintenance of the network. Amongst other things, this ensures consistency across the country. Thus, for roads, this means that road-users know exactly what to expect and road managers know what they must achieve and maintain (SEACAP, 2009).

3.2.5 Technical Specifications

Technical specifications define and provide guidance on the design and construction criteria for rural roads to meet their required level of service. They define actions, procedures or materials that should be used to design, construct, and maintain LVR networks and their constituent roads.

3.3 Geometric design standards

3.3.1 General

The geometric design is the process whereby the layout of the road through the terrain is designed to meet the needs of all road users. The geometric standards are intended to balance two important objectives, namely, to provide appropriate levels of safety and comfort for road users and to minimise earthworks and reduce construction costs.

Geometric design covers road width; cross-fall; horizontal and vertical alignments and sightlines; and the transverse profile or cross-section. The cross-sectional profile includes the geometry of the carriageway, shoulders, verges and side drainage.

The cross-section essentially adapts the pavement or carriageway to the road environment and is closely tied-in with drainage. For paved roads, wide, sealed shoulders and high camber or cross-fall can significantly improve the operating environment for the pavement layers by minimising the ingress of surface water, an essential component for improving the climate resilience of the road.

Geometric design standards provide the link between the cost of building and subsequently maintaining the road and the cost of its use by road users. Usually, the higher the geometric standard, the higher the construction cost and the lower the road user costs. The aim is to select design standards that minimise total society costs. Thus, the relatively low traffic characteristics of LVRs mean that road improvements should be planned at the lowest practicable standards (without unduly impairing safety requirements) if costs are to be justified by the benefits obtained.

Guidelines for LVR geometric design standards in this manual are based on manuals developed in the SADC region with adjustments for local conditions, where deemed necessary.

3.3.2 Approach to design

a. General

The geometric design of LVRs presents a unique challenge because the relatively low volumes of traffic make designs normally applied on higher-volume roads less cost-effective. The approach to design adopted in this chapter addresses the unique needs of such roads and the geometric designs appropriate to meet these needs. By so doing, it enables design engineers to apply criteria that are less restrictive than those generally applied to HVRs. Thus, the approach discourages high geometric standards and roadside improvements, except where there is site-specific evidence of safety problems, where additional expenditure on improvements is likely to provide substantial safety benefits.

The approach outlined above should consider the potential effects of future development that may affect the function of the road within its design life in terms of changes in traffic volumes and type, patterns, and operating conditions. Should such changes result in a likely reclassification of the road to a higher class, then the standards for the latter class should be adopted in line with the recommendations of the relevant local authority.

The necessity to determine influence of road structures on the pre-developed flood lines needs to be determined to meet legislative requirements. The National Water Act 144 requires that a flood line needs to be determined before the development.

b. Characteristics of LVR Affecting Design

The particular characteristics of LVRs affecting their geometric design include:

- The majority of LVRs are relatively short in length and travel time would therefore most often not be a deciding factor for the required service level and associated geometric standard.
- Existing land use and adjacent properties often limit the effective cross-section width that can be constructed without major disturbances for the local population and associated costs for land acquisition and compensation.
- LVRs are often constructed by labour-based methods, which limits the amount of earthworks that can be done within reasonable costs.

In light of the above LVR characteristics, the main concerns of the engineer are:

- To design a road that is “fit for purpose” by fitting the road into the physical environment at least cost allowing the existing alignment to fix the travel speed and variable cross-section width to accommodate the prevailing traffic.

- To address potential "black spots" with properly engineered solutions such as appropriate traffic calming or road widening and lane segregation at blind crest curves.

In some cases where entirely new roads will be constructed, these are likely to be of a higher class justifying a conventional approach to geometric design, although elements of the LVR design principles could still be applied.

c. Design and Operating Speed

Design speed is traditionally used in highway design as an index that links road function, traffic flow and terrain to the design parameters of sight distance and curvature to ensure that a driver is presented with a reasonably consistent speed environment. However, the design speed concept should be reconsidered as a basis for the design of LVR for two reasons:

- Low-volume access roads are distinctly different from higher-volume mobility roads, for which higher, consistent design and operating speeds may be justified.
- Applying design speeds to LVR designs to obtain a consistent speed environment will inevitably lead to increased earthworks, acquisition of adjacent land and properties for adjustment of horizontal and vertical alignment, and consequently unjustified project costs.

Operating speed on LVRs will therefore normally be variable and dictated by the terrain, existing alignment (in case of upgrading) and roadside developments. Normally LVRs will accommodate variable operating speeds up to 80 km/h, but some access roads have long open stretches traversing easy terrain where it may be feasible and desirable to allow for higher speeds without incurring unjustifiable costs.

d. Design vehicle

For LVRs the volume of traffic is sufficiently low that congestion issues do not arise from traffic volume but from the disparity in speed between the variety of vehicles and other road users that the road serves. In other words, traffic composition is the key factor; traffic capacity is not the problem. Nevertheless, it is the size of the largest vehicles that use the road that dictates many aspects of geometric design. Such vehicles must be able to pass each other safely and negotiate all aspects of the horizontal and vertical alignment.

LVRs should be designed for the prevailing means of transport. For the lowest class, access by cars, 4x4 and utility vehicles is sufficient. The design vehicle for the higher classes will normally be a 7-ton truck with a width of 2.6 m. The geometric requirements for accommodating these types of vehicles are well documented and will not be dealt with here.

One potential problem is the possibility of large trucks using the road to transport heavy loads of natural products and resources such as crops, timber, minerals etc. Restrictions on trafficking by oversized and overloaded trucks will facilitate more cost-effective pavement design, preserve the investment and greatly enhance road safety for other road users.

3.3.3 Geometric design elements

a. General

The road design process includes the selection, sizing and linking of the following elements that largely affect the construction/upgrading cost of the road:

- Horizontal alignment
- Vertical alignment
- Cross-section width

- Camber and crossfall
- Side slopes and low embankments
- Side drainage

To produce appropriate standards a careful balance needs to be struck between the cost of improving the existing alignment, both horizontally and vertically, or of widening the road, as well as the benefits to be derived from doing so – an approach that emphasizes the economic aspects of geometric design which need to be applied with an appropriate understanding of economics and flexibility.

b. Horizontal alignment

Two main options may be considered for the design of the horizontal alignment of LVRs as follows:

- Option A – Alignment engineered for fulfilling an access function:
  - The adoption of an alignment in which "the existing alignment fixes the travel speed". This option accepts the existing alignment generally as it is, except in potentially problematic areas where traffic safety may be an issue and for which specifically engineered measures, such as appropriate traffic calming or road widening at blind crest curves may be required. This option could result in variable cross-section widths and travel speeds but will not incur significant earthworks costs.
- Option B – Alignment engineered for fulfilling a mobility function:
  - A fully engineered alignment is one in which the design speed fixes the alignment. This option entails the provision of a consistent cross-section width throughout which is based on a pre-determined design speed and the need to satisfy various geometric design requirements, such as passing and stopping sight distances, engineered curvature, both horizontally and vertically, etc.
- Recommended option:
  - In many cases, based on the least cost criterion discussed above, Option A is the more appropriate economic standard in that it will result in the provision of an alignment that is "fit for purpose" and that provides an appropriate level of access at minimum costs.

  However, Option A will require that several qualifying requirements are satisfied:
  - The road is unlikely to change its function over its design life, and
  - The road is likely to be used mostly by local people and seldom by other users not familiar with the characteristics of the alignment.

The adoption of Option A should be coupled with the following measures:

- Installation of traffic calming measures where required, particularly in areas with a high incidence of non-motorised traffic (NMT), e.g., speed humps, rumble strips, warning and speed limit signs etc.;
- Fully engineered solutions on potentially hazardous spots that can be achieved within reasonable costs (e.g., road widening/lane separation over sharp crests, alignment improvement to straighten out blind curves);
- Adequate advance warning to drivers and speed-reducing measures where potentially hazardous situations cannot be avoided without incurring prohibitive costs, and
- Varying road carriageway width dictated by the amount and mix of traffic and terrain.

c. Vertical alignment

The same principle as applied above for the design of the horizontal alignment of an LVR also applies to the vertical alignment, except where there is site-specific evidence of safety problems for which appropriate countermeasures can be put in place. For example, where vertical sight distances do not comply with those specified for HVRs, mitigating countermeasures should be considered such as widening and line marking of the road at the approach to the vertical curve rather than embarking on large-scale earthworks to flatten the crest curve.

d. Cross-section width

In addition to such factors as traffic composition and travel speed, topography/terrain and nature of the road population, the number of conflicts (vehicles passing in either direction) on an LVR is a key determinant of carriageway width. Although the number of conflicts for traffic volumes at different speeds differ from one source to another, the number of conflicts/km/hr, even at 300 vpd, is very low and considerable periods elapse between potentially hazardous meeting situations.

Table 13 (MHID, 2019) shows the average daily and an hourly number of conflicts/km and the average time between conflicts/km.

Table 13 Indicative conflicts/km and the average time between conflicts/km on LVRs

AADT	300		100		300	100
Speed (km/h)	Average Conflicts/km		Average Conflicts/km		Average time between Conflicts/km	Average time between Conflicts/km
	Per Day	Per Hour	Per Day	Per Hour		
40	46	3.8	5.0	0.4	16 min	2 hr 21 min
60	31	2.6	3.5	0.3	23 min	3 hr 30 min
80	23	1.9	2.5	0.2	31 min	4 hr 39 min

From observations on LVRs, vehicles tend to travel toward the centre of the road even with a road width of 6.0 m which, in practice, allows for lane-segregated traffic. With this width, the outer wheel path is usually not clearly defined but will typically be ≥ 1.0 m from the edge of the road. Given the above, it can be concluded that most of the time LVRs at all traffic levels, as defined above, are effectively operating as single-lane roads and that this feature can be used to ensure satisfactory levels of service and safety for all road users without resorting to unnecessarily generous standards. A consequence of this is that shoulders in the normal sense or additional width to accommodate non-motorised traffic (NMT) in a low-speed environment can be omitted except in particularly busy areas within villages, trading areas, etc. This would lead to substantially reduced costs compared to standards that are related to HVRs. On this basis, the recommended roadway widths for four different basic geometric standards (LVR 4 to LVR 1) are presented in Table 14. The traffic level is the sum of traffic in both directions and is estimated at the middle of the design life period.

i. Modifications for high proportion of heavy vehicles

The AADT of motorised vehicles with two or more axles provides the basic means of defining the different geometric road standards but these are modified based on the proportion of heavy vehicles in the traffic stream. For an LVR 4 road, this means that if there are more than 80 heavy vehicles per day, then the road should be designed as a high-volume road in accordance with the specifications of the responsible local authority.

Table 14 Recommended carriageway widths

Road Class	Design Traffic Flow (AADT) (Mid-life)[5]	Surface Type	Width (m)	
			Carriageway	Shoulders
LVR 4[2]	150 – 300	Paved/Unpaved	6.0 – 7.4	As required[1]
LVR 3	75 – 150	Paved/Unpaved	5.5 – 6.0	As required[1]
LVR 2	25 – 75	Paved[3]/Unpaved	4.5 – 5.5[4]	As required[1]
LVR 1	< 25	Paved[3]/Unpaved	3.0 – 4.5[4]	As required[1]

1. Normal width 1.0 m where required and feasible, but width varying with terrain;
2. LVR4 roads with < 300 vpd and not likely to change to a higher functional classification within the design period;
3. On steep sections;
4. Passing bays may be required in certain circumstances, and
5. Adjust for exogenous benefits.

ii. Modifications for many non-motorised vehicles and motorcycles

Modification of the basic geometric standards may also be required, mainly for safety reasons, in areas with a high incidence of motorcycles and motorcycle-powered vehicles, non-motorised vehicles including bicycles, animal-drawn carts and pedestrians. These are assessed in terms of the effective road space that they occupy (dependent on size and speed) measured in terms of Passenger Car Units (PCUs) according to Table 15. Table 16 shows the proposed adjustments to the basic standards.

Table 15 PCU values for different vehicle types

Vehicle	PCU value	Vehicle	PCU value
Pedestrian	0.15	Motorcycle with trailer.	0.45
Bicycle	0.20	Small animal-drawn cart.	0.70
Motorcycle	0.25	Large animal-drawn cart.	2.00
All based on a passenger car = 1.0			

Table 16 Adjustments for non-motorised and motorcycle PCUs (>300 PCUs per day)

LOS class	AADT[1]	Surface	Proposed modification.
LVR 4	150 – 300	Paved	Shoulder width increased to 2.0m on each side.
		Unpaved	Increase carriageway width by 2.0m.
LVR 3	75 – 150	Paved	Shoulder width increased to 2.0m on each side.
		Unpaved	Increase carriageway width by 1.5m.
LVR 2	25 – 75	Paved	None (paved sections will be short).
		Unpaved	Increase carriageway width by 1.25m.
LVR 1	<25	Unpaved	Not required

The proposed adjustment of shoulder or carriageway width is just one of many possible ways of accommodating mixed road users. There is no standard way of addressing this issue, and the designer must seek the best design in each case based on the particular circumstances and available budget.

3.3.4 Camber and Crossfall

Achieving proper camber and crossfall is essential to ensure the rapid shedding of water off the carriageway and to prevent moisture ingress into the pavement from the top, especially because of climate resilience related to projected climate changes.

On low volume paved roads, a camber of 3.0 per cent is recommended. Although steeper than traditional specifications, it does not cause problems for drivers in a low-speed environment. It also accommodates reasonable construction tolerance of +/- 0.5 per cent (taking into account the skills and experience of small-scale contractors) and provides an additional factor of safety against water ingress into the pavement should slight rutting occur after some time of trafficking. It also improves climate resilience.

On curves, a reversed camber in the outer lane will normally provide sufficient super-elevation if speeds are kept low. Otherwise, the design of super-elevation in curves should be in accordance with the specifications of the local authority.

3.3.5 Side Slopes and Low Embankments

Side slopes should be designed to ensure the stability of the roadway and, on low embankments, to provide a reasonable opportunity for recovery if a vehicle goes out of control across the shoulders, but also to ensure successful drainage of rain-water.

Figure 17 illustrates the general cross-section and defines the various elements. The position of the side drain invert should be a reasonable distance away from the road (at least 1 m) to minimise the risk of infiltration of water into the road pavement structure when water stands in the drain for any length of time.

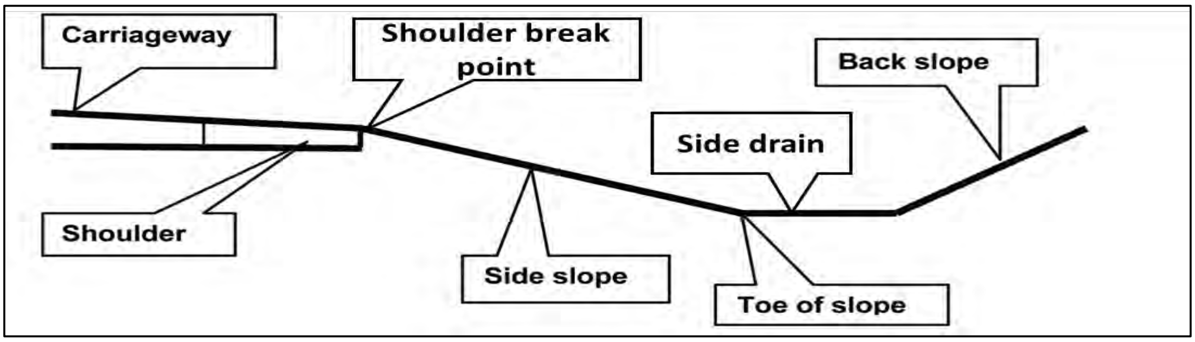


Figure 17 Details of road edge elements

The side slope is defined as ‘recoverable’ when drivers can generally recover control of their vehicles should they encroach over the edge of the shoulder. Side slopes of 1:4 or flatter are recoverable. Research has also shown that rounding at the shoulder break point and at the toe of the slope is also beneficial.

A non-recoverable slope is defined as one that is traversable but from which most drivers will be unable to stop safely or return to the roadway easily. Vehicles on such slopes can be expected to reach the bottom. Slopes between 1:3 and 1:4 fall into this category.

A critical slope is one on which the vehicle is likely to overturn and these will have slopes of greater than 1:3.

The selection of the side slope and the back slope is often constrained by topography, embankment height, the height of cuts, drainage considerations, soil properties, right-of-way limits and economic considerations. For rehabilitation and upgrading projects, additional constraints may be present such that it may be very expensive to comply fully with the recommendations provided in this TRH.

Slope dimensions for the various conditions are summarised in Table 17.

a. Side drainage

i. Types and function

Side drains serve two main functions, namely, to collect and remove surface water from the immediate vicinity of the road and, where needed, to prevent any sub-surface water from adversely affecting the road pavement structure. It is essential to install a system of side drains that discharges water frequently to avoid high flow concentrations and velocities that will inevitably lead to erosion.

Table 17 Recommended slope dimensions

Material	**Height of slope (m)**	**Side slope**		**Back slope**	**Safety classification**
		Cut	Fill		
Earth	0.0-1.0	1:4	1:4	1:3	Recoverable
	1.0-2.0	1:3	1:3	1:2	Not recoverable
	>2.0	1:2(1)	1:2(1)	1:1.5	Critical
Rock	Any height	Dependent on costs			Critical
Expansive clays(2)	0-2.0	n/a	1:6		Recoverable
	>2.0	n/a	1:4		

Notes:

1. Certain soils may be unstable at slopes of 1:2. Geotechnical advice is required.
2. The side drains should be moved away from the embankment.
3. If critical and non-recoverable side slopes cannot be avoided, it is often appropriate to install ‘guard posts’ at critical locations.

Side drains can be constructed in three forms: V-shaped, rectangular or trapezoidal as follows:

- V-shaped drains: Although relatively easily constructed by a motor or towed grader, they should be discouraged if materials are sensitive to scour;
- Rectangular-shaped drains: These require little space but need to be lined with rock, brick or stone masonry or concrete to maintain their shape, and
- Trapezoidal drain: These can be constructed and maintained easily by hand and improve traffic safety.

The choice of side-drain type depends on the type of technology used for construction and maintenance (i.e., use of graders, labour-based technology, etc.), the required hydraulic capacity, arrangements for maintenance, space restrictions, traffic safety, and any requirements relating to the height between the crown of the pavement and the drain invert. For road safety reasons, a wide trapezoidal and shallower drain for a given flow, capacity is preferable to a deeper “V” or rectangular drain.

The minimum recommended width of the side drain is 500 mm, and the minimum recommended longitudinal gradient is 1.0 per cent. A slackening of the side drain gradient in the lower reaches over significant lengths of the drain should be avoided to prevent siltation.

Side drains are normally located beyond the shoulder breakpoint and parallel to the centreline of the road. While usually employed in cuts, they may also be used to run water along the toe of a fill to a point where the water can conveniently be diverted, either away from the road prism or through it using a culvert. When used in conjunction with fills, side drains should be located as close to the edge of the reserve boundary as is practicable to ensure that erosion of the toe of the fill does not occur.

The following recommendations are made regarding desirable slopes for side drains:

- To avoid ponding and siltation, the minimum slope should be more than 1 per cent, and
- To avoid erosion, drains steeper than 3 per cent may need scour protection, depending on the erodibility of the soil and the vegetative cover. Ideally, as the flow is supercritical, these drains should be lined with suitable energy dissipation structures downstream. The distance between scour checks depends on the road gradient and the erosion potential of the material. Table 18 shows the recommended values for normal soils. The spacing should be reduced for highly erodible soils.

Table 18 Recommended spacing of scour checks

Road gradient (%)	**Distance between scour checks (m)**
< 3	Usually not necessary
4	17
5	13
6	10
7	8
8	7
9	6
10	5
12	4

Access across side drains for pedestrians, animals and vehicles needs to be considered. Community representatives should be consulted concerning locations, especially for established routes and in villages or towns. The methods that could be used are:

- Widening the drain, taking its alignment slightly away from the road and hardening the invert and sides of the drain, and
- Beam/slab covers or small culverts.

The arrangement must be maintainable and not risk blockage of the side drain. Failure to accommodate these needs will usually result in ad hoc arrangements by communities that compromise the function of the side drain causing blockage of the water flow.

ii. Depth of side drains in relation to crown height

To achieve adequate external drainage, the road must be raised above the natural ground level such that the crown height (h) of the road (i.e., the vertical distance from the bottom of the side drain to the finished road level at the centreline) is maintained at a minimum height, h_{min}. This height must be sufficient to prevent moisture ingress into the potentially vulnerable outer wheel track of the carriageway. The recommended minimum crown height of 0.75 m applies to unlined drains located in relatively flat ground (longitudinal gradient, g, less than 1 per cent %). The recommended values for sloping ground (g > 1 per cent) or where lined drains are used, for example, in urban or peri-urban areas, are shown in Table 19. The capacity of the drain should meet the requirements for the design storm return period taking into account future climate change effects.

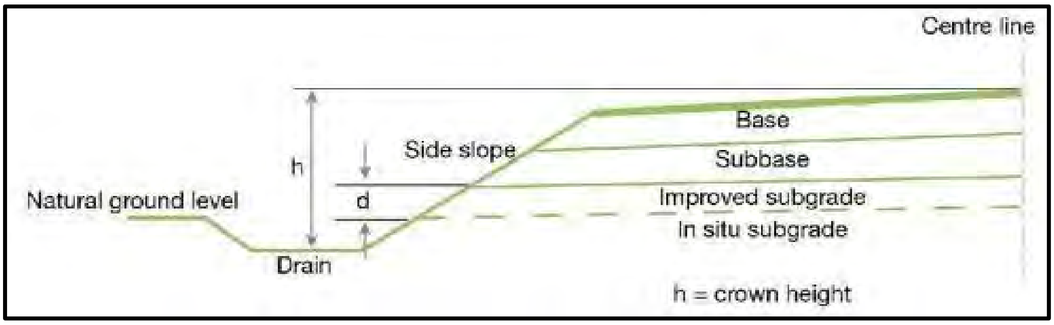


Figure 18 Crown height for a paved road in relation to the depth of drain

Table 19 Ideal crown height, h_{min}, above drainage ditch invert

Unlined drains		Lined drains	
Gradient < 1%	**Gradient > 1%**	**Gradient < 1%**	**Gradient > 1%**
0.65	**0.55**	**0.55**	**0.40**

In addition to observing the crown height requirements, it is also equally important to ensure that, where practicable, the bottom of the sub-base is maintained at a height of at least 150 mm above the existing ground level (distance d as indicated in Figure 18) to minimise the likelihood of wetting up of this pavement layer from moisture infiltration from the drain.

Irrespective of climatic region, if the site has effective side drains and adequate crown height, then the in-situ subgrade moisture is likely to remain below OMC. If the drainage is poor, the in-situ moisture will increase above OMC with a corresponding loss of layer strength.

iii. Mitre drains

Mitre drains are constructed at an angle to the centreline of the road. They are intended to remove water from a side drain and discharge it beyond the road reserve boundary. The amount of water in the drain should ideally be dispersed, and its velocity correspondingly reduced before discharge. Water flow velocity can be reduced not only by reducing the volume (more frequent spacing of mitre drains), and hence the depth of flow, but also by positioning the mitre drain so that its toe is virtually parallel to the natural contours. The downstream face of a mitre drain is usually protected by stone pitching since the volume and speed of flow of water, which it deflects, may cause scour and ultimately lead to breaching of the mitre drain.

To ensure that water flows out of the side drain into the mitre drain, a ‘block-off’ may be required, as shown in Figure 19.

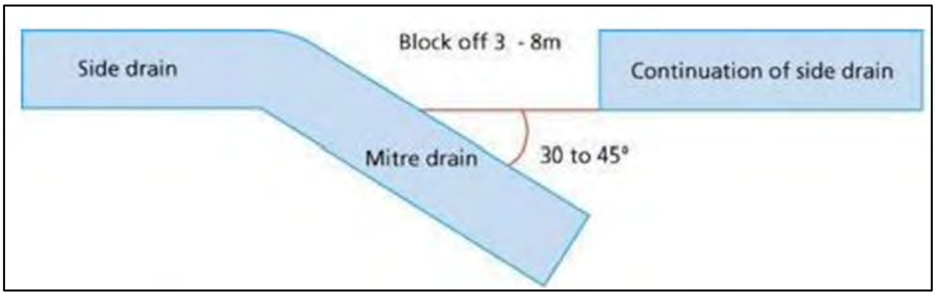


Figure 19 Schematic layout of mitre drains

The mitre drain must be able to discharge all the water from the side drain. If the slope of the mitre drain is insufficient, the mitre drain needs to be made wide enough to ensure this.

The angle between the mitre drain and the side drain should not be greater than 45°. An angle of 30° is ideal. If it is necessary to take water off at an angle greater than 45°, it should be done using a long radius curve.

The desirable slope of mitre drains is 2 per cent. The gradient should not exceed 5 per cent, otherwise, there may be erosion in the drain or on the land where the water is discharged. The drain should lead gradually across the land, getting increasingly shallower. Stones may need to be laid at the end of the drain to help prevent erosion.

In flat terrain, a small gradient of 1 per cent may be necessary to discharge water, or to avoid very long drains. These low gradients should only be used when absolutely necessary. The slope should be continuous, with no high or low spots. For flat sections of the road, mitre drains are required at frequent intervals to minimise silting. In mountainous terrain, it may be necessary to accept steeper gradients. In such cases, appropriate soil erosion protection measures should be considered.

As indicated in Table 20, the maximum spacing of mitre drains is dependent on the road gradient. However, depending on engineering judgment, mitre drains could be required more frequently than this and values as low as one every 20 m may be required to avoid damage to adjacent land, especially where it is cultivated.

Table 20 Maximum spacing of mitre drains

Gradient (%)	2	4	6	8	10	12	14
Erodible material (min)	20	40	30	20	10	10	10
Clayey material (max)	300	150	100	75	60	50	40

When land availability does not permit the inclusion of mitre drains at the intended intervals, widening and lining of the drains may be required to cope with the increased volume of water and to protect against erosion in the side drains.

iv. Unlined and lined drains

The critical length is defined as the maximum length of an **unlined** ditch in which water velocities do not give rise to erosion. The maximum velocity of the water can be calculated from the slope, shape and dimensions of the ditch, volume of water, and the roughness coefficient of the material. Knowing the maximum permissible velocity for each type of material, the maximum length of the unlined ditch in this material can then be determined.

Where flow velocities are likely to cause scouring, the velocity in the drains must be reduced or the erosion resistance increased. Methods include:

- Scour checks;
- Grassed waterways, and
- Drain lining.

Scour checks act as small dams and, when naturally silted up on the upstream side, effectively reduce the gradient of the drain on that side, and therefore the velocity of the water. Scour checks are usually constructed with natural dry-packed stone, stone masonry, concrete or with wooden stakes in combination with dry-packed stones.

The level of the scour check must be a minimum of 200 mm below the edge of the carriageway to avoid the water being diverted out of the side drains.

Particularly on steep gradients or where the distance between mitre drains is long, it may be necessary to consider **lining the side drains** to avoid severe erosion. The drain lining should not provide a route for water ingress into the road (

Figure 20) but must connect to the edge of the surfacing, as shown in Figure 21. Drain lining can be made from mass concrete, concrete blocks, stone masonry or brick masonry. Dump rock (riprap), if available in the vicinity of the road, is the preferred (lowest cost) option and can be laid as dry or wet masonry. The size of the stone should be a minimum of 200 mm to avoid rock being washed away by water. The masonry work needs to be well laid to ensure that water does not permeate underneath the lining, allowing it to become unstable, undercut and eventually wash away.

Figure 20 Poor design - Opening between seal and drain

Figure 21 Good practice – Drain lining connected to the edge of the seal

v. Shoulders, Flush Kerbs and Edge Beams

The functions of shoulders include:

- Giving structural support to the carriageway;
- Allowing wide vehicles to pass one another without causing damage to the carriageway or shoulder;
- Providing extra room for temporarily stopped or broken-down vehicles;
- Allowing pedestrians, cyclists and other vulnerable road users to travel safely, and
- Limiting the penetration of water into the pavement.

Ideally, on paved roads, the whole roadway width should normally be sealed, whether shoulders are provided or not.

Gravel shoulders tend to be badly maintained and can pose a danger to traffic (edge drop) and trap water that will penetrate the pavement layers

As much as the provision of shoulders may be desirable, it may not always be economically feasible and strictly warranted in very low traffic situations.

When permeable base materials are used, particular attention must be given to the drainage of this layer. Ideally, the base and sub-base should extend right across the shoulders to the drainage ditches. In addition, proper crossfall is needed to assist in the shedding of water into the side drains. **A slope of about 4 to 6 per cent is suitable for the shoulders.**

Where shoulders are not provided other means of giving lateral support and protecting the edge of the surfaced area include flush kerb stones (thickened road edges) which may be set in mortar or just properly embedded in the top of the side slope.

Where minor accesses join the road or on sections with frequent “off carriageway” driving or parking occurs, concrete edge beams or flush kerbstones could be used to protect the edge of the seal.

b. Single Lane Roads and Passing Bays

There is good agreement internationally about the recommended carriageway width for single-lane roads, namely 3.5 to 4.0 m, depending on traffic volume, mix and terrain. Passing bays may be required, depending on the traffic level, and provision for other traffic and pedestrians will need to be introduced (e.g., wider shoulders) if the numbers of other road users exceed specified levels. The increased width should allow two vehicles to pass at a slow speed.

The spacing between passing bays should normally be 100 m to 300 m depending on the terrain and geometric conditions. Care is required to ensure good sight distances and the ease of reversing to the nearest passing bay if required. Passing bays should be built at the most economic places rather than at precise intervals provided that the distance between them does not exceed the recommended maximum. Ideally, the next passing bay should be visible from its neighbour.

The length of passing bays is dictated by the maximum length of vehicles expected to use the road, indicating the need to define a design vehicle. A typical large vehicle for LVRs is about 13 m long, therefore passing bays of twice this length should be provided. In most cases, a length of 25 m will be sufficient for LVRs.

A suitable width depends upon the width of the road itself. The criterion is to provide enough overall width for two design vehicles to pass each other safely at low speeds. Therefore, a total trafficable minimum width of 6.3 m is required (providing a minimum of 1.1 m between passing vehicles). Allowing for vehicle overhang when entering the passing bay, a total road width of 7.0 m is suitable.

3.3.6 Traffic Calming

Several relatively low-cost traffic calming measures can be introduced, particularly within villages, to reduce vehicle speed and thus improve the safety of road users.

Specific measures include:

- Encouraging police to enforce local speed limits;
- Providing regulatory traffic signs of local speed limits, and
- Calming traffic with speed humps or dips (often combined with drainage), rumble strips, road narrowing, pedestrian crossings and specially demarcated low-speed zones. Traffic calming measures in villages require special attention, for example, in terms of a comprehensive “village treatment” which will induce a driver to reduce speed significantly as he or she passes through a village.

a. Village treatment – surfaced roads

The objective of the “village treatment” approach to traffic calming is to develop a perception that the village is a low-speed environment and to encourage the driver to reduce speed because of this perception. To this end, the road through the village is divided into three zones, namely:

- The approach zone;
- The transition zone, and
- The core zone.

Approach zone: This is the section of the road before entry into the village, where the driver needs to be made aware that the open road speed is no longer appropriate. This is the section of road where speed should be reduced to about 60 km/h, before entering the village. The village entry should be marked.

Transition zone: This is the section of road between the village entrance, and the core zone of the village. The target speed and posted speed limit in this zone would typically be 40 km/h. The first road hump or humps in a series of humps will be sited in this zone. In this context, with adequate advance warning provided by the approach zone, road humps are quite safe.

Core zone: This is the section identified as being in the centre of the village, where most vehicle/ pedestrian conflicts would be expected to take place. This would normally be where the majority of shops, bus-bays or other pedestrian-generating activities are located. This is the section where pedestrian crossing facilities are most likely to be established, animals may be on the road and where the target speed, and posted speed limit, should typically be reduced further to 30 km/h. Road humps would normally be provided within this zone.

b. Road humps

These are the main self-enforcing means of producing a speed reduction. There are two types of humps as follows:

Circular profile hump that has been designed to provide the required reduction in speed while at the same time providing a reasonably comfortable ride for passengers and the least damaging effect on vehicles when travelling at the advisory speed. The specific purpose of the Circular profile hump is to lower traffic speeds so that drivers have little option but to slow down before reaching the core zone. For this reason, the first hump in a series of humps should always be a circular profile hump and should always be sited in the transition zone.

Flat-top hump: of which the top portion of this hump is flat with a ramp on either side. The flat-top hump will generally be used at locations within the core zone of the village where there is a need for zebra crossings on popular pedestrian routes (usually near schools, bus stops and markets). In this situation, the hump may be combined with a pedestrian crossing, which would be sited on the flat part of the hump.

Humps can also be used to assist with road drainage, by diverting water off the road regularly.

3.3.7 Design process

The goal of the provision of surfaced LVRs is to minimise costs while providing an appropriate LOS. The main saving lies in the minimisation of earthworks and additional pavement layers and, the provision of cross-drainage structures providing capacity for selected flood return periods.

Therefore, the optimum geometric design of an LVR is an interactive and iterative process with drainage and pavement design.

Recommended steps in the process are as follows:

- Topographical survey:
  - Unless the existing unpaved road has been in existence for a long time with drainage problems and accident blackspots removed and the alignment is appropriate for approximately 80 km/h, a topographical survey is required. The cost of such a survey is a fraction of the total design costs;
- Cross-drainage requirements. This defines the required low-level crossings and culvert sizes (with cover thickness), providing a minimum height from the existing road level;
- Cover thickness on poor subgrades. From a pavement design perspective, certain areas would require a minimum thickness of suitable imported material to support the pavement structure;
- Fit horizontal and vertical alignment with given constraints to match recommended standards for the relevant recommended LOS;
- Evaluate costs and risks of reducing standards in isolated situations;
- Interaction with drainage and pavement design engineers regarding possible further cost minimisation bearing in mind future possible precipitation changes;
- Re-evaluate geometric options, and
- Finalise design with fixed alignments and safe posted speeds.

4. Cross Drainage Standards

4.1 Introduction

The greatest potential cost savings for water crossing options is in the choice of structure type.

Based on international research, several guideline documents have been published in Sub-Saharan Africa, incorporating valuable information on the selection and design of Low-level crossings.

The South African Road Drainage Manual (1981) was revised by a team of experts incorporating research by the CSRA Committee of State Road Authorities (1994). Chapter 6 "Low-level crossings and causeways" was introduced in the SANRAL Drainage Manual (2006) with guidelines and criteria required for the planning, design, location and construction of low-cost low-level submersible road structures. Practical examples with calculations are provided in an Application Guide to this manual. The latest revision of Drainage Manual 6th Edition (September 2013) is available from the SANRAL website..

Utility Programs for Drainage were developed by the University of Pretoria, which complement the calculations done in the SANRAL Drainage Manual. The software can be obtained from: http://www.sinotechcc.co.za/Software/UPD/upd.html

4.2 Purpose and scope

The purpose of this Chapter is to highlight different cross-drainage options for LVRs and to summarise basic recommendations from the SANRAL Drainage Manual (2013), Sub-Saharan Africa guidelines and adjustments recommended by experienced local practitioners. Note that more than 260 Low-level River Crossings (LLRCs) have been constructed in one province of South Africa over the past ten years.

For detail regarding economic evaluation, design and scour protection, the reader is referred to the SANRAL Drainage Manual.

LLRCs and lesser culverts are considered, in most cases, appropriate for LVRs with traffic volumes of less than 300 vehicles per day.

Aspects of importance are dealt with under the following headings:

- Definitions of cross-drainage structures;
- Characteristics of cross-drainage structures;
- Levels of service, and
- Risks and liability.

4.3 Definitions of cross-drainage structures

Definitions applicable in South Africa are provided in this section.

4.3.1 Bridge structures

A structure is classified as a bridge if one or more of the following criteria are satisfied:

- Any single span, measured horizontally at the soffit along the road centre line between supports is greater or equal to 6 m;
- The individual clear spans as measured above exceed 1.5 m and the overall length measured between abutment faces exceeds 20 m;

- The opening height, which is the maximum vertical distance from the streambed or structure floor at the inlet to the soffit of the superstructure is equal to or greater than 6 m;
- Where the total cross-sectional opening is equal to or larger than 36 m^2, and
- The structure is a road-over-rail, or rail-over-rail structure, even if the span is less than 6 m.

4.3.2 Major culvert

A cellular structure with dimensions less than those defining a bridge but with a clear span length (as measured horizontally at the soffit perpendicular to the faces of its supports) equal to or larger than 2.1 m, or diameter equal to or larger than 2.1 m, or a culvert with a total cross-sectional opening equal to or larger than 5m^2.

4.3.3 Lesser culverts

These are all culverts smaller than that defined as a Major Culvert above. These culverts are small enough to be designed using simplified hydraulic and hydrological analyses.

4.3.4 Low-Level River Crossings (LLRCs)

A road structure which could be submerged under flood conditions, designed in such a way as to experience no or limited damage when overtopped. LLRCs are categorised as follows:

- Drift: A drift does not contain any openings underneath but has a specially prepared surface for the vehicles to travel on. In the case of surfaced roads, the surface would mainly be constructed with concrete.
- Causeway (vented drifts or vented fords): A structure with a suitable surface to accommodate traffic and withstand overtopping but contains openings underneath to allow water to run through the structure, and
- Low-level bridge: A structure consisting of a short-span deck (typically between 4 m and 7.5 m) supported by a sub-structure consisting of two abutments and any number of piers. The height of the deck above the riverbed is typically less than 2 m.

Note: A causeway has culverts with the bed protected by concrete, while the bridge does not have bed erosion protection between piers and the low-level bridge is designed for overtopping.

4.4 Characteristics of cross-drainage structures

Characteristics and examples of typical LVR cross-drainage structures are provided under the following headings:

- Drifts;
- Causeways;
- Low-level bridges, and
- Culverts.

Note: Examples of standards plans could be downloaded from the Western Cape Provincial Government Road Network Information System:

https://rnis.westerncape.gov.za/rnis/rnis_web_reports.main

4.4.1 Drifts

A drift consists of a flat slab and two inclined approach ramps over which water and vehicles can pass, thus a drift carries water over the road. Drifts are the cheapest form of watercourse crossing. Very small drifts constructed with local materials are also referred to as splashes.

Drifts are suitable for shallow watercourses with a gentle gradient and at sites where raising the road over a culvert would require the transport of large quantities of earth.

There are two types of drifts:

- Relief drifts: These relieve side drains of water where the road is on sloping ground and water cannot be removed from the uphill side drain by mitre drains. It is an alternative to a relief culvert, and
- Small watercourse (or stream) drifts: Where stream flows are very low (with a normal water depth of less than 150 mm), drifts may be used to allow the stream to cross the road, as illustrated in Figure 22.

a. Key Features of drifts

The key features of drifts as highlighted in Figure 22 and Figure 23 are:

- Stream drifts are structures that provide a firm place to cross a river or stream. Relief drifts transfer water across a road without erosion of the road surface. Water flows permanently or intermittently over a drift - therefore vehicles are required to drive through the water in times of flow;
- Drifts are particularly useful in areas that are normally dry with occasional heavy rain causing short periods of floodwater flow;
- Drifts provide a cost-effective method for crossing wide rivers that are dry for the majority of the year or have very slow or low permanent flows;
- Drifts are also easier to maintain than culverts and could act as traffic-calming measures;
- Drifts are particularly suited to areas where the material is difficult to excavate, thus making culverts difficult to construct;
- Drifts are also particularly suited in flat areas where culverts cannot be buried because of lack of gradient;
- The approaches must extend above the maximum design flood level flow to prevent erosion of the road material;
- Guide blocks must be provided and be visible above the water when it is safe for vehicles to cross;
- Buried cut-off walls are required upstream and downstream of the drift to prevent under cutting by water flow or seepage;
- The approach road alignment will require that approach ramps are provided. Approach ramps should be provided to the drift in the bottom of the watercourse with a maximum gradient of 7 per cent;
- Drifts should not be located near or at a bend in the river, and
- Some form of protection is usually required downstream of a drift to prevent erosion.

Guide blocks should ideally be provided to indicate the water level and edges of the roadway when water is flowing over it. It is also possible to construct guide blocks at suitable spacings along the sides of the drift to help pedestrians to pass when water is flowing. riprap, cement grouted riprap, grouted stone pitching or concrete is placed in the watercourse (apron) to prevent erosion downstream and upstream of the drift.

Drifts should be constructed with a shape as close as possible to the shape of the existing watercourse. The slab should be at the same level as the bed of the watercourse and road cross fall should not be more than 3 per cent. If the riverbed gradient is more than 2 per cent, a stepped structure (cascade) (Figure 24) should be used at the outlet.

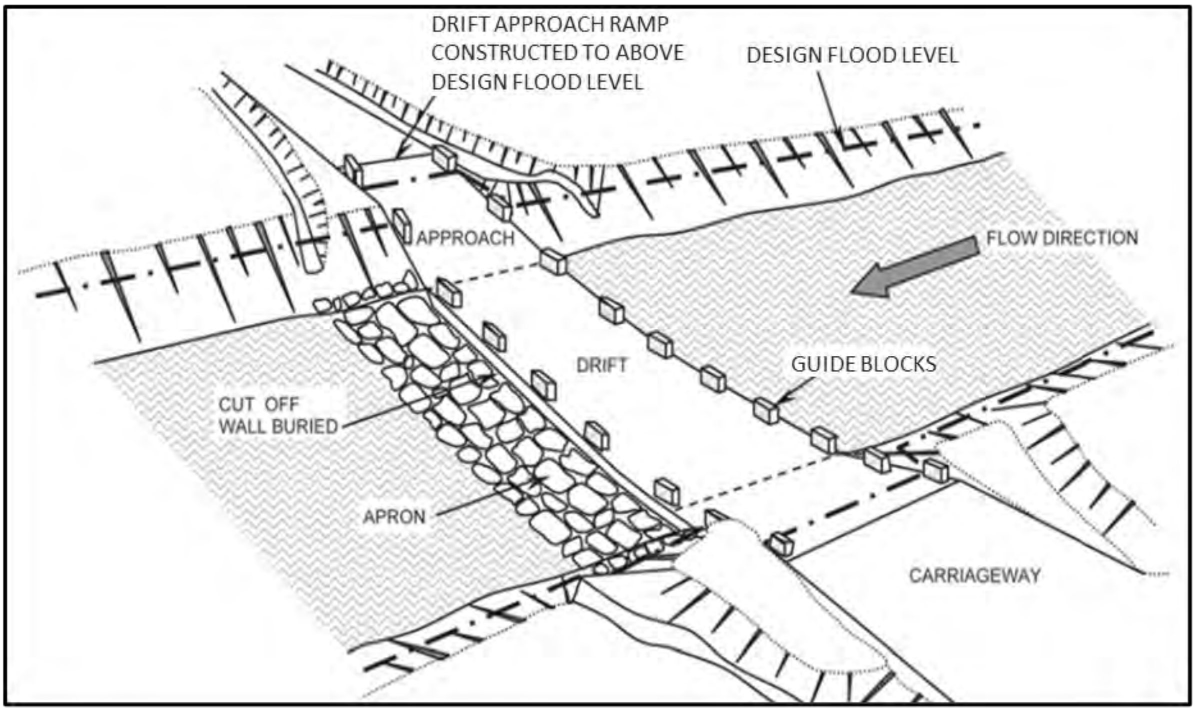


Figure 22 Key features of a stream drift

Figure 23 Example of a stream drift

Note: The drift in Figure 23 should be horizontal (not with a vertical curve) and the erosion protection should be extended downstream to guide the flow back to the main channel.

Figure 24 Stepped cascade drift

Note: With reference to Figure 24, guide blocks should be provided on both sides. It could also be argued that the drift should be longer to minimise flow concentration and scour.

The slab and the ramps (Figure 25) should be durable and non-erodible. When concrete is used, the 200 mm thick slab should be reinforced with high tensile steel mesh (10 mm bars laid in a 200 mm grid). Construction joints should be provided so that each slab is no more than 5 m long.

Vehicles that pass over a drift can spread water on the approach roads. This can make the road surface slippery or suffer from erosion, especially if the approach road is steeper than 5 per cent and if the water flows over the drift for more than two days after rain. If the road is not surfaced, it is recommended that an improved surface be provided for 50 m in each direction.

The following criteria should be considered when designing drifts:

- The level of the drift should be as close as possible to the existing riverbed level;
- The depth of water should be a maximum of 150 mm for subcritical flow and 100 mm for supercritical flow, and
- Approach ramps should have a maximum gradient of 7 per cent.

Figure 25 Approach ramps at 5 per cent grade

Note: Guide blocks should be provided on both sides of the drift

Figure 26 Example of downstream scour protection

Note: Guide blocks should be provided on both sides of the drift

b. Splash

A splash (Figure 27) consists of a shallow channel that is protected against erosion. Splashes are only recommended for low water volumes and are mainly recommended for unsealed roads or very low-volume sealed roads if the water flows for less than three hours after rain. The surface of the channel is protected by a material that is low-cost and non-erodible, such as a layer of flat stones or locally manufactured concrete blocks.

Figure 27 Example of a splash

When the watercourse is flowing, all the water should pass between the edges of the splash to prevent damage to the surface of the road.

Splashes can also be used to reduce the flow in a side drain, in the same manner as a relief culvert.

4.4.2 Causeway (Vented Drift)

a. General

A causeway (Figure 28 and Figure 29) is a combination of a culvert and a drift. They are suitable for carrying roads across watercourses which have a perennial (permanent) water flow for most of the year and which have large flows for a few days after heavy rains.

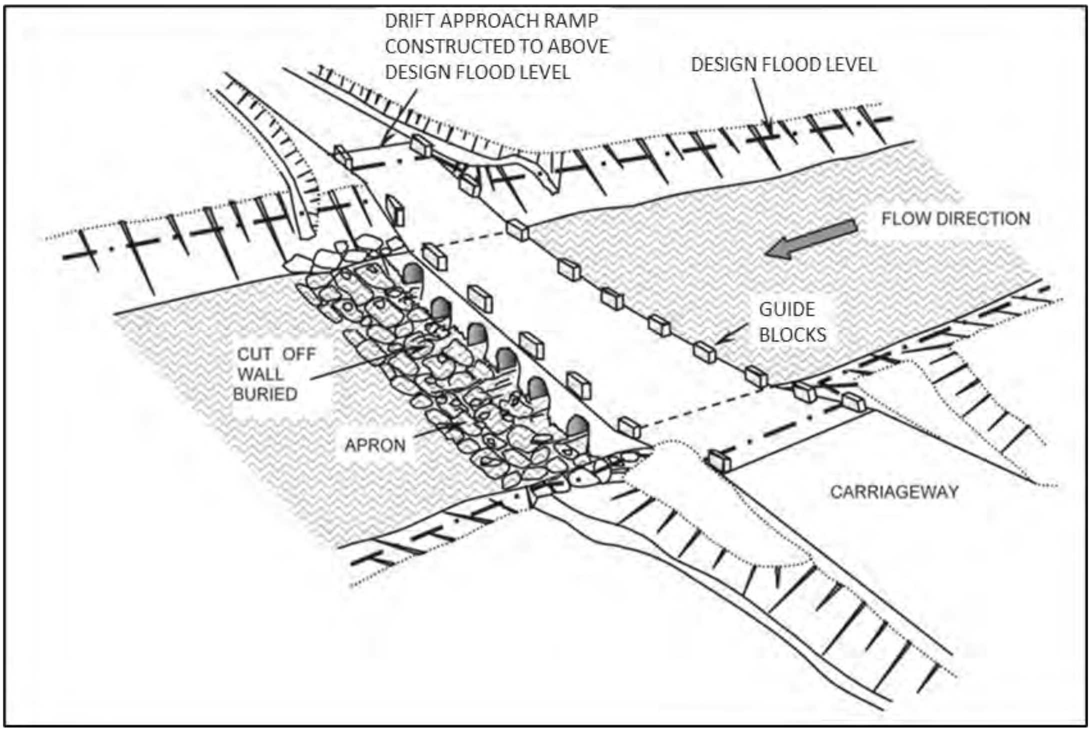


Figure 28 A typical causeway (schematic)

Figure 29 Example of a causeway

b. Key Feature of Causeways

The key features of a vented drift are, inter alia, that:

- These structures are designed to pass the normal dry weather flow of the river through culverts below the road. Occasional larger floods pass through the pipes and over the road, which may make the road impassable for short periods;
- The level of the road on the causeway should be high enough to prevent overtopping except at times of peak flows;
- There should be sufficient pipes or box culverts to accommodate standard flows. The location of these apertures will depend on the flow characteristics of the river;
- A causeway should be built across the whole width of the water-course;
- A causeway in an unsealed road requires approach ramps which must be surfaced with a non-erodible material and extend above the maximum flood level;
- Watercourse bank protection will be required to prevent erosion and eventually damage to the entire structure;
- Current recommendations suggest that the approach ramps should not have a steeper grade than 7 per cent;
- The upstream and downstream faces of a causeway require buried cut-off walls (preferably down to rock) to prevent water undercutting or seeping under the structure;
- An apron downstream of the pipes/culverts and an area of overtopping are required to prevent scour by the water flowing out of the pipes/culvert or over the structure. The apron downstream of riprap on suitable filter, grouted riprap or concrete, should be as long as the stable hydraulic jump length downstream;
- There is also a requirement to protect the watercourse from erosion downstream from the structure. There could be considerable turbulence immediately downstream of the structure in flood conditions;
- The road surface longitudinal alignment of a causeway should preferably be horizontal with slight sag curves on the approach ramps;
- There should be guide blocks on each side of the structure to mark the edge of the carriageway and indicate when the water is too deep for vehicles to cross safely, and
- A thorough investigation should be done to determine the risk of silting and/or transporting and deposit of large stones.

Figure 30 Dry weather flow of the river through culverts/pipes below the road

Figure 31 Example of surface protection on the approach ramps

Figure 32 Deposit of large stones downstream of a causeway

Note: Figure 32 highlights the requirement for proper surveys and investigations

4.4.3 Low-level bridge (Submersible bridge)

a. General

By definition, a low-level bridge is a structure consisting of a short-span deck (typically between 4 m and 7.5 m) supported by a sub-structure consisting of two abutments and any number of piers. The height of the deck above the riverbed is typically less than 2 m (Figure 33).

Figure 33 Submersible bridge

b. Features of Submersible Bridges

The apertures and the area above the apertures must be sufficient (up to a depth of 150 mm for subcritical flow and 100 mm for supercritical flow) for 1:2-year floods.

Each approach ramp should extend at least beyond the expected 1:5-year flood (LOS 1 and 2) or 1:10-year flood (LOS 3 and 4). The level of the deck should be sufficiently high to allow the normal flow of water to pass under the bridge.

All the piers and abutments should be seated on a rock foundation. If the bridge is fixed on a rock foundation with steel dowels, it can be up to 2.5 m high. If the bridge is not fixed with steel dowels, it can be up to 1.5 m high.

If it is not possible to provide a sufficient open area with a submersible bridge of 1.5 or 2.5 m in height, it is necessary to construct a high-level bridge.

The structure should be routinely inspected to check that maintenance and repairs are being carried out as required.

4.4.4 Culverts

a. General

Culverts are usually constructed in narrow well-defined watercourses, but they can also have many apertures to cross wide and shallow watercourses. Culverts perform two basic functions as described in the following sections.

b. Relief culverts

These are placed at low points in the road alignment (where there is no definable stream) or along long downhill gradients, but the topography of the ground requires a significant amount of cross drainage that cannot be accommodated by side drains, as illustrated in Figure 34. A relief culvert should be located at the point where the high volume of water starts to cause erosion or the drain to overtop. Relief culverts should be used only when solutions such as regular drain clearing to maintain and ensure maximum flow and the use of a mitre drain are not possible.

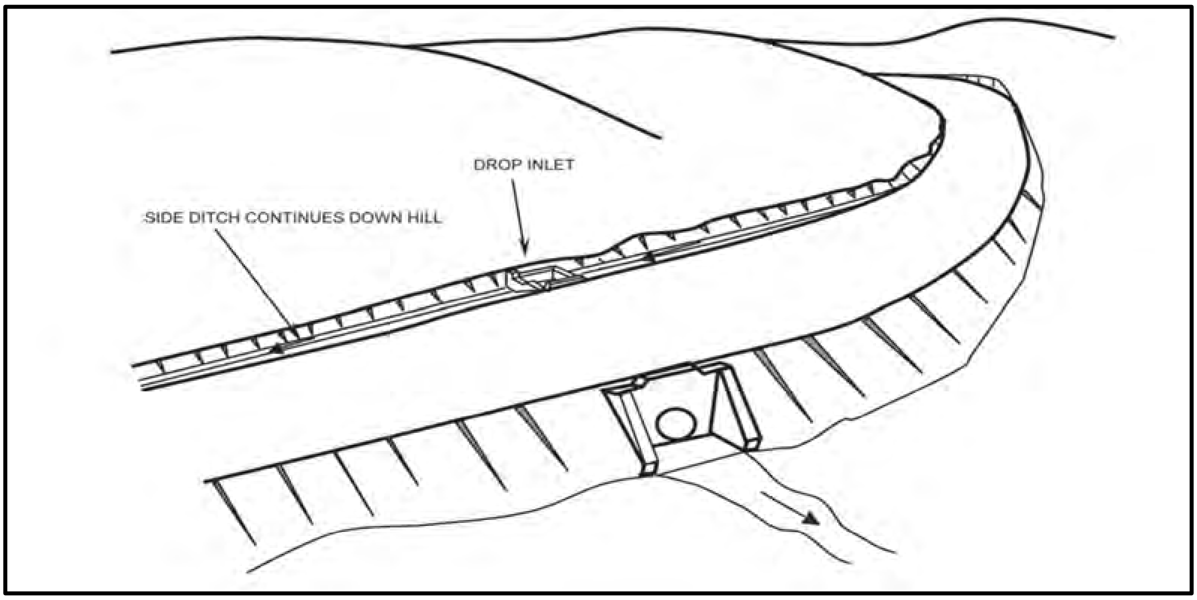


Figure 34 Key features of a relief culvert

c. Stream culverts

These allow a small watercourse to pass under the roadway. Culverts can be a pipe, box, slab or arch type, round, elliptical or square.

d. Key Features of Culverts

The key features of culverts are:

- Culverts are the most used drainage structures on low-volume roads. They can vary in number from about two per kilometre in dry and gently rolling terrain up to six or more for hilly or mountainous terrain with high rainfall. In flat areas with high rainfall, the frequency may also be increased to allow water to cross the road alignment in manageable quantities;
- In addition to well-defined water crossing points, culverts should normally be located at low points or dips in the road alignment;
- Relief culverts may be required at intermediate points where a side drain carries water for more than about 200 m without a mitre drain or another outlet;

- Headwalls are required at the inlet and outlet to direct the water in and out of the culvert and prevent the road embankment from eroding (sliding) into the watercourse. Wingwalls at the ends of the headwall may also be used to direct the water flow and retain the material of the embankment or inner ditch slope;
- Aprons with buried cut-off walls are also required at the inlet and outlet to prevent water seepage, scouring and undercutting;
- Culvert alignment should follow the watercourse both horizontally and vertically where possible;
- The gradient of the culvert invert should be between 2 and 5 per cent. Shallower gradients could result in silting whereas steeper gradients result in scour at the outlet because of a high-water velocity;
- Culvert invert levels should be approximately in line with the water flow in the streambed, otherwise, drop inlet and/or long outfall excavations may be required;
- Cross culverts minimum recommended sizes are:
  - 600mm diameter or 750mm span x 450mm high for culvert length <30m
  - 900mm diameter or 900mm span x 450mm high for culvert length >30m;
- Where in situ foundation material is poor, culverts should be placed on a good foundation material or raft foundations to prevent settlement and damage. On very soft ground, it may be necessary to consider concrete or steel piles to provide adequate foundations. This will require specialist design expertise not covered in this Manual;
- It is necessary to protect the watercourse from erosion downstream from the structure;
- Culverts can exist in pairs or in groups to enable larger stream flows to be accommodated using standard unit designs, and
- When the silt supply is high, culverts may need to be installed at higher gradients or extra maintenance may be required.

4.4.5 Standards for Low-Level River Crossings (LLRCs)

Key recommendations for geometric and structural design standards, as provided in SANRAL (2013) are summarised in the following sub-section for LLRCs.

a. Width of LLRCs

The recommended cross-sectional detail is provided in Figure 35, with recommended widths as follows:

- Single lane structure – 4 m between guide blocks (Example Figure 36)
- Two-lane structure – 7.5 m between guide blocks (Example Figure 37)

Widths between 4.0 m and 7.5 m should be avoided as these widths create the impression that it is a two-lane structure, increasing the risk of collisions.

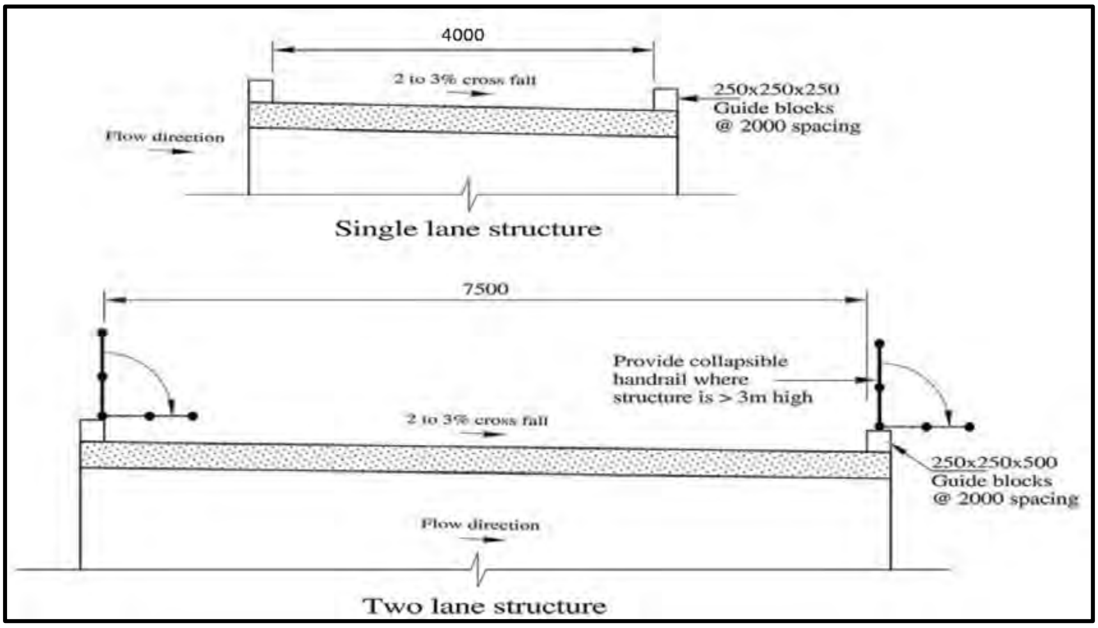


Figure 35 Recommended cross-sectional detail

Figure 36 Single Lane structure

Figure 37 Two-lane structure

A single-lane structure may be considered where:

- The approach gradients are moderate and there is no significant curvature on the immediate approach roads;
- The LLRC is long and considerable savings associated with a single-lane structure are likely;
- There is good visibility on approaches to the structure, and LLRCs are infrequent on an otherwise good section of road;
- Traffic volume is not expected to exceed 500 vehicles per day during the life of the structure, and
- Pedestrian volume is low, with less than 100 pedestrians in the peak hour. For longer bridges provision can be made for a dedicated walkway with or without handrails.

Where significant numbers of pedestrians are expected, especially on longer single-lane structures (current recommendation > 30 m), then separate provision should be made using a dedicated walkway (suggested 900 mm) on the upstream side of the deck. In addition, handrails that can collapse under large floods should be provided where structures are higher than 3.0 m measured from the top of deck level to river invert (refer Figure 38).

Figure 38 Single-lane structure with a pedestrian walkway and collapsible rail

b. Cross-sectional slope

A cross-sectional slope of 2 to 3 per cent is recommended to prevent sediment from being deposited on the driving surface.

c. Guide blocks

Guide blocks could perform several functions namely:

- Guiding the road user to maintain direction;
- Assist with gauging the depth of the water when overtopped;
- Prevent vehicles from slipping off the bridge structure, and
- Demarcate a pedestrian walkway.

The general recommendation is a block 250 mm high, 250 mm wide and 250 mm or 500 mm in length at a spacing of 2 000 mm.

d. Road horizontal alignment

Although not always possible, crossing a river at an angle or in a horizontal curve should be avoided.

A skew approach, coupled with the possible blocking of openings with debris, tends to direct the full force of the river towards one of the riverbanks, which increases the possibility of the approach being washed away.

A horizontally curved structure will be subject to similar problems of undesirable concentration of flow and it is extremely dangerous for road users to cross such a structure when overtopped. This might result in changing the road alignment (Figure 39).

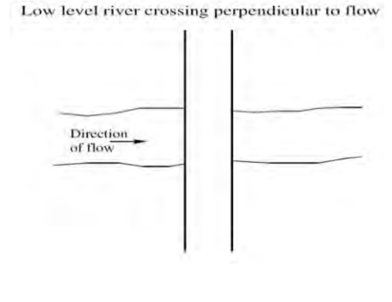
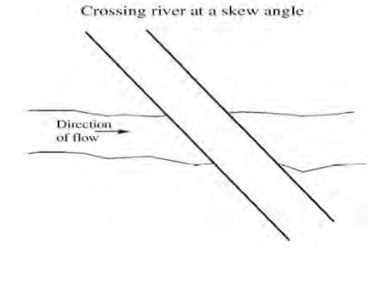
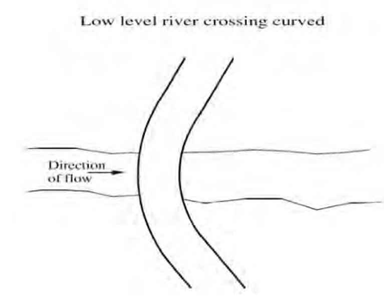
Preferable	Undesirable	Undesirable
		

Figure 39 Horizontal alignment over LLRCs

The designer should also pay attention to the sight distance towards an LLRC, to ensure that the road user observes the structure in good time. Sharp horizontal curves near an LLRC should be avoided for this reason.

e. Vertical alignment

The design speed over the bridge should preferably be the same as the road section, or at the minimum 20 km/h less. Advance warning signs must be provided.

It is highly recommended that the structure is level in the travel direction with short vertical sag curves on the approaches with less than a 7 per cent grade difference to the level structure.

From a road user's perspective, a variation in the water depth is undesirable. From a hydraulic point of view, the concentration of the water flow is undesirable.

Crest vertical curves are not applicable/allowed on LLRCs. The applicable K-values for sag curves for the approaches are shown in Table 21.

Table 21 Sag K-values relevant to design speed

Design speed (km/h)	K value
40	7
60	17
80	32
100	50
120	73

f. Length of the structure

The length of the structure should equal the width of the river with openings (in case of a causeway) preferably across the full length, especially if the structure protrudes significantly above the riverbed (Figure 40).

g. Size of openings

The size of openings depends on the design discharge. However, in the design of openings, it is desirable to provide as much waterway within the river channel to:

- Minimise obstruction of the river flow, and
- Allow as much possible debris to flow through the openings.

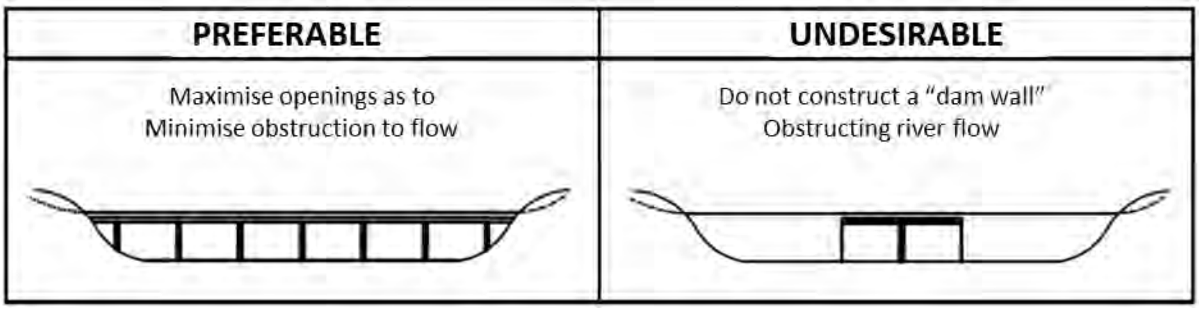


Figure 40 Cross-sectional area

h. Approach slabs

Approach slabs (Figure 41) should preferably be built high enough to accommodate the 1:5 to 1:10-year flow, dependent on the selected LOS. In remote areas where regular maintenance is not possible, consideration could be given to increasing the return period that is used in designing the approach slab to prevent undermining and failure of the bridge approach.

Apron and approach slabs would normally be constructed using concrete. Reno mattresses could be considered under certain circumstances for apron slabs.

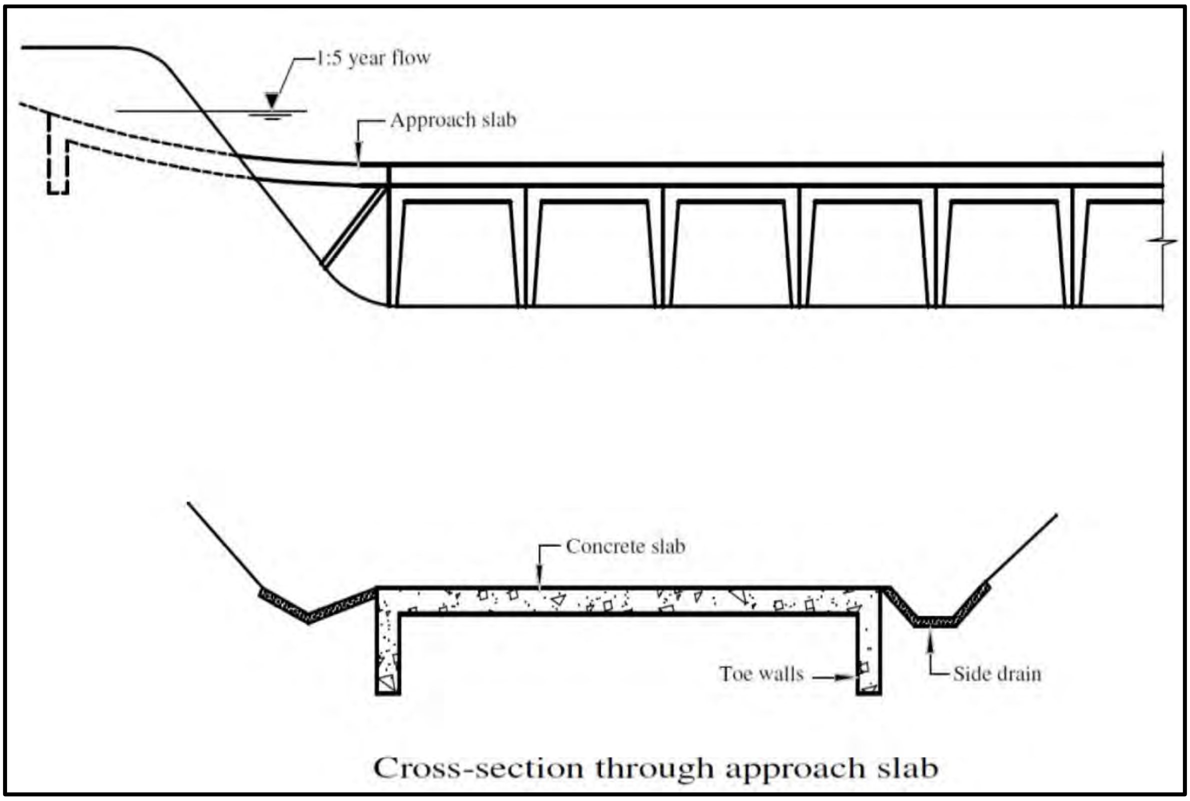


Figure 41 Approach slabs

i. Cut-off walls

Cut-off walls are essential to prevent scouring and undermining. This applies to aprons and approach slabs as shown in Figure 41 as well as to drifts and causeways as shown in Figure 42 and Figure 43.

The location of cut-off walls for the various structures is shown in Table 22.

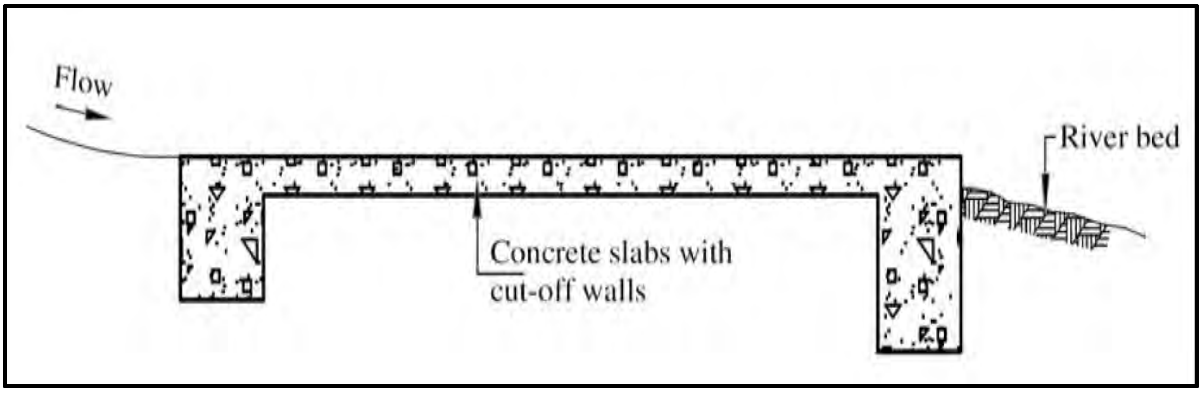


Figure 42 Cross-section through drifts with cut-off walls

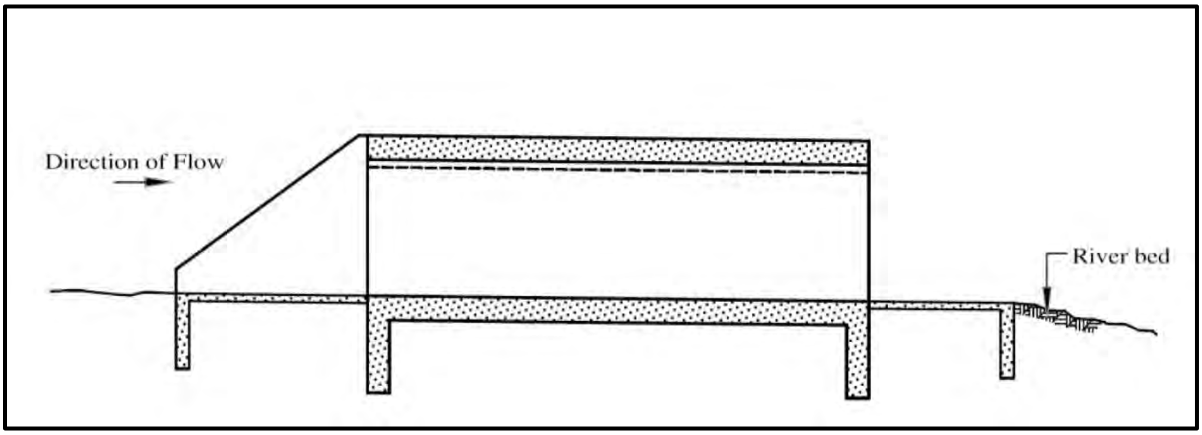


Figure 43 Cross-section through causeways with cut-off walls

Table 22 Cut-off wall locations

Structure	Locations
Drift	Upstream and downstream sides of the slab.
Culvert	Edges of inlet and outlet apron.
Causeway	Upstream and downstream sides of the main structure and approach ramps.
Large opening culvert	Upstream and downstream sides of approach ramps. The foundations of the main structure should be built at a greater depth than standard cut-off walls below the possible scour depth.

The minimum depth of the cut-off walls depends on the ground conditions. Where a rock layer is close to the ground surface the cut-off walls should be built down to this level and firmly keyed into the rock using dowels. In other situations, the depth of the cut-off wall should be greater than the expected depth of scour. This is best estimated from local experience under similar conditions. The depth is measured from the lowest point in the bed of the watercourse at the crossing point. If no information is available, Table 23 provides guidance. For larger structures, advice should be sought from an experienced engineer.

Table 23 Cut-off wall depths

Structure	Cut off wall depth (m)
Drift	1.5
Relief culvert	1.0
Watercourse culvert	1.5
Causeway	2.0

j. Apron slabs

The use of apron slabs on both the upstream and downstream sides of a culvert or LLRC is recommended to absorb the energy of water flowing over the structure and to protect the foundations of the structure.

These slabs also contribute towards increased stability of water flows near the structure.

As the water flows out of or off a structure it will tend to erode the watercourse downstream, causing undercutting of the structure. Aprons should be constructed from a material, which is less susceptible to erosion than the natural material in the streambed:

- Drift aprons. Where the discharge velocity across the drift is less than 1.2 m/s, which may be experienced for relief drifts, a coarse gravel layer (10 mm) will provide sufficient protection downstream of the drift. For discharge velocities greater than 1.2 m/s protection that is more substantial will be required utilising dump rock (riprap). The length in the flow direction should rather be based on the stable hydraulic jump length and extend across the watercourse for the whole length of the drift;
- Culvert aprons. Aprons should be provided at both the inlet and outlet of culverts. They should extend the full width between the headwall and any wing walls. If the culvert does not have wing walls the apron should be twice the width of the culvert pipe diameter. The apron should also extend a minimum of 1.5 times the culvert width/pipe diameter. Ideally, the length in the flow direction should be based on the stable hydraulic jump length. Cut-off walls should also be provided at the edge of all apron slabs. The choice of apron construction is likely to depend on the type of material used for the construction of the culvert. It may be constructed from riprap (dumped rock), grouted stone pitching/masonry, Reno mattresses, grouted riprap, or concrete, and
- Causeway aprons. The apron for causeways should extend the whole length of the structure including downstream of the approach ramps to the maximum design level flood. The other design requirements for causeway aprons are the same as culvert aprons.

Note: Standard plans for erosion protection could be downloaded form:

https://rnis.westerncape.gov.za/rnis/rnis_web_reports.main

k. Approach fills

The abutments of LLRCs should be keyed into the riverbanks where possible. In the case of flat river cross-sections, the approach road should be constructed as close to natural ground level as possible, to avoid embankments being breached when overtopped by floods. Where the overtopping of embankments is likely, provision should be made for erosion protection by suitably cladding the upstream and downstream faces and the road formation. Flow depth and velocity for the 1:5 or 1:10

year flood should be determined, and provision should be made to accommodate their impact on the approach roads and structures.

In certain circumstances, it may be necessary to protect banks downstream of the structure to a level calculated based on the 1:5-year flood.

l. Inclined buttresses

It is considered good practice to provide LLRCs with inclined buttresses on the upstream side of each pier. Benefits recorded are:

- Assist in lifting floating debris over the structure
- Provides additional stability in the case of debris loads

m. Safety

The following road signs as recommended in SANRAL (2013), should be considered for LLRCs:

- Warning signs:
    - W350: Drift;
    - W326: Narrow bridge;
    - W327: One vehicle width structure;
    - W328: Road narrows both sides;
    - W202 and W203: Gentle curve;
    - W204 and W205: Sharp curve;
    - W348: Jetty edge or riverbank, and
    - W41 and W402: Danger plate.
- Regulatory Signs:
    - R1: Stop;
    - R6: Yield to oncoming traffic, and
    - R201: Speed limit.

4.4.6 Selection process

The selection of an appropriate cross-drainage structure is often an iterative process, taking cognisance of the LOS, risks, costs, road geometry and founding conditions.

Figure 44 provides a basic summary of the flow in the selection process, with each component discussed in the following sections.

4.4.7 Levels of service

Four LOS classes have been selected to assist in the standardisation of LVR provision and to provide the road user with information regarding possible delays and speed of safe travel. The basic principles are provided in Table 11 and Table 12.

SANRAL (2013) recommends three levels of design for Low-Level River Crossings (LLRC) based on the Annual Average Daily Traffic (AADT), the availability and distance of alternative routes. These recommendations have been slightly adjusted to utilise the LOS classes for road geometry (refer to Table 24).

For LLRCs the target LOS is defined by the expected frequency and hours of inaccessibility/pass ability as provided in Table 25.

.

The designer should clarify the selected design level with the relevant local authority/owner of the structure.

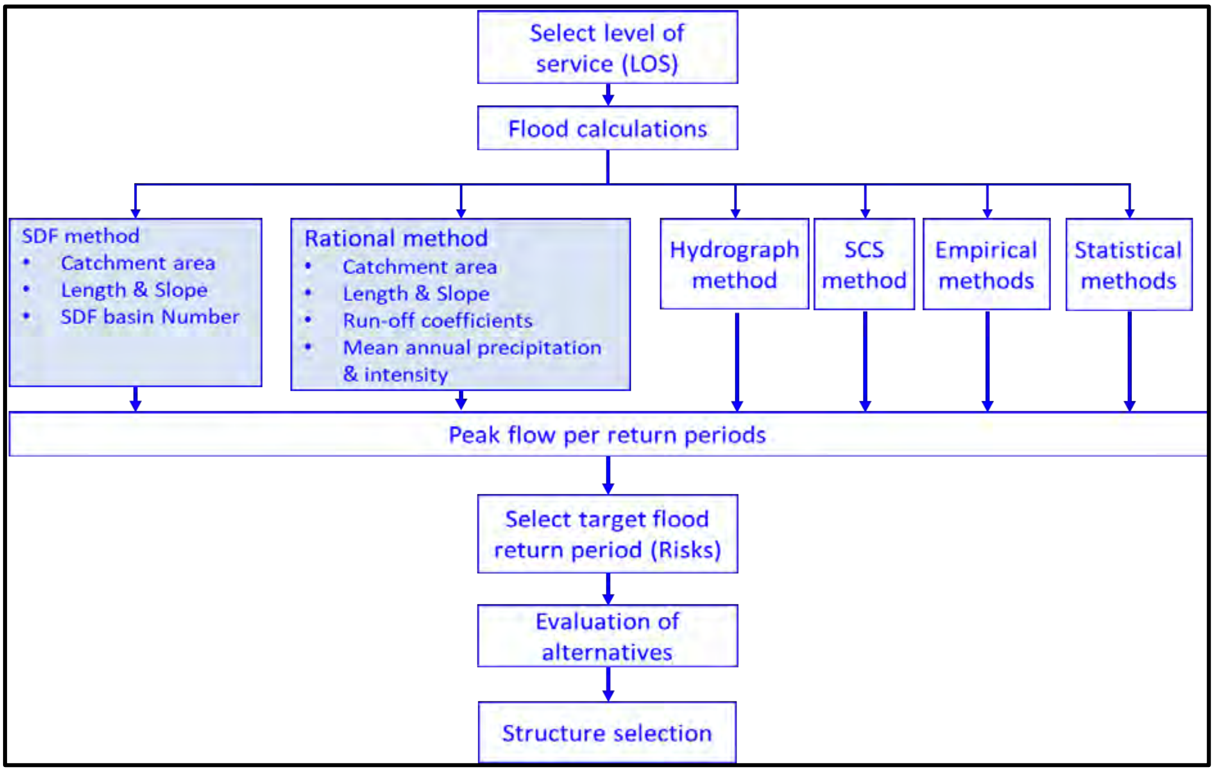


Figure 44 Selection process

Table 24 Recommended structure design level per LOS design class

LOS Design Class	Alternative route (km)	Structure Design level
LVR 4	> 50 or no available alternative	3
	< 50	2
LVR 3	> 20	2
	< 20	1
LVR 2		1
LVR 1		1

Note: If no alternative route is available on LVR 3, a Structural Design Level 3 should be considered

Table 25 Level of Service: Expected frequency and hours of inaccessibility

Structure Design level	Dimensionless factor, f_i	Average no of times flow can be expected to be exceeded per year			Average length of period flow is exceeded (hours)		
		Min value	Max value	Average value	Min value	Max value	Average value
1	0,25	0,0	4,2	1,3	0,0	30	9,0
2	0,50	0,0	2,4	0,8	0,0	13	5,5
3	1,00	0,0	1,4	0,5	0,0	6	3,4

4.4.8 Risks and liability

a. General

Apart from providing access, the safety of road users is a primary concern. In any claim due to accidents, damage, injury or life loss, the Road Authority would be the first defendant to prove non-negligence.

Cognisance should be taken of:

- The National Water Act (Act No 36 of 1998);
- The Environmental Conservation Act (Act No 73 of 1989);
- Geoscience Amendment Act, and
- CSRA (1994). Committee of State Road Authorities. Guidelines for the Hydraulic Design and Maintenance of River Crossings.

b. Minimise risk

Key aspects to minimise risks are:

- A comprehensive survey within a circle with a 200 m minimum radius is required to establish the profile and gradient along the river and levels to position the structure. Surveys extending 400 m upstream and 600 m downstream would be beneficial;
- Quantification of flood levels and intensities, taking projected climate change into consideration;
- Detailed evaluation of erosion and scour risks and, cost of repair;
- Provision and maintenance of adequate warning signs;
- Recording and submission of all design parameters, assumptions, and as-built data to the responsible Road Authority
- The designer must be a registered professional with specific experience in this field of work as the process can be as complex as the planning and design of a high-level river bridge on a high-class road.

Table 26 provides a basic guideline to categorise risk.

If potential damage caused and the impact of disruption, due to failure of the structure are high (Category 3), the design flood should be enlarged as deemed necessary based on local incidences in the past. In the case of Risk Category 1, consideration might be given, with the consent of the local authority, to alter the design period. The design return period, discussed in Section 4.3.10, could also be adapted with increasing risks.

c. Incorporating climate change

Climate change will affect roads in many different ways. The accepted characteristics, amongst others, are higher temperatures, higher or lower rainfall, more windy conditions, more intense storms and storms that are more frequent. This will lead to the need to cope with generally more water, more frequent floods, and faster and more destructive water velocities. Thus, much of the historic data on which hydrological analysis and hydraulic design rely may lead to an under-estimation of design floods and high-water levels.

The DEA (2014) National study could be used where climate models were applied to bridges in the country to assess the risk of flood peak change for the 100-year flood due to future climate change impacts (Figure 45). This provides frequency distributions of extreme potential impacts on the design flood (1:100 year) for key infrastructure under four climate change models and the relative risk for individual structures for the climate model with the greatest general impact up to 2100. For more detailed studies hydrological modelling is proposed.

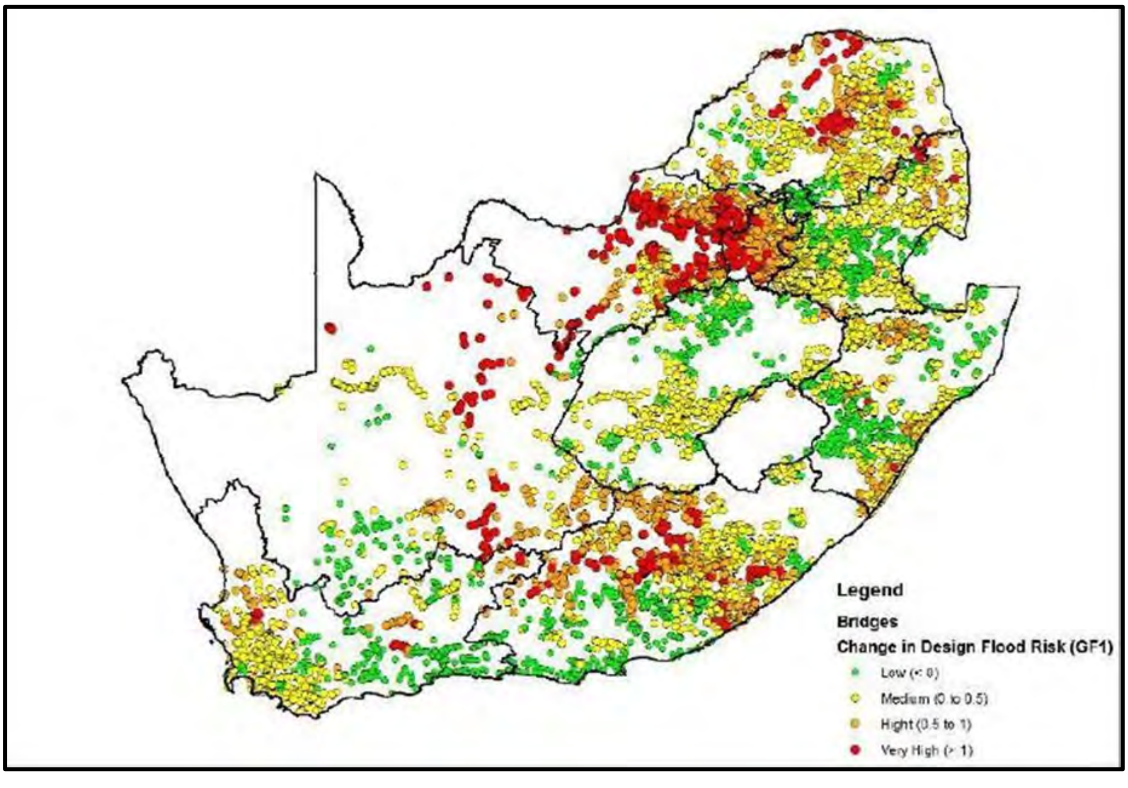


Figure 45 Frequency distributions of extreme impacts on the design flood (1:100 year)

Table 26 Risk categories

FACTORS TO BE CONSIDERED	RISK CATEGORY		
	1	2	3
Extent of possible damage			
Potential damage to the road and associated cost of repairs	Low	Medium	High
Potential other damage such as saturation of agricultural land, etc.	Low	Medium	High
Extent of loss of use			
Time needed for repairs to make route trafficable again	Short	Medium	Long
Availability of detours	Good	Medium	None
Obstruction of traffic flow			
Period of flooding	Short	Medium	Long
Traffic density	Low	Medium	High
Depth and velocity of floodwaters	Low	Medium	High
Strategic and economic importance of route			
Strategic and economic importance: military, police, fire brigade, medical services, etc.	Low	Medium	High
Economic importance	Low	Medium	High

In addition, various other strategies will help to increase climate resilience. In general, these comprise:

- Identifying the most vulnerable areas and essentially increasing the 'safety factor' inherent in their design;
- Adding extra high quality/impermeable surface protection to minimise the effects of erosion during flooding and overtopping.
- Ensuring that the drainage systems are well maintained and functioning correctly, and
- In critical areas where the consequences of failure and closure are more severe, local realignment, if appropriate, may be required

Increasing the safety factor includes using drifts and causeways that can be safely overtopped instead of culverts that can become blocked by debris; adding additional protection to culverts that might be blocked by debris; better surface drainage so that water is dispersed off the road more frequently; reducing water concentration utilizing additional cross drains and mitre drains to lower the volume of water that each one needs to deal with; installing debris traps upstream of the structure.

Erosion is a serious problem in many areas and adverse climate change and deforestation will make matters worse.

Ensuring that the drainage system is working correctly is essentially a maintenance issue although there will be examples of poorly designed culverts with improper alignment or grade that will need to be repaired or replaced, usually, after failures have occurred.

d. Risk of overloading

If the loading capacity is limited in any way, signage should be provided to clearly state the loading capacity of the structure. Local road network managers and administrators should also be made aware of any load limitations and the likely consequences of these being exceeded.

If it is not possible, with the resources available, to construct a crossing that will withstand the largest vehicle that could travel down the road, it will be necessary to install a robust non-removable barrier on each side of the structure to prevent overloaded vehicles from crossing.

4.4.9 Hydrology

a. Design flood frequency

The recommended design flood frequency for bridges and culverts is different to LLRCs where the latter is allowed to be overtopped.

The design flood Q_t is the flow rate in m^3/s with a return period of T years for which the hydraulic structure must be designed. For bridges and culverts, not allowed to be overtopped, the 20-year flood is used as the "indicator" flood and reflects the hydrological risk of the road river crossing. The selection of the return period for design is normally determined using the road classification but is also influenced by other factors such as the importance of the road, costs and risks.

The design flood frequency, T, for bridges and culverts can be obtained from Figure 46, for LVR classifications and design levels of this manual. For roads crossing major rivers where high flood flows are maintained for several days, it may be advisable to build the bridge to the standard required for a higher class than the given classification if alternative access is not available to the community.

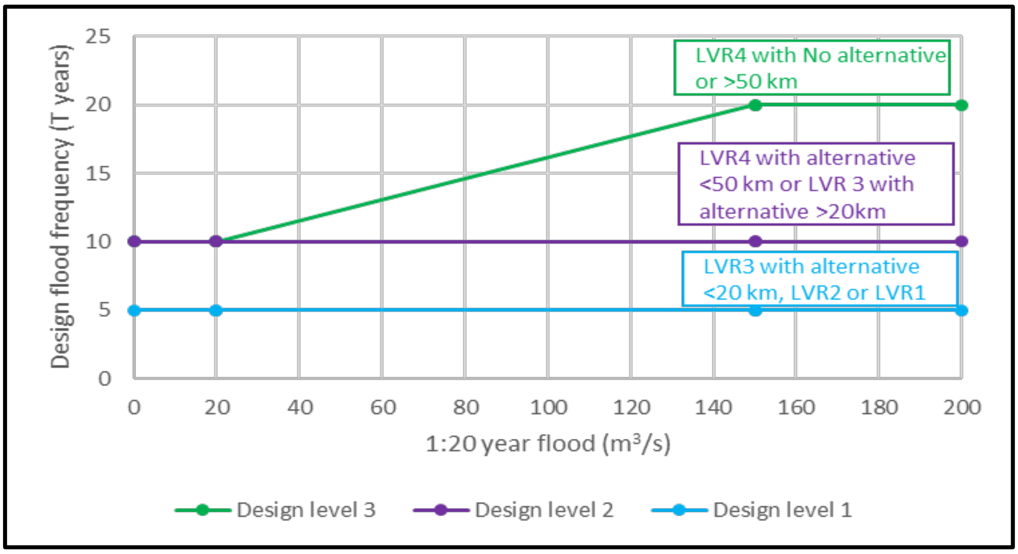


Figure 46 Design flood frequency estimate - Adapted from SANRAL (2013)

For LLRCs a 2-year return period (design flood frequency) is recommended.

The design discharge is calculated as follows:

$Q_{design} = f_i Q_2$

Where:

Q_{design} = design discharge (m^3/s)

f_i = a dimensionless factor related to the selected design level

Q_2 = discharge with a 2-year return period

The structure should be designed in such a way that:

$Q_{over} + Q_{under} \geq Q_{design}$

Where:

Q_{over} = discharge that can be accommodated over the structure within the acceptable flow depth as defined below

Q_{under} = discharge capacity of the openings through the structure (m^3/s), if any

Regarding flow depth, it is accepted that a vehicle should not pass over an LLRC if the depth of flow over the structure exceeds the underbody ground clearance height of the vehicle. However, the flow velocity increases the risk of washaway and should be taken into account. Recommended design depths are provided in Table 27.

Note: The road user must be warned when the risk is too high through adequate signage or other innovative means e.g., Indicators posts and/or height of guiding blocks

Table 27 Recommended maximum flow depths

Flow characteristic	Maximum flow depth
Supercritical flow	100 mm
Subcritical flow	150 mm

Even though the designed LLRC will provide access with a safe flow depth for the 2-year return period, **approach slabs should extend to accommodate at least the calculated flood for an expected 5-year or 10-year return period (dependent on the selected LOS).** The principle is shown in Figure 47.

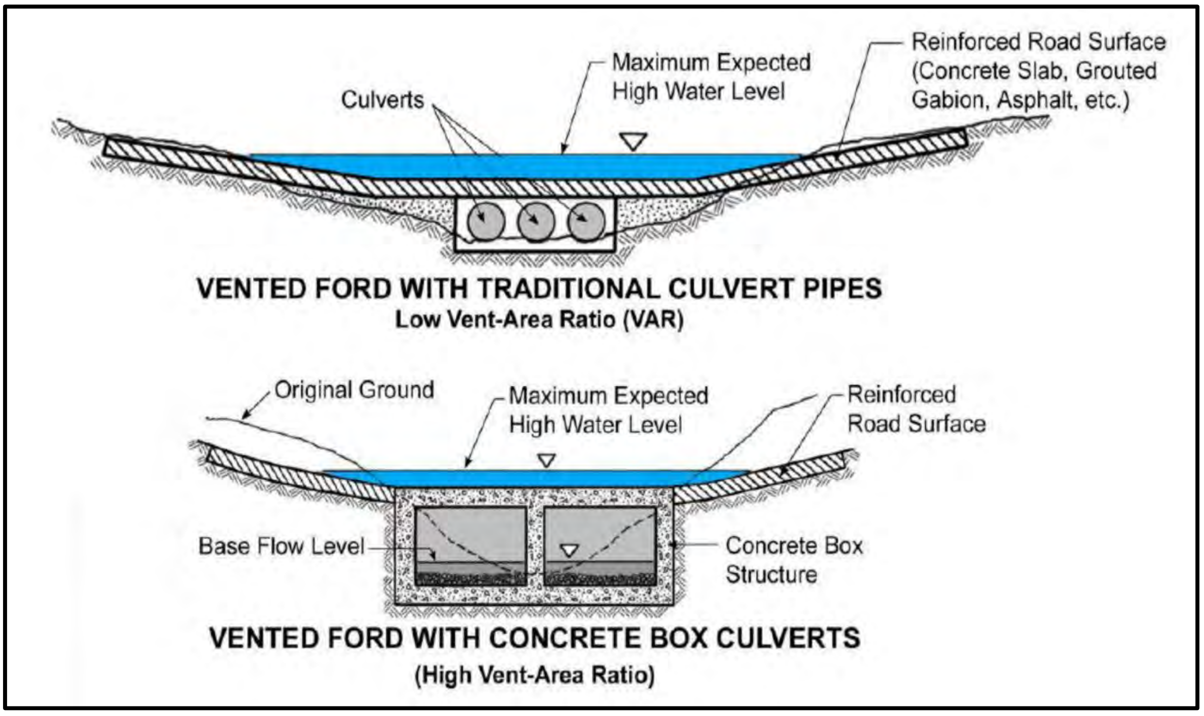


Figure 47 Provision of approach slabs

b. Methods of flood calculation

Water crossing structures must be designed to have a capacity equal to or greater than the maximum water flow that is expected in the watercourse. This maximum flow depends on the characteristics of the storm itself, namely the intensity, duration and spatial extent of the rainfall, and the characteristic of the ground, or catchment, on which the rainfall falls.

The area of the drainage catchment (A) should be estimated from topographical maps or using aerial photographs.

Methods used for estimating maximum flow in a watercourse are provided in Table 28

Table 28 Methods for estimating maximum flow

Method	Input data	Recommended maximum area (km^2)	Return period of floods that could be determined (years)	Reference paragraph
Statistical method	Historical flood peak records	No limitation (larger areas)	2 – 200 (depending on the record length)	3.4
Rational methods	Catchment area, watercourse length, average slope, catchment characteristics, design rainfall intensity (3 alternative methods)	Usually < 15, depends on method of calculating rainfall intensity	2 – 200, PMF	3.5.1
Unit Hydrograph method	Design rainfall, catchment area, watercourse length, length to catchment centroid (centre), mean annual rainfall, veld type and synthetic regional unit hydrographs	15 to 5000	2 – 100, PMF	3.5.2
Standard Design Flood method	Catchment area, watercourse length, slope and SDF basin number	No limitation	2 – 200	3.5.3
SCS-SA method	Design rainfall depth, catchment area, Curve Number=f(soils, land cover), catchment lag	< 30	2 - 100	3.5.4
Empirical methods	Catchment area, watercourse length, distance to catchment centroid, mean annual rainfall	No limitation (larger areas)	10 – 100, RMF	3.6

Note: The "Reference paragraph" refers to the relevant section in SANRAL (2013), where detail could be obtained.

Depending on the available information and the importance of the road and structure, different methods could be applied. No weighting of the different flood calculation methods to determine the design floods should be done. The results of the various methods should be reviewed and the most appropriate one selected to determine the design flood. In this regard, the following will be of value to aid the decision:

- Direct observation of the size of the watercourse, erosion and debris on the banks (visible high-water mark), historical and local knowledge of maximum floods and occurrence, and
- Evaluating successful practice in the area.

For LVRs in South Africa, the SDF method and the Rational method are mostly used, especially if the catchment area does not exceed 500 km². The SDF is an empirical regionally calibrated version of the Rational method. The only information required for its application is the area of the catchment, the length and slope of the main stream, and the drainage basin in which it is located (Figure 48)

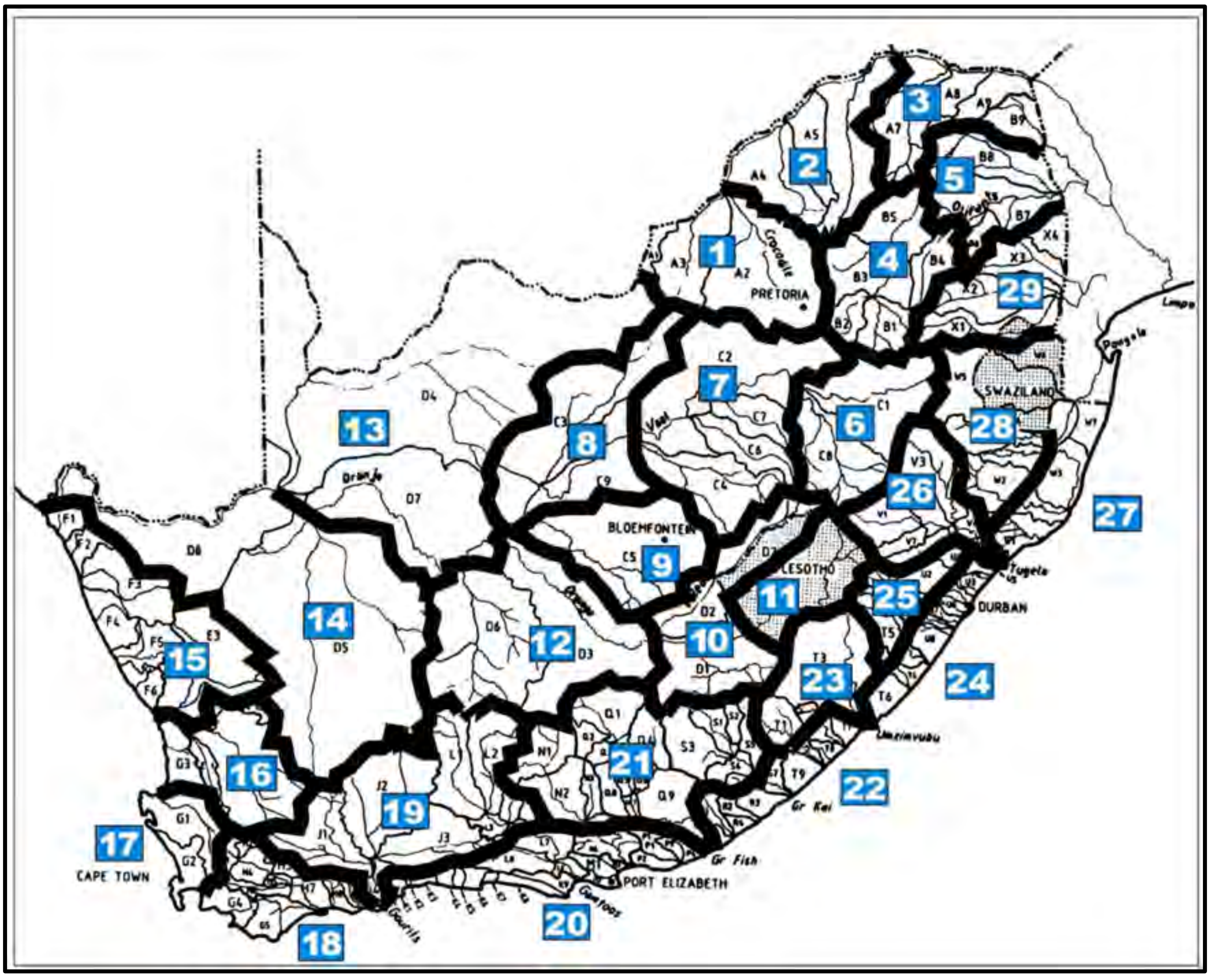


Figure 48 Standard design flood drainage basins

The Standard Flood Frequencies (SDF) from years of experience provide a good representation of the optimum design flood. The rate of flow varies little over short distances along a water course and constitutes the most significant parameter in quantifying the amount of damage done to a road as well as the extent of traffic obstruction. For this reason, the peak flow calculated for a flood with a return period of 20 years is used as the basis for the selection of the appropriate design period.

Note: Factors that have a large influence on the SDF, requiring the designer's consideration are:

- Catchments in dolomitic areas where the flood run-off may be less than half of the SDF values, and
- Catchments that have very flat growth curves (low coefficients of variation) e.g., catchments in the south-western Cape. In these rivers e.g., Brede River, the SDF may appreciably over-estimate the flood magnitude for long return periods.

c. Hydraulic considerations for LLRCs

The capacity of a structure is determined as the sum of the discharge that could be accommodated over the structure within the acceptable depth, and the discharge to be accommodated underneath the structure. The sum is then compared with the design discharge, Q_{design}, to evaluate the adequacy of the structure.

Detailed discussion is provided in Section 6.4 of SANRAL (2013).

4.4.10 Erosion protection

a. General

Erosion refers to a general lowering of the ground surface over a wide area due to heavy rains, floods, etc. and a general movement of soil by water. Scour refers to a localized loss of soil as could occur around foundations or in a channel bottom, etc.

Erosion is a frequent problem that must be addressed during drainage design. The majority of structural failures of drainage structures occur during flood periods and over 50 per cent of these failures can be attributed to scour.

Erosion/scour is also closely linked with the geotechnical problems of slope stability. Thus, erosion and scour are wide subjects that often require specialist advice.

b. Characteristics of Scour

There are three types of scour or erosion. The first two are caused by the existence of the drainage structure itself in concentrating the flow of water and/or increasing its velocity. There are two aspects:

- Scour around the structure itself that threatens its integrity and its continued existence, and
- Scour that occurs in the channel or erosion (especially downstream away from it) of the roadway and surrounding areas because of the structure.

The third type is essentially natural scour that occurs within all natural water channels irrespective of the existence of man-made drainage structures. This will alter the hydraulic environment over time and needs to be considered in the design of the road.

The amount of scouring depends on the speed of the water flow and the erodibility of the material that the water comes into contact with. If the flow is not parallel to the constriction, more scour will occur on one side than the other. Water flow is accelerated around abutments, piers and other obstructions, creating vortices with high velocities at abrupt edges on the obstruction, increasing the scour depth, often dramatically.

Trapped debris can also restrict the flow of water and cause an increase in water velocity. Structures must be designed to minimise the chances of debris being trapped and to ensure that inspections and maintenance are carried out after flood periods to remove any lodged debris.

Finally, if the water is already carrying a large amount of material eroded from further upstream, a greater amount of scour will occur at the structure.

Because they are designed to be overtopped, erosion protection is particularly important with LLRCs. Attention should be given to:

- The downstream apron slab area;
- Approach roads to the structure, and
- The banks downstream of the LLRC.

It is difficult to predict the level of scour that may be experienced for a particular design.

SANRAL (2013) addresses this issue in Chapter 7 (relevant to lesser culverts) and Chapter 8 (relevant to bridges and major culverts)

A design manual for small bridges, Overseas Road Note 9 (TRL, 1992) is also a useful reference.

4.4.11 Site and structure type selection

a. Site selection

As highlighted in Section 3.3.3.1, changing the existing alignment could significantly increase costs. However, several factors could result in significant increases in the cost of the structure, maintenance, damage repair and environment, leading to lower costs and risks by realignment of the road.

Considerations affecting the selection of the site:

- Straight river section

  A LLRC should be located within a straight section of a river where the river flow is as uniform as possible. Riverbanks on the outsides of bends tend to erode which might lead to the floodwater bypassing the structure during flooding;

- Crossing angle

  As described, construction will be cheaper and there will be a reduced risk of erosion and damage if the road crosses the watercourse at an angle of 90°;

- River channel cross-section

  Where the width of a river channel varies, the advantages of locating the structure in a narrower section should be compared with those associated with a location in a wider section. The benefits of a narrower section are the shorter length and, therefore, lower construction costs. Benefits also cover the possibility that the narrower section is associated with less weathered in-situ material, which may offer better founding conditions. The benefits of a wider section in the river are that the flow velocity is relatively lower with a shallower depth. These two benefits reduce the risk that the structure may be damaged and increase the safety of vehicles crossing the structure.

  Generally speaking, a LLRC should be as low as possible to minimise the impact on water flow by the obstruction placed in the river channel. The depth of the natural river channel, compared with the width, should be considered. With narrow, deep sections, the depth-to-width ratio may not allow the structure to be placed at a low-level due to the geometric alignment limitations of the road. LLRCs are generally more suitable for river cross-sections with low depth-to-width ratios.

The following should be considered:

- Signs of erosion or sedimentation and strength of bedding material in the water course - Can the road be aligned to a more suitable crossing site?
- Is the watercourse in a deep valley? If so, the approaches can be very steep and at risk of erosion and failure;
- Does the watercourse flood the surrounding land? If so, an embankment will also be needed across the area, and
- Are there strong soils or rocks on both sides of the watercourse? If so, the structure will be able to support the weight of vehicles passing on the road.

After considering these questions, the engineer may decide that it is cheaper to realign the road to a more suitable river crossing site.

b. Structure selection

The objective in selecting a structure for a water crossing is to choose the most appropriate design for each location.

For small watercourses and relief structures, the choice of structure will, in general, be between a culvert and a drift and, for larger watercourses, between a causeway, a low-level bridge, a major culvert, or possibly a high-level bridge. The choice of the structure depends on various factors, but particularly on the predicted maximum water flow, the topography and the duration of road closures that can be tolerated. Figure 49 provides typical outcomes for LVRs in South African conditions, with the catchment area used as a surrogate for the peak flow.

Table 29 further highlights the suitability of different LLRCs based on founding conditions.

Figure 49 provides a decision tree that could be of assistance in the selection process. It should also be noted that this figure only highlights the key issues and should only be used as a guide when determining the most appropriate structure.

The final decision will be based on an economic evaluation, incorporating all costs and benefits to society.

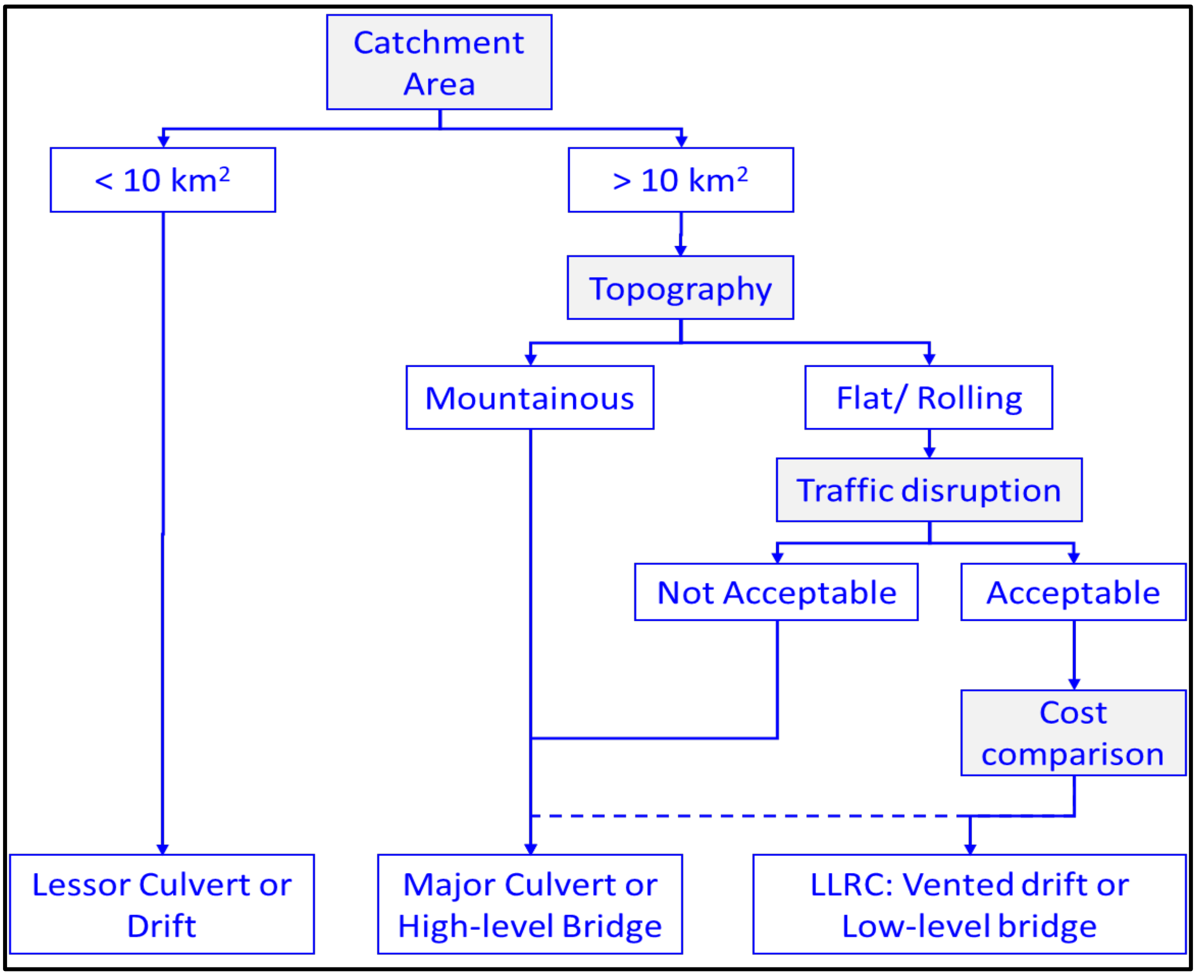


Figure 49 Typical outcome for cross-drainage structures on LVRs in South Africa

Table 29 Suitability of LLRCs based on founding conditions

Foundation condition	LLRC type		
	Drift	Causeway	Low-level bridge
Uneven rock	Unsuitable	Unsuitable	Very suitable
Even rock	Very suitable	Very suitable	Very suitable
Stiff clay	Suitable – use raft foundation	Suitable – use raft foundation	Spread footings, or piling/caissons may be required. Consider longer spans.
Sand	Consider a raft foundation	Consider a raft foundation	Piling/caissons required. Consider longer spans.

4.4.12 Economic evaluation

a. General

As is the case with any other infrastructure improvement project, the economic evaluation of drainage systems and hydraulic structures measures costs and benefits from the point of view of society as a whole.

Chapter 2 of SANRAL (2013) provides comprehensive detail regarding the principles, techniques, and processes, incorporating the risk of flood damage and dealing with the uncertainty of available data. Recommendations regarding specific components incorporated into life-cycle cost analyses e.g., analysis period, non-user benefits and terminal/salvage value require specific attention.

The optimal design of drainage systems and hydraulic structures could be defined as that which maintains a proper balance between the cost of the project, the cost of potential flood damage (economic risk) and benefits to society.

Different alternatives could be appropriate for one river crossing and should be evaluated to select the optimum (Figure 50 is an example).

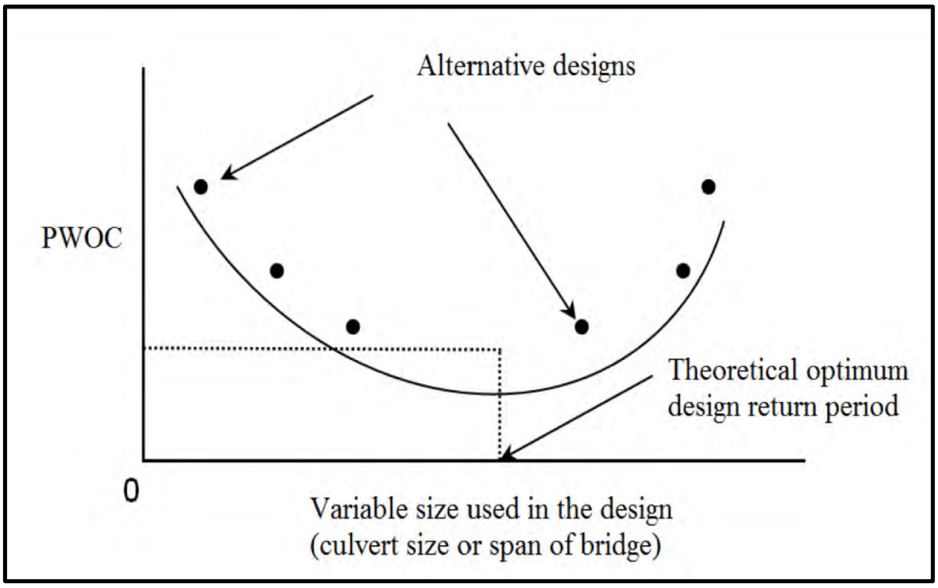


Figure 50 Selection of optimum alternative based on Present Worth of Costs

b. Costs

Different Road Agency (RA) cost components incorporated into the life-cycle cost analysis are:

- Construction cost;
- Maintenance and operation costs, and
- Additional costs associated with abnormal floods.

i. Construction costs

The approximate costs of drainage structures are provided in Table 30.

Table 30 Cost of drainage structures (2024)

Structure Type	Category Description	Start Range	End Range	Unit Cost R/m^2	Expected useful life (years)
Bridge	Max Pier/Abutment height	0	8	35 820	80
		8	30	53 708	80
		30	1000	71 630	80
Bridge Cellular	Fill above bridge	0	3	29 090	80
		3	6	34 921	80
		6	10	40 742	80
		10	1000	46 562	80
Bridge - Arch	Max Arch Span length	0	100	71 630	80
		100	200	89 528	80
		200	1000	107 439	80
Bridge - Cable	Max Cable Span length	0	150	89 528	80
		150	300	125 326	80
		300	1000	161 147	80
Culvert Major	Fill above culvert	0	3	29 090	80
		3	6	34 921	80
		6	10	40 742	80
		10	1000	46 562	80
Culvert Large	Fill above culvert	0	3	29 090	80
		3	6	34 921	80
		6	10	40 742	80
		10	1000	46 562	80
Culvert Lesser				6 022	30
Drift				3 660	50
Causeway/ Vented Drift				21 521	50

ii. Maintenance and operation costs

These costs include both routine and periodic maintenance estimates and may include minor damage to the structure that would occur with expected minor flood damage associated with the design flood, Q_D, of the specified return period.

iii. Additional costs associated with abnormal floods

These costs include:

- External costs, such as damage to private property, upstream and downstream of the structure;

- Capital and maintenance expenses, including damage to road pavement, shoulders, culverts and other roadway items;
  - **Note:** Recent flood damage repair on twenty-two structures after one abnormal flood amounted to an average of approximately R 1.0 million per structure, and
- Road user costs as a result of the disruption, including vehicle operating costs for travel along the detour and stop, travel time cost for lower travel speed and longer travel distance, and accident costs as a result of the conflict at and along detours.

4.4.13 Evaluation of existing drainage structures

The condition and effectiveness of hydraulic structures on unpaved roads selected for upgrading must be evaluated to meet the requirements for the selected LOS.

Chapter 10 of the SANRAL Drainage Manual provides detail regarding the assessment and improvement of existing drainage structures under the following headings:

- Design return period review for existing hydraulic structures;
- Hydraulic review of existing road drainage structures;
- Flood routing;
- Utility program for level-pool routing;
- Different forms of inflow hydrographs, and
- Remedial actions to be considered to increase the hydraulic capacity of existing hydraulic structures.

4.4.14 Design of lesser culverts

The term “lesser culverts” refers to culverts that are small enough to be designed using simplified hydraulic and hydrological analyses.

Chapter 7 of the SANRAL Drainage manual provides comprehensive guidelines with an emphasis on:

- Practical considerations;
- Determination of the required culvert size;
- Flood attenuation at culverts, and
- Erosion protection downstream of culverts.

Worked examples on the latter three aspects are provided in the SANRAL Drainage Manual Application guide.

The minimum acceptable recommended practical sizes for culverts are:

- 600mm diameter or 750mm span x 450mm high for culvert length <30m
- 900mm diameter or 900mm span x 450mm high for culvert length >30m;

4.4.15 Headwalls and wing walls

Headwalls and wing walls are required at each end of a culvert and serve several different purposes:

- They direct the water in or out of the culvert;
- They retain the soil around the culvert openings, and
- They prevent erosion near the culvert and seepage around the pipe, which causes settlement.

The headwall can be positioned at different places in the road verge or embankment as shown in Figure 51.

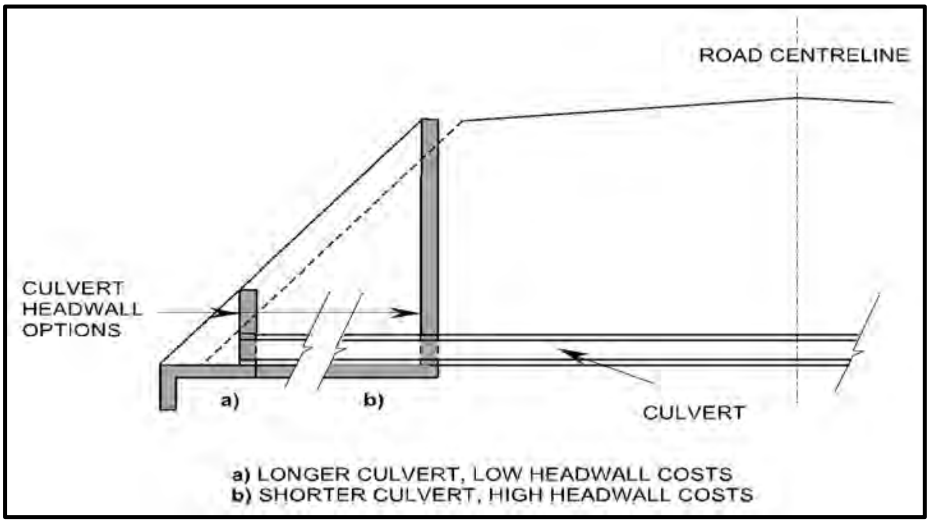
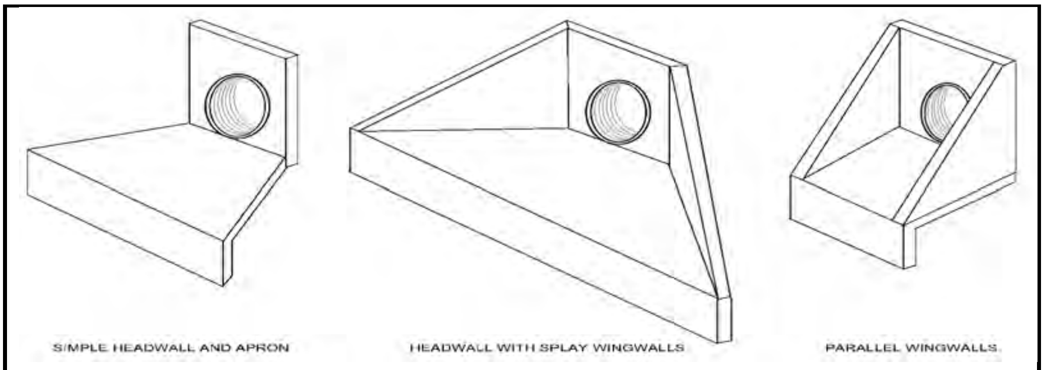


Figure 51 Possible culvert headwall positions

The closer the headwall is placed to the road on an embankment the larger and more expensive it will be. The most economical solution for headwall design will be to make it as small as possible. Although a small headwall will require a longer culvert, the overall structure cost will normally be smaller. If, due to special circumstances at a proposed culvert site, a large headwall with wing walls is required it should be designed as a bridge wing wall (with a soil retaining function).

Where a road is not on an embankment the size of the headwall will be small regardless of position. In this case, the position of the headwalls will be determined by the road width and any requirements of local authority standards. The headwalls should be positioned at least 1m beyond the edge of the carriageway to prevent a restriction on the road and reduce the possibility of vehicle collisions.

Headwalls should project just above the road surface (+/- 150 mm) and preferably be painted white so that they are visible to drivers. Marker posts should be used to warn drivers of the existence of a headwall that may be a potential road safety hazard. Different layout options for culvert headwalls are shown in Figure 52.



This arrangement can be used for simple low-flow relief culverts. It is the cheapest option but is prone to erosion for larger flows.	This arrangement should be used for larger flows instead of the simple arrangement. The wing walls increase the protection from erosion.	Where the road is on an embankment, wing walls must be provided to prevent the risk of water seepage and subsidence of the embankment. This arrangement is likely to be the most economical.

Figure 52 Headwall and wing wall arrangements

Inlet considerations:

- Headwall with drop inlet:
  This arrangement should be used when the road is on a steep side slope to reduce the invert slope of the culvert.
- Headwall with L inlet:
  This arrangement should be used where the road is on a gradient and water is to be transferred from the carriageway side drain on the high side of the road.

Note: Headwalls and adjacent works must be designed so that the culverts can be desilted manually under maintenance arrangements. This can be difficult with a drop inlet and silt trap arrangements.

5. Pavement Structural Evaluation and Design

5.1 General

The objective of any pavement design is to produce an economical, well-balanced pavement structure, in terms of material types and layer thicknesses. The designed pavement structure must be able to withstand the expected traffic loading over a specified design period (the chosen design life of the pavement), without deteriorating below a pre-determined level of service. To achieve this goal, sufficient knowledge of the subgrade strength, pavement materials, traffic loading, local environment factors (particularly climate and drainage) and their interactions is required to be able to predict the performance of any pavement configuration with an acceptable degree of accuracy. In addition, there should be a clear view as to the level of performance and pavement condition that is considered applicable to the road category and circumstances for which the pavement structure is being designed.

Pavement design for the upgrading of unpaved roads presents a particular challenge to designers. This is largely because, until relatively recently, such roads were not specifically catered for, and the step from a gravel road to a paved road has, to a large extent, not been adequately addressed in design manuals with specific reference to the optimisation of LOS, applicable standards, materials utilisation and structural design inputs.

5.2 Design philosophy

The design of the pavement structure is done in coordination with the geometric and drainage design as discussed in Chapter 1.2, Figure 7 in combination with Figure 9 and Figure 10, depending on the phase of investigation. **It should be noted from the figures that the pavement design is not done in isolation and that a close link must be maintained between the geometric design, drainage design and pavement design throughout the various design phases as shown.**

The design philosophy enables the designer to fully take into account all relevant factors before embarking on more detailed testing and analyses. This approach ensures that all testing done is of relevance to the project and optimises all testing. Testing must be accurate, adequate and statistically meaningful to enable the designer to proceed with confidence to the next phase of the design process.

In line with the design approach summarised in Figure 7, Figure 9 and Figure 10, the various aspects that are to be addressed within the pavement design part of the section (taking into account the design inputs (e.g. alignment) from the geometric design and drainage design) are summarised as follows:

- Phase 1A – Concept Initial Assessment;
  - Category of road and Risk assessment;
  - Design traffic loading;
  - Selection of pavement structural evaluation and design method;
  - Identification of uniform sections along the route;
  - Identification of test positions to determine in-situ bearing capacity;
  - Identification of material sources if required;
- Phase 1B: Concept Development – Detailed Assessment;
  - Testing of the Inherent bearing capacity of identified uniform material sections;
  - Processing of data to determine the inherent bearing capacity;
  - Determine applicable strengthening options for a life-cycle cost comparison;

- Phase 2A: Preliminary design;
  - o Development of the approved applicable pavement design option;
  - o Detailed materials testing and stabilisation tests where recommended;
- Phase 2B: Detailed design;
  - o Finalise design specifications and Bill of Quantities (BOQ).

This chapter only deals with the testing, evaluation and design of the pavement structure. Detailed material testing for the recommended stabilising agent is addressed in **Chapter 6**, and the selection and design of applicable surfacings are addressed in **Chapter 7**. Recommended "End Product Specifications" are addressed in **Chapter 9**.

5.3 Phase 1A – Concept Initial Assessment

The purpose of this phase is to become familiar with the environment and to obtain and evaluate all available information to proceed with detailed surveys and testing for design. This design phase in conjunction with the geometric design and drainage design is summarised in Figure 9.

5.3.1 Category of road and risk assessment

Roads identified to be upgraded to a surfaced standard, are normally defined as Category D and E roads (TRH26) in line with the approach followed in regions such as the SADC countries (SATCC, 2003). Many Implementing Agencies are currently using design documents intended for higher-order roads (e.g., for Category A, B and C roads (Jordaan and Steyn, 2019)), for the upgrading of unpaved roads. Table 31 gives a risk profile recommended for the various Road Categories, based on a statistical approach to applicable standards.

Table 31 Recommended design reliability and risk profile for the various category of roads

Category of Road	Design Reliability (Percentile level)	Percentage Confidence Interval	Network level	Project level
			Accuracy: ± Percentage Error	Accuracy: ± Percentage Error
A	95	95	40	10
B	90	95	40	10
C	80	95	40	10
D	65	95	40	20
E	45	95	40	20

The design recommendations contained in this document are typically aimed at the surfacing of unpaved roads associated with Category D and E roads. It is realised that there are numerous unpaved roads currently in operation in South Africa carrying traffic volumes normally associated with relatively high traffic loadings.

The design of Category D and E roads is linked to the role of a specific route identified for upgrading as a function also of the number of vehicles and the number of trucks to be carried on these roads. The uncertainties associated with expected future developments, traffic growth rates and environmental impact on the future performance of these roads make a detailed traffic analysis on these roads of limited practical value. A simplified design and analysis approach are applicable to these roads in line with the associated risk profile of the roads and the considerable impact of the environment on the performance of these roads.

5.3.2 Design traffic loading

Environmental factors are the controlling aspect in the performance or long-term behaviour of surfaced roads with relatively low design traffic loadings (below 1 million E80s). Traffic loading measurements and future estimates for the upgrading of unpaved roads are associated with high degrees of uncertainty. It follows that more emphasis on materials resistant to environmental impact may well be a cost-effective approach to address the upgrading of unpaved roads to ensure that a required distress-free surfacing life is achieved. The incorporation of new technologies with proven resistance to environmental effects can be more effective than a detailed analysis of expected future traffic loading over the design period.

Hence, a simplified approach with regard to the design traffic loading will be more appropriate for the upgrading of unpaved roads in line with the above assessment of pavement structural distress. Table 32 provides the recommended design traffic loading for category D and E roads.

If deemed required for traffic loadings in excess of 1 million E80s, a more comprehensive analysis of the design traffic loading with an applicable sensitivity analysis can be done based on detailed guidelines contained in draft TRH16 (COLTO, 1994, draft TRH4 (COLTO, 1996) and/or draft TRH12 (COLTO, 1997).

Table 32 Number of vehicles and design traffic loadings to be considered for design purposes

Road Category	Vehicles per day	Activity along Road - Local Communities together with	Assumed Design Traffic Loading (million E80s) (MESA)
D	200 - 300	Several farming/ plantations/packhouses	3.0
		Some seasonal farming activities	1.0
E	100 - 200	Farming activities and local deliveries	1.0
		Tourism/ local deliveries	0.5
	< 100	Remote communities	0.1 - 0.3

5.3.3 Selection of a structural evaluation and design method

The empirically derived DCP evaluation and design method is identified as the most applicable design method for the upgrading of gravel roads based the inherent advantages and disadvantages of design methods applicable to relatively low design traffic loadings. It should be noted that the applicability of the DCP design method is **not** only limited to the design of LVRs and **can, with confidence, be used for the design and evaluation of pavement structures for design traffic loadings up to at least 10 million E80s (10 MESA)** (Jordaan, 1988; Jordaan et al 1990; Jordaan, 1994).

The successful implementation of the recommended DCP method is based on two factors, i.e.:

- Adequate, accurate and statistically meaningful testing and data processing, and
- Implementation of a DCP design approach that enables the basic objectives to be met with confidence.

Preceding any commissioning of a DCP survey along the length of any road, the recommended desk-top survey and preliminary geometric design need to be done as per recommended procedure. This process will ensure that the DCP survey is done in accordance with the recommended flow-diagram (Figure 9) and relevant to the analysis and assessment of the in-situ bearing capacity of the existing pavement structure as applicable and according to the preliminary identification of uniform pavement sections.

5.3.4 Identification of uniform pavement sections for a DCP survey

A simplified approach is recommended, based on the identification of the variation of materials along a route to identify uniform pavement design sections. The objective is to optimise the design while keeping complexity and costs to a minimum:

- Identify the route to be upgraded (use “Google Earth” if no formal map exists), an example of which is shown in Figure 53;
- Superimpose available Geological Maps onto the route area at the same scale to get an indication of the variability of the basic geological formations and variability of the materials that can be expected along the route;
- Superimpose available Soil Maps onto the route area in a similar way to obtain information on the weathered and transported material that can be expected near the surface, taking into account the slope of the area. A slope in excess of ± 15° will result in most of the highly weathered materials being washed downhill to lower-lying areas (as a function of the annual rainfall of an area);
- Use both the Geological Maps and Soil Maps (according to scale), to identify the variability of the materials along the unpaved road to be upgraded, and
- Visit the route and visually assess variations in materials along the route. Divide the route into “uniform material” sections using the desktop investigation as confirmation or adjustment by the visual inspection, with special attention and identification of localised potential problem areas that need to be assessed separately;
- During the site visit, all road related aspects should be identified, including:
    - Flat terrains with small streams that may be associated with floodplains and associated silt deposits that may require different treatments;
    - Rocky areas with little covering that would require the importation of material to create an acceptable water-resistant (or alternative) layer;
    - Localised, potential geological and soil problem areas, at the interface with cut-fill areas which may require additional drainage facilities;
    - Change in the colour of the in-situ materials along the length of the road is an indication of material/geology changes;
    - Identify natural or man-made obstacles that would warrant adjustments in terms of, inter alia, road widths, stormwater management, facilities for pedestrians, etc., and
- Identify test positions for DCP surveys to be performed during Phase 1B: Concept Development – Detailed Assessment within each of the identified different geology/soil/drainage (e.g., old flood plain) or topography areas along the route that may have different inherent material properties and hence, differences in bearing capacity. This also includes the identification of any localised area that may require a special provision in terms of design to prevent any premature distress.

It is clear that the physical environment plays a major role in the identification of the uniform sections along a route. This includes the:

- Topography;
- Geology;
- Soils, and
- Climatic zones and classification.

Information related to any part of the world is easily accessible through the internet. *Appendix C* contains more details regarding available detailed maps and internet links.

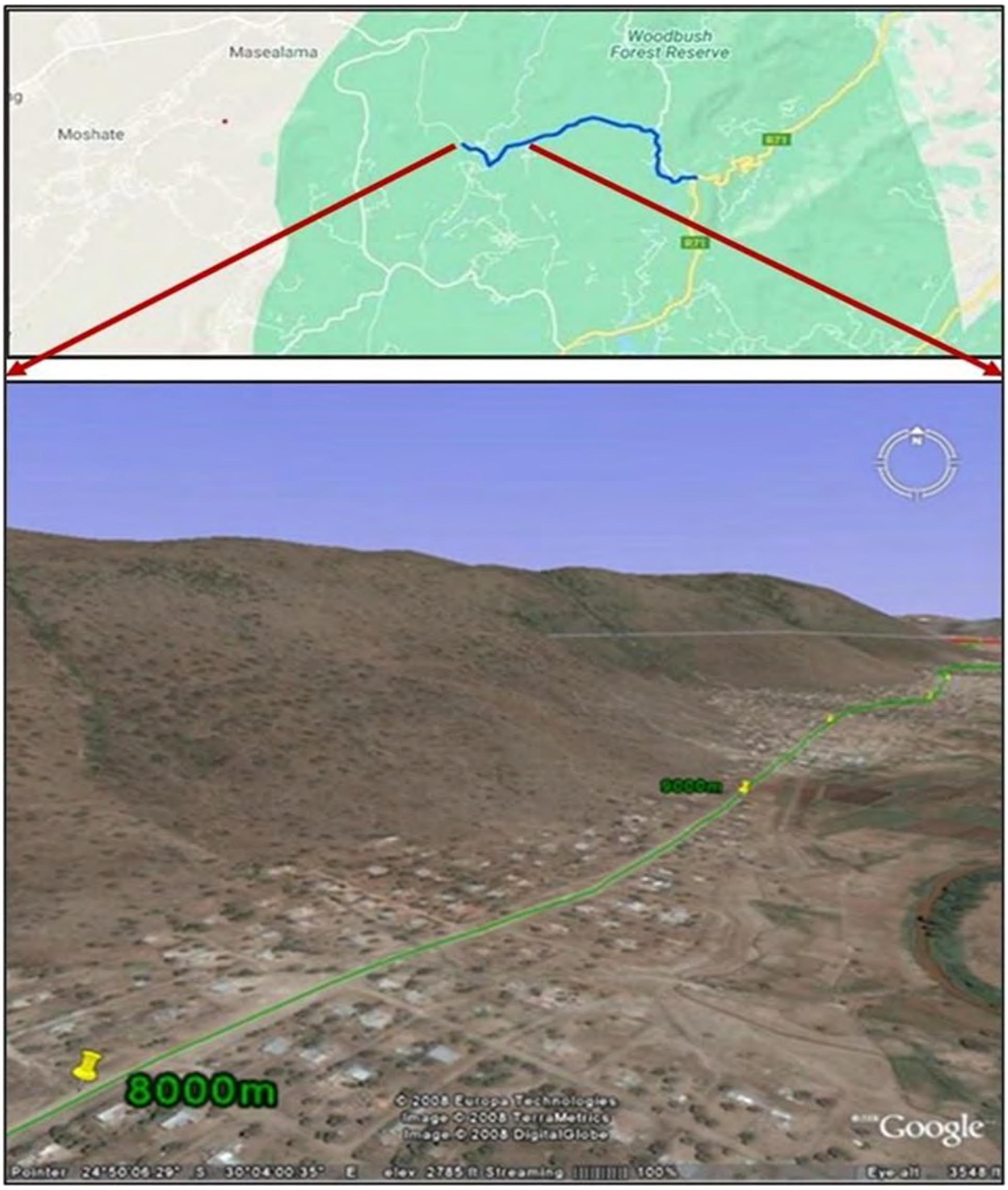


Figure 53 Example: Route mapping using available information and Google Earth

5.3.5 Identification of test positions to determine in-situ bearing capacity

The DCP survey to be commissioned should be finalised on site. After the desk-top study and initial geometric design, a site visit and visual assessment are essential and will provide inputs for the planning of a cost-effective detailed DCP survey.

The DCP survey must be carried out along the full length of the road for each of the identified uniform pavement sections. Preferably, each measurement should be done to a depth of at least 800 mm unless refusal is reached before this depth. The frequency of the DCP measurements depends on the variability in road/subgrade conditions and the level of confidence required. Where obvious changes in surface conditions occur, the frequency of the testing should be increased near the locations where the changes occur. Similarly, where surface conditions are uniform, the frequency of testing may be reduced. A simple guideline for the minimum frequency of testing for upgrading an existing unpaved road to a paved standard is shown in Table 33.

Table 33 Minimum frequency of DCP testing

Road condition	Frequency of testing (number/km) (minimum)
Uniform, fairly flat, reasonable drainage – low risk	7
Non-uniform, rolling uneven terrain, variable drainage – medium risk	10
Distressed, uneven terrain, poor drainage – high risk	20

An evaluation of the number of tests and the influence thereof on the accuracy of percentile values has been carried out. The results of this investigation gave a statistical analysis of error as a function of the number of tests on roads throughout South Africa (Jordaan, et al., 1992). The recommended number of DCP tests from this analysis is given in Table 34.

Table 34 Recommended number of DCP tests per pavement section

Accuracy %	Number of DCP tests required to determine the applicable Percentile level (P)							
	50th P	60th P	70th P	80th P	85th P	90th P	95th P	99th P
50	4	4	8	11	16	16	16	18
60	5	6	11	16	18	26	26	26
70	6	8	16	20	26	29	34	>40
80	7	16	26	>40	>40	>40	>40	>40
90	9	26	>40	>40	>40	>40	>40	>40

It follows that between 7 and 20 tests are recommended for a statistically meaningful determination of the in-situ bearing capacity along the route on each of the identified different materials and possible localised problem areas (uniform sections) for an accuracy of 80 per cent (allowable error of 20 per cent) as a function of the road category. Hence, as rounded totals, the following number of tests are recommended to obtain statistically meaningful results as a function of the road category:

- Category D Roads – 65th Percentile value - 20 DCP tests per identified materials and potential localised problem sections, and

- Category E Roads – 45th Percentile value – 10 DCP tests per identified materials and potential localised problem sections.

The number of tests should be spaced along each identified material section (the position of the testing should be verified by the engineer to be representative of the perceived weakest area of the uniform materials section, considering, for example, cut areas where the most weathered materials would have been removed at the point of the deepest cut), at a spacing not exceeding 1 test every 200 m. Hence, for long uniform material sections, the recommended number of tests will be exceeded. For short uniform material sections, the spacing will be less than one test every 200 m. In the case of identified localised pavement sections, the engineer should determine test positions across the width of the road.

DCP tests are relatively quick and easy to do and it is, in most cases, more cost-effective to increase the frequency of testing, especially if any doubt exists as to the uniformity along any section along the length of the road. Localised identified potential problems, e.g. old flood plains in the vicinity of an existing river may require testing at intervals as close as 10 to 20 m. It is preferable and in terms of the procurement of services, desirable to rather increase the frequency of testing than to remobilise for a second round of testing. All testing should be performed at places identified by the design engineer to enable the evaluation, analysis and design of each uniform pavement section to be done with confidence.

Tests staggered across the width of a road at the outer wheel-tracks (left and right) and the centreline may not have been subjected to the same traffic loading and cannot be combined for a statistical meaningful analysis. It is recommended that testing is done along the length representing the worst condition, which will statistically represent results subjected to the same influences and be representative of an identified uniform section. To gather statistically meaningful results, the minimum DCP test frequencies within each uniform section as discussed, should be considered as a minimum requirement. Hence, additional tests may be identified visually in the field. Additional tests cannot be ruled out after an initial evaluation of the results.

Care must be exercised in carrying out the DCP survey by discarding any measurements that could produce anomalous results. Such results could arise, for example, where the material is relatively coarse which will influence the variability as a function of the angle of the aggregate to the direction of penetration. In these cases, the in-situ strength as determined with the DCP tests will give abnormally higher indications of the bearing capacity of the road. Any such outliers should be removed in the final analysis of a uniform pavement sections during the processing and evaluation of the data in the following phase of the investigation as they could lead to the under-design for specific sections along the length of road.

5.3.6 Identification of material sources if required

During the Initial Assessment as part of the Concept Development phases of the design approach, any possible source of materials should be identified. Consultations with local communities along a road may give valuable information on the location of old borrow-pits. Where high resolution photographic records are available (e.g., as shown in Figure 53), old existing borrow pits can be identified during the desk study and verified in the field for testing.

5.4 Phase 1B – Concept Detailed Assessment

5.4.1 Testing of the inherent bearing capacity of identified uniform material sections

A DCP survey is initiated in accordance with the test programme prepared during the preceding Design phase, i.e., Concept Development 1: Initial Assessment. Accuracy of testing is ensured through adequate supervision during testing.

5.4.2 Processing of data to determine the inherent bearing capacity

The analysis of the DCP test results can be done automatically through the use of the freely available British funded AFCAP LVR DCP software (https://dcp-dn.csir.co.za/) for design traffic loadings **up to 1 MESA** or through the freely available EBIT-DCP software developed at the Faculty of engineering, Built Environment and Information Technology (EBIT), Department of Civil Engineering, University of Pretoria, for design traffic loadings **up to 10 MESA** (https://www.ebitpostgraduatelife-cycle.website/EBIT-DCP/index) or manually, using a simple Excel spreadsheet (South African DOT Research Report RR91/241 (Jordaan, 1994) as adapted (Jordaan and Steyn, 2020)). The approach discussed in detail is the approach incorporated in the e EBIT-DCP software. The use of the approach is demonstrated though the use a simple Excel spreadsheet.

However, the interpretation of the data and variations caused by, for instance, weak or hard interlayers or a sudden drop in strength or increase in DN values, cannot be automated. Sound engineering judgement is required to visually identify relatively strong or relatively weak testing points within any identified uniform section that can result in a high Coefficient of Variation (COV) and will negatively affect the statistical analysis of the data. Data points indicative of relatively strong localised sections should be removed from the data set within a uniform section. For practical reasons, designs cannot be changed over short sections of road and these localised strong sections will be adequately catered for within the design for any uniform pavement section.

Similarly, the DCP results from "relatively" weak localised points should be excluded from the design values over the length of identified uniform pavement sections. However, these relatively weak localised problem sections should be investigated separately to identify the cause and mechanism of the problem. Additional DCP tests at close intervals may be required on these localised weak sections to determine the extent of the problem to separately evaluate and adequately address the structural requirements of these localised relatively weak sections within a uniform pavement section. Sections along a length of road with similar characteristics can be grouped together for a single design for these sections. In-situ DCP testing and processing of the data to determine the representative DCP-DN strength for identified uniform sections along the length of the road is summarised in Figure 54.

Ultimately, the challenge of good pavement design for the upgrading of unpaved roads is to provide a pavement that is appropriate to the road environment in which it operates and fulfils its function at minimum life-cycle cost at an optimal level of service. However, positive action in the form of timely and appropriate maintenance and good drainage design will be required to ensure that the assumptions of the design phase is met over the design life of the road.

5.5 Determination of applicable strengthening options using the DCP design method

5.5.1 General

The DCP-DN approach as incorporated in the EBIT software and easily applied using an Excel spreadsheet, was derived and further developed from the initial work done at the Koedoespoort laboratory of the now Gauteng Province Department of Roads and Transport (GPDRT) (Kleyn, 1975;

Kleyn, 1984). Using the original Moisture Regimes (Kleyn, 1984), the approach has been correlated against the different Climatic Zones of the World (Köppen and Geiger, 1954), the Thornthwaite Moisture Index (Thornthwaite, 1848) and the Weinert N-value (Weinert, 1980) (Jordaan and Steyn, 2020).

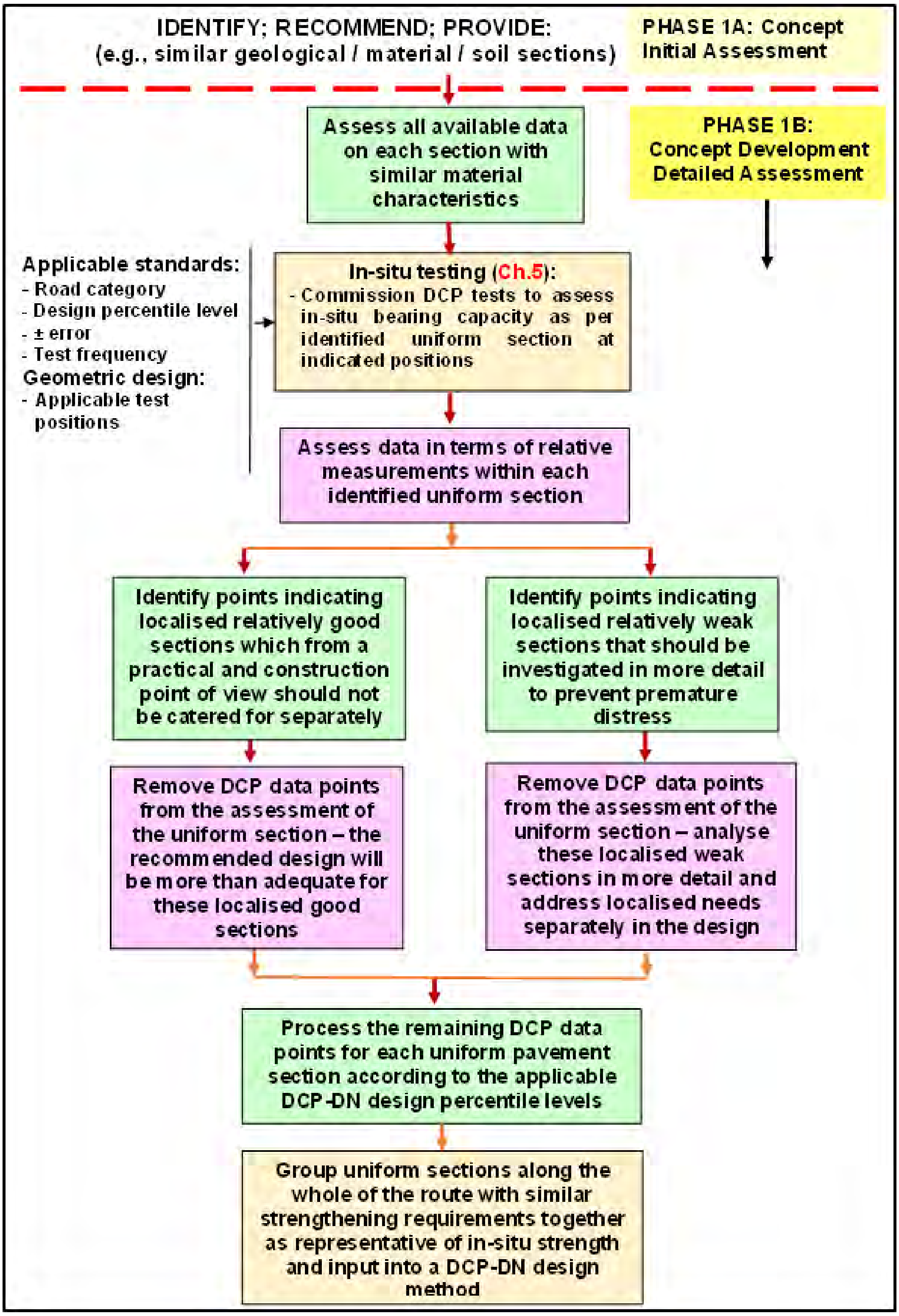


Figure 54 Summary of the process for the commission and processing of DCP tests

Applicable surfacing designs are discussed in Chapter 7 and are not addressed during the structural design for the upgrading of unpaved roads using any DCP-DN design approach. However, from work done by the Asphalt Institute (Asphalt Institute, 1962) any thickness of an asphalt surfacing can be considered to have a similar bearing capacity to double the thickness of a good granular material. Similarly, a flexible stabilised layer (e.g., a MC-NME layer) could conservatively have the same influence as 1.5 times that of a good granular material. Such considerations are easily incorporated in the method as will be demonstrated.

5.5.2 The rational of the recommended DCP-DN approach

a. Introduction

The DCP device, is used to measure the penetration rate through a gravel or soil material and provides a close approximation of only the shear strength of the material in depth as a function of the DCP-DN value in depth. It is used for the assessment of the in-situ shear-strength properties of granular materials and/or lightly cemented materials as an indication of the existing in-situ bearing capacity. In essence, the aim is to ensure that the shear strength of the pavement structure in depth is not exceeded by the required shear stress for the design traffic loading as influenced by the climatic zone applicable to the road under investigation.

The philosophy behind the DCP-DN method is to achieve a balanced pavement design when any new pavement layers have to be added to the existing pavement structure, whilst optimising the utilisation of the in-situ material strength in terms of the measured properties. The fundamental basis of the method is a simplified structural number concept, similar to most design methods in use internationally. This optimal design is achieved by:

- Determining the in-situ strength profile of the existing pavement structure using an adequate, accurate and statistically meaningful number of tests;
- Determine the design strength profile needed for the estimated design traffic loading for comparison with the in-situ measurements, and
- Comparing the in-situ pavement profile with the required structural requirements.

The basic approach of the DCP pavement evaluation and design method is shown in Figure 55.

The DCP measures the rate of penetration through an existing pavement structure at the prevailing in-situ moisture content and density of the pavement layers at the time of testing. Any existing pavement structure has been subjected to numerous seasons and climatic changes and unless under extreme conditions, has reach an equilibrium condition in depth. Areas subjected to seasonal rainfall will show higher moisture conditions in the top part of the pavement. However, this excess moisture can be expected to evaporate within a period of two weeks. With the upgrading of unpaved roads, the materials in the pavement structure will be protected from the effect of water-ingress and will operate (with timeous periodic maintenance at an equilibrium moisture condition (tested at about 60 per cent of the Optimum Moisture Content (OMC)). The subgrade moisture can usually be associated with the Climatic zone over the design life of the pavement structure and is adjusted for by the incorporation of a Climatic Factor (C_f) similar to the original DCP design method as discussed.

DCP measurements done under wet conditions will be adversely affected by the ingress of water. In such cases, the true potential of the materials in the top of the existing pavement structure can be determined in a laboratory at the anticipated long-term (equilibrium) moisture conditions in each uniform section.

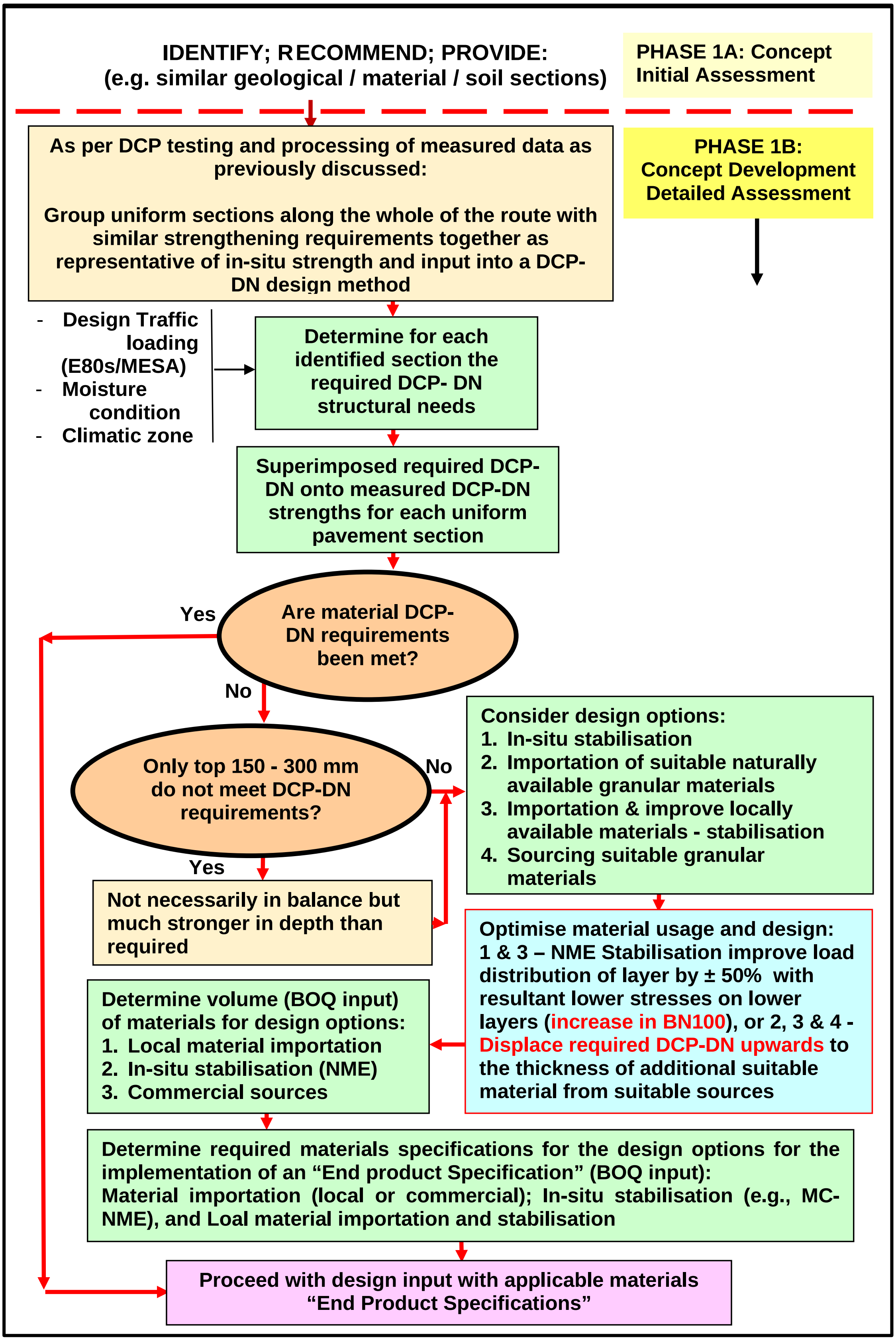


Figure 55 Basic concepts of the recommended DCP-DN design method

The laboratory testing will provide a measure of the sensitivity of the materials to moisture and density variations and can give the designer a good understanding of the material properties and the use of the in-situ material in the design for the upgrading of the unpaved road in each uniform pavement section.

Each DCP test along the road provides a profile through the depth of the pavement, which gives an indication of the in-situ properties of the materials in each pavement and material layer down to a minimum depth of 800 mm at the time of testing, as illustrated in Figure 56 in which the DCP-DN profiles for three uniform pavement sections along a road are shown.

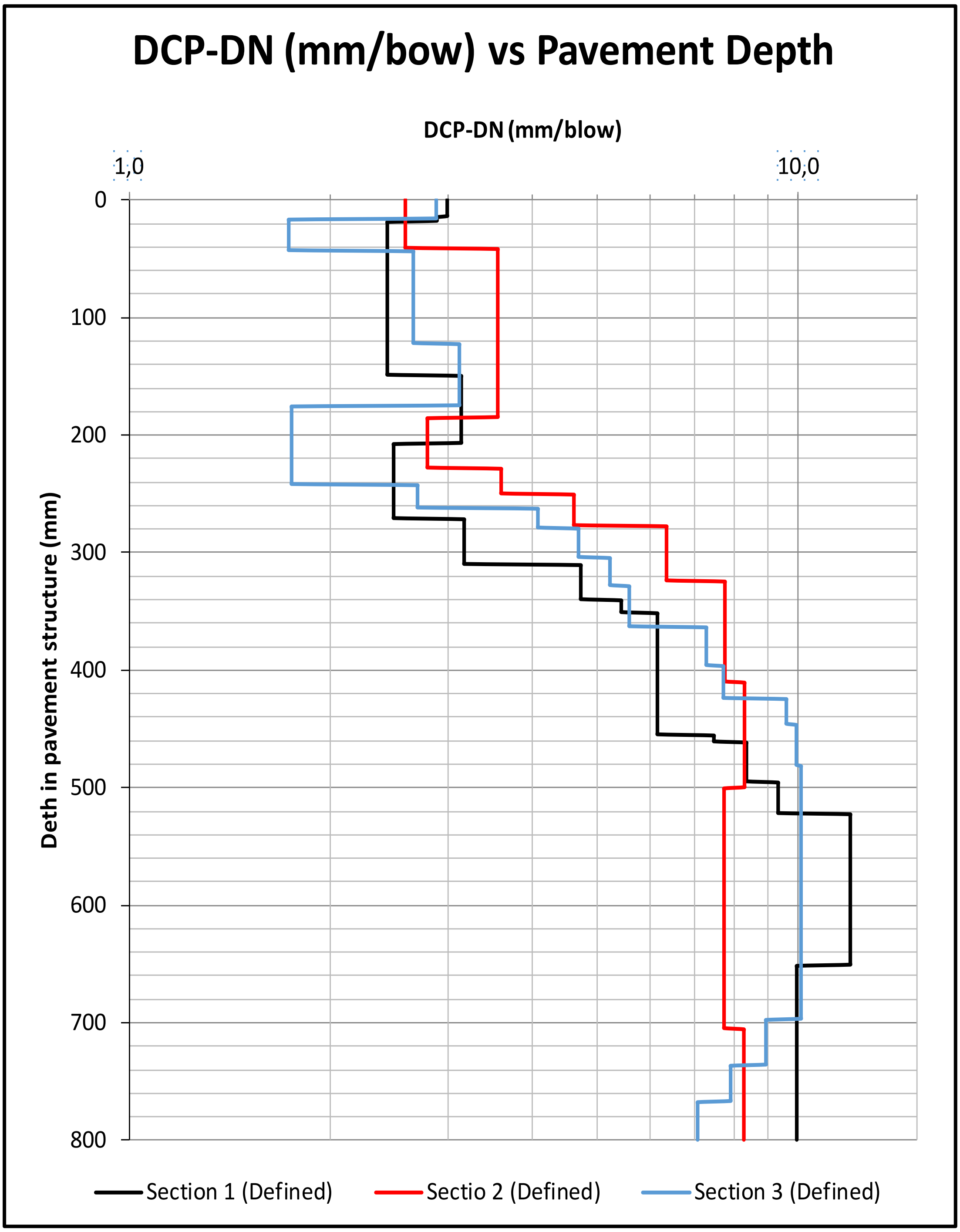


Figure 56 Typical profile of actual DCP-DN values with depth

The DCP Structure Number (DSN) is the number of DCP blows required to penetrate a pavement structure or layer to a specified depth. This DSN value allows the bearing capacity of different pavements to be compared. Accordingly, the DSN_{800} is the number of blows required to penetrate the pavement to a depth of 800 mm. However, it should be noted that the use of a DSN_{800} approach as an indication of the structural bearing capacity is generally only accurate when the pavement structure remains well-balanced. Material properties at any depth still need to meet the minimum required DCP-DN values for the design traffic loading and climate.

Pavement strength/balance is a fundamental feature of the DCP-DN method in which the strength balance of a granular pavement structure is defined as the change in the strength of the pavement layer with depth. A well-balanced pavement structure is one in which the strength of the pavement layers decreases progressively and smoothly with depth from the surface without any significant discontinuities, typically with a balance curve of 35 to 45 (i.e., 35 to 45 per cent of the DCP-DN values within the top 100 mm on the pavement structure). This approach is in line with basic pavement engineering aimed at protecting the sub-grade with an increase in the strength profile of the materials up to the surfacing of the road.

b. Basic principles of the in-situ structure evaluation based on load distribution in depth

Pavement structures are constructed in layers due to practical considerations. However, any load applied to the surface is distributed as a function of the properties of the materials and the ability of any material to reduce the stresses at any point in depth within the pavement structure. It follows, that the material at a certain depth within a pavement structure will lead to a reduction of the stresses in-depth, irrespective of any layer thickness, as demonstrated in Figure 57.

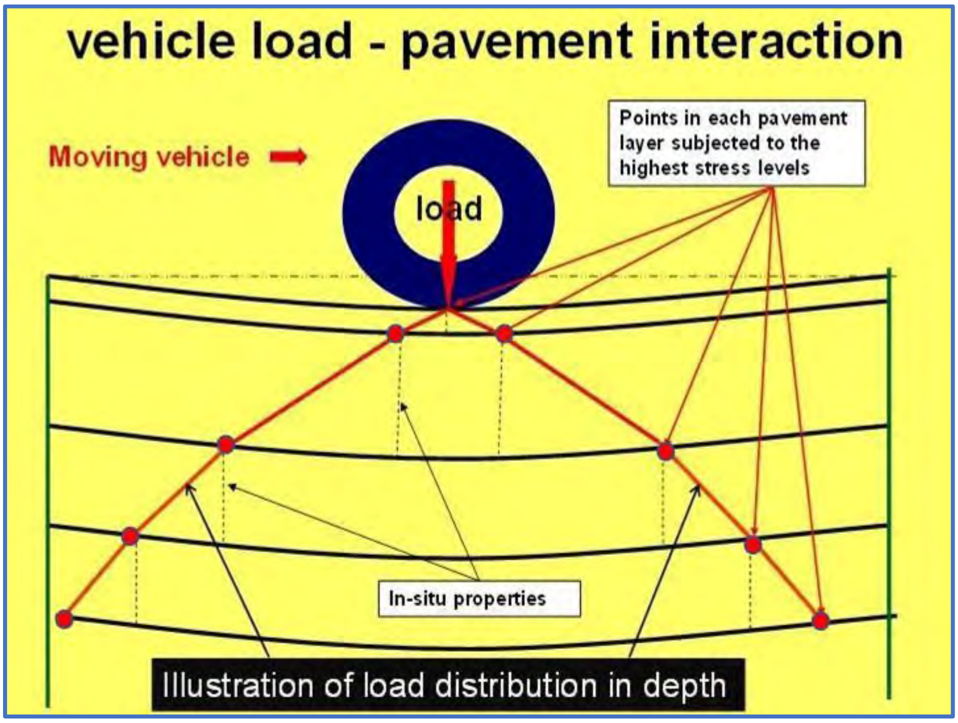


Figure 57 Illustration of the load distribution in depth in a pavement structure

Any in-situ pavement structure or in-situ gravel structure can be evaluated in terms of the load distribution in depth, irrespective of any original layer thicknesses (or not), to evaluate the in-situ bearing capacity (as shown by the solid red lines in depth in the pavement structure). The material characteristics (in terms of the DCP-DN values), associated with these critical points (indicated by the red dots at the top of any layered structure in Figure 57) within a pavement structure, need to be able to withstand the impact of the traffic loading associated with the design period, preventing excessive distress occurring in terms of the distress parameters embedded in the empirically derived method.

Based on the principles shown in Figure 57, the original design curves (Kleyn, 1975) were analysed deriving the following variables as input:

- Design Traffic loading in Million Equivalent Standard Axles (MESA);
- Depth at the top of the layer thicknesses used for evaluation for each design traffic loading, and
- DCP-DN critical values at the top of the pavement layers associated with the depth within the pavement structure for the recommended traffic loading.

A best fit between these variables resulted in the derivation of the following relationship (Jordaan, 1994), applicable up to **10 MESA**, with an associated pavement balance curve shown in Figure 58:

$$Depth = 194\ Log(Design\ traffic\ loading) + 457\ Log(DCP - DN) - 1285 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5.1)$$

Where:

Depth	=	Depth within the pavement structure in mm
Design traffic loading	=	Accumulated traffic loading over the design period in MESA (E80s) (required bearing capacity)
DCP-DN	=	Required DCP-DN at any depth in mm/blow

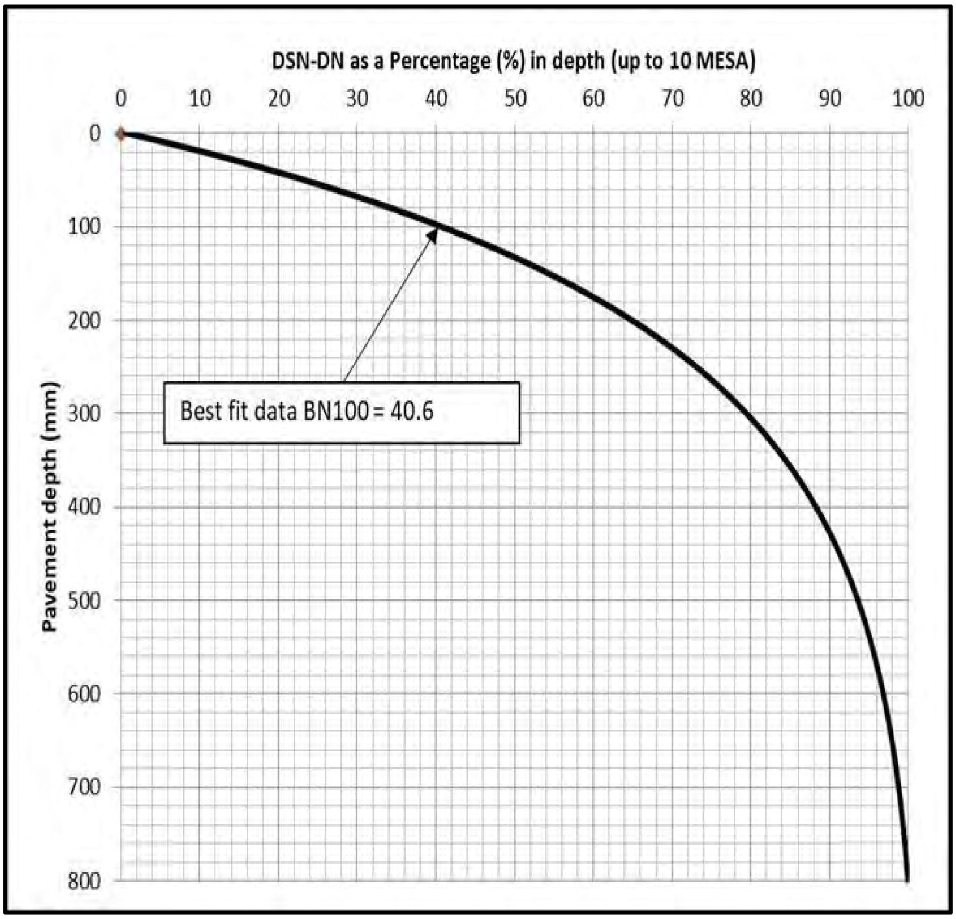


Figure 58 DCP-DN balance curve derived from Equation 5.1

The pavement balance curve shown in Figure 58 is a function of the main input values of the DCP-DN design method as contained in Equation (5.1), i.e., the:

- Design traffic loading in E80s (MESA),
- Depth within the pavement structure, and
- Required minimum DCP-DN value of the materials at that depth.

c. Adjustment for the required DCP-DN values for the different "Climatic Zones of the World"

The original DCP-DN design developed by Kleyn (1984), provides for 4 different Moisture Regimes for adjustment of the bearing capacity of a pavement structure, i.e.:

- M1 -Dry;
- M2 - Optimum;
- M3 – Wet, and
- M4 - Saturated.

The Moisture Regimes are correlated with the Köppen-Geiger Climatic Zones of the World (generally recognised by Meteorologists throughout the World), the Thornthwaite Moisture Index and the Weinert N-value (recommended for use by pavement engineers in South Africa as best representing granular material weathering patterns). The correlation between these different indices is given in Table 35 (Jordaan, 2019; Jordaan and Steyn, 2020).

The Climatic Adjustment Factor ($\acute{C}_f$) is incorporated in the required DCP-DN value in depth by the adjustment of Equation (5.1) to Equation (5.2) (Jordaan, 2019; Jordaan and Steyn, 2020) as follows:

$$Depth = 194\ Log(Design\ traffic\ loading) + 457\ Log((\acute{C}f)(DCP - DN)) - 1285 \qquad (5.2)$$

or

$$DCP - DN = \left(\frac{1}{\acute{C}f}\right)\left(10^{\left(\frac{Depth + 1285 - 194 Log(Design\ traffic\ loading)}{457}\right)}\right) \qquad (5.3)$$

Where:

DCP-DN = required (design) DCP-DN in depth in mm/blow as a function of the design traffic loading;

$\acute{C}_f$ = climatic adjustment factor, with:

- Ćf = 0.75 for M1 region (dry) – Arid;
- Ćf = 0.90 – Semi Arid;
- Ćf = 1.00 for M2 regions (Optimum) – Temperate;
- Ćf = 1.10 – Temperate Wet;
- Ćf = 1.25 for M3 regions (Wet) – Wet-humid;
- Ćf = 1.35 – Sub-Tropical, and
- Ćf = 1.50 for M4 regions (Soaked) – Tropical Monsoon.

For a more detailed adjustment of the required bearing capacity in-depth, Table 35 should be used in combination with the various climatic indicators.

The effect of the Climatic Adjustment Factor ($\acute{C}_f$) on the required bearing capacity of a pavement structure is shown in Figure 59 for a design traffic loading of 0.5 MESA.

Table 35 Recommended Climate Adjustment Factors (Cf) (Jordaan and Steyn, 2020)

Adjusted Moisture Regimes	Climatic Adjustment Factor (C_f)	Climatic Zones of the World (Köppen, 1923)*	Thornthwaite's * Moisture Index	Weinert N-value
M1A: (Dry) - Arid	0.75	Bwh; Bwk	< - 40	> 10
M1B: Semi-Arid	0.90	Bsh; Bsk	-20 to -40	5 - 10
M2A: (Optimum) - Temperate	1.00	Csa; Csb; Cwa; Cwb	-20 to 0	2 - 5
M2B: Temperate-Wet	1.10	Csc; Cwc	0 to 20	< 2
M3A: (Wet) - Wet-humid	1.25	Cfa; Cfb; Cfc	20 to 60	
M3B: Sub-Tropical	1.35	Aw; As	60 - 100	
M4: (Soaked) - Tropical /Monsoon	1.50	Af; Am	> 100	

***These recommendations are not exact as the Climatic factor calculations, Thornthwaite's Moisture Index and Weinert N-value are not based on the same assumptions and data inputs

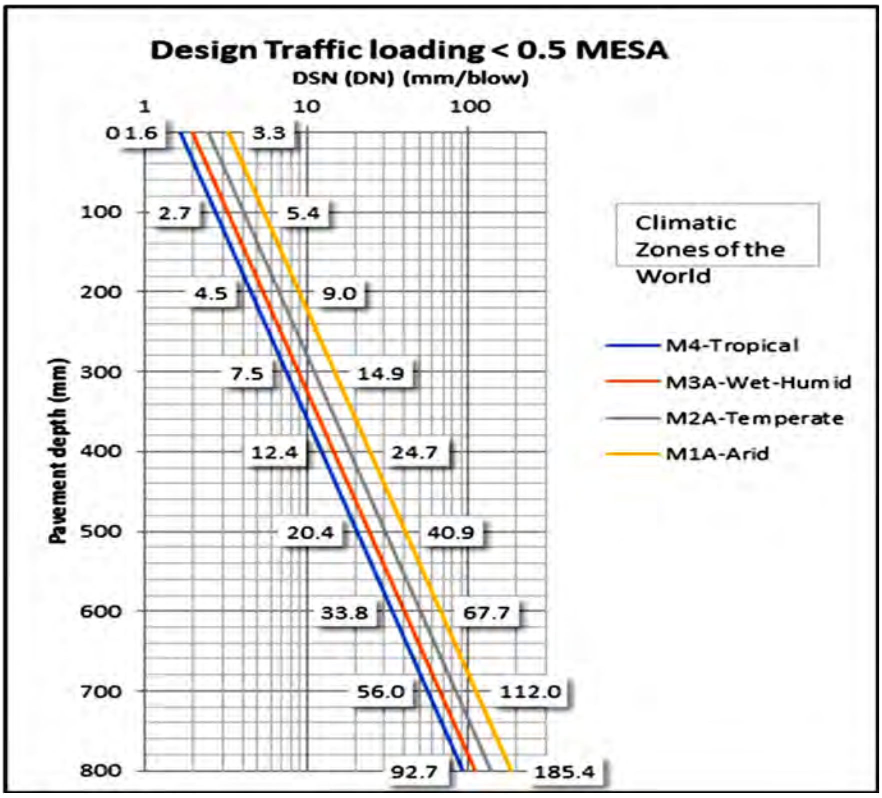


Figure 59 Effect of required design DCP-DN values with the Climatic adjustment Factor (Cf)

d. DCP DN design procedure – basic inputs

The following steps are required for the DCP-DN design approach recommended and contained in this document:

Step 1:

Determine applicable road risk profile (Chapter 5.3.1).

Step 2:

Determine the design traffic load over the design period (Chapter 5.3.2).

Step 3:

Determine uniform sections (Chapter 5.3.4) and commission a DCP survey.

Step 4: Determine in-situ DCP-DN properties per uniform section:

It is considered essential to analyse the DCP test points (after eliminating localised good test points and localised weak points (refer Figure 54), in detail (*for each mm*) to identify variations in depth within the structure that is being analysed, in terms of the measured DCP-DN values as calculated. This can easily be done using a simple Excel spreadsheet (or the freely available EBIT software), calculating the recommended applicable percentile value for the road category under investigation, an example of which is shown in Table 36.

The differences between a detailed analysis (per mm) of the measured data and an approach based on pre-assumed layer thicknesses for the evaluation of in-situ DCP-DN data along a uniform section of road are illustrated in Table 36, showing the results of the achieved results from actual measurements taken along a uniform pavement section.

Step 5: Determination of in-situ bearing capacity in depth

With the detailed processed DCP-DN data available for each uniform section readily available in a spreadsheet, the in-situ bearing capacity of the in-situ structure can be calculated using Equation (5.1) to derive Equation (5.4) as follows:

$$Depth = 194\ Log(Design\ traffic\ loading) + 457\ Log((Ć f)(DCP - DN)) - 1285 \ldots\ldots \quad (5.2)$$

Conversed to:

$$In - situ\ bearing\ capacity = 10^{\left(\frac{Depth + 1285 - 457\ Log\ ((Ć f)(DCP - DN))}{194}\right)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5.4)$$

Where:

In-situ Bearing capacity	= DCP-DN related bearing capacity in depth in E80s;
Depth	= depth in pavement structure in mm
DCP-DN	= processed percentile value of DCP tests in mm/blow
$Ć_f$	= Climatic adjustment factor (Table 35)

Data could be processed to determine the in-situ bearing capacity in depth for each mm within the pavement structure. A comparison of the in-situ bearing capacity of the top 25 mm of the data shown is given in Table 36 and displayed in Figure 60.

Table 36 Abbreviated example of the detailed Excel analysis of the measured DCP-DN

Tests	N1	N2	N3	N4	N5	N18	N19	N20	N21			0,385
Depth	Blow/(	Blow/mm	Blow/mm	Blow/mm	Blow/mm	Blow/mm	Blow/mm	Blow/mm	Blow/mm	Mean	SDEV	65 P
1,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,0	0,1
2,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,0	0,1
3,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,0	0,1
4,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,0	0,1
5,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,0	0,1
6,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,0	0,1
7,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,0	0,1
8,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,0	0,1
9,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,0	0,1
10,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,0	0,1
11,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,0	0,1
12,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,0	0,1
13,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,0	0,1
14,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,0	0,1
15,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,0	0,1
781,0	4,6	8,4	1,2	4,0	3,0	2,4	6,0	4,0	10,0	5,5	2,9	6,6
782,0	4,6	8,4	1,2	4,0	3,0	2,4	6,0	4,0	10,0	5,5	2,9	6,6
783,0	4,6	8,4	1,2	4,0	3,0	2,4	6,0	4,0	10,0	5,5	2,9	6,6
784,0	4,6	8,4	1,2	4,0	3,0	2,4	6,0	4,0	10,0	5,5	2,9	6,6
785,0	4,6	8,4	1,2	4,0	3,0	2,4	6,0	4,0	10,0	5,6	2,9	6,7
786,0	4,6	8,4	1,2	4,0	5,4	2,4	6,0	4,0	10,0	5,7	2,8	6,8
787,0	4,6	8,4	1,2	4,0	5,4	2,4	6,0	4,0	10,0	5,7	2,8	6,8
788,0	4,6	8,4	1,2	4,0	5,4	2,4	6,0	4,0	10,0	5,7	2,8	6,8
789,0	3,2	8,4	1,2	4,0	5,4	2,4	6,0	4,0	10,0	5,6	2,9	6,7
790,0	3,2	8,4	1,2	4,0	5,4	2,4	6,0	4,0	10,0	5,6	2,9	6,7
791,0	3,2	8,4	0,8	3,2	5,4	2,4	6,0	4,0	10,0	5,3	2,6	6,3
792,0	3,2	8,4	0,8	3,2	5,4	2,4	6,0	4,0	10,0	5,3	2,6	6,3
793,0	3,2	8,4	0,8	3,2	5,4	2,6	6,0	4,0	10,0	5,3	2,6	6,3
794,0	3,2	8,4	0,8	3,2	5,4	2,6	6,0	4,0	10,0	5,3	2,6	6,3
795,0	3,2	8,4	0,8	3,2	5,4	2,6	6,0	4,0	10,0	5,2	2,7	6,3
796,0	3,2	8,4	0,8	3,2	5,4	2,6	6,0	4,0	10,0	5,2	2,7	6,3
797,0	3,2	8,4	0,8	3,2	5,4	2,6	6,0	4,0	10,0	5,2	2,7	6,3
798,0	3,2	8,4	0,8	3,2	5,4	2,6	6,0	4,0	10,0	5,2	2,7	6,3
799,0	3,2	8,4	0,8	3,2	5,4	2,6	6,0	4,0	10,0	5,2	2,7	6,3
800,0	3,2	8,4	0,8	3,2	5,4	2,6	6,0	4,0	10,0	5,2	2,7	6,3

Note: Measurements of some of 21 DCP tests done to a depth of 800 mm on a Category D Road (Applicable Percentile value = 65)

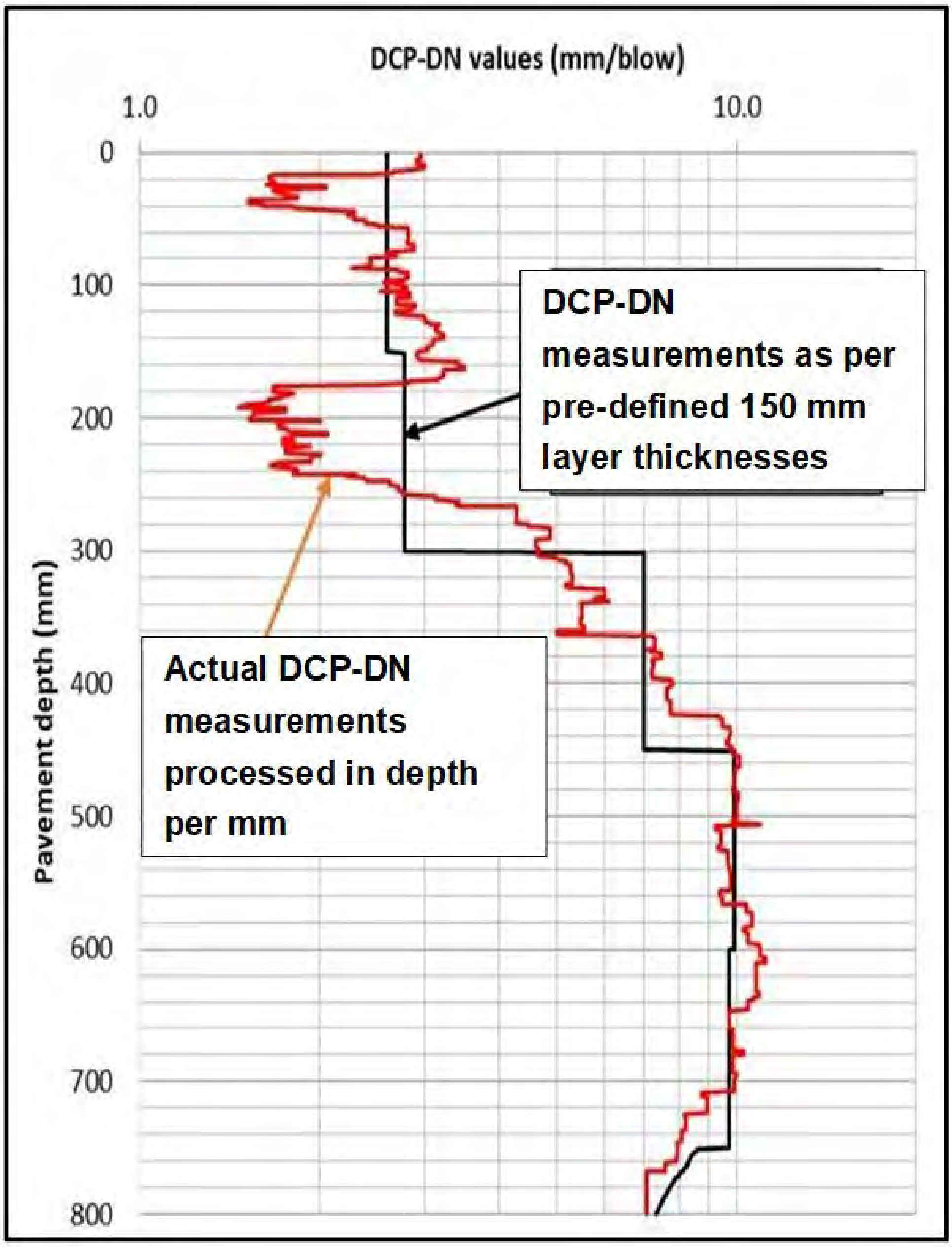


Figure 60 Differences in different approaches for the processing of DCP-DN data

Table 36 also shows a comparison in bearing capacity of the calculations done using a statistical approach for each mm in depth (red line in Figure 60 compared to the average penetration of a 150 mm assumed layer (black line in Figure 60). The differences in the results for a design traffic loading of 1 million E80s (1 MESA) are highlighted in the green colours (adequate bearing capacity) and pink (inadequate bearing capacity) for the top 25 mm of the pavement structure only.

The calculated in-situ bearing capacity of the data in Table 37 in-depth is shown in Figure 61 (black line). The calculated in-situ bearing capacity can now be compared with any design traffic loading. For example, the design traffic loading of 3.0 million E80s (red line) is shown in Figure 61 . Any materials in depth within the pavement structure with inadequate bearing capacity are now easily identifiable as an input into design considerations.

Table 37 In-situ bearing capacity of the top 25 mm of the pavement structure

Depth (mm)	Processed DCP-DN as measured (mm/blow)	In-situ bearing Capacity (MESA)	DP-DN averaged over 150 mm (mm/blow)	In-situ bearing Capacity (MESA)
0	3.0	0.33	2.60	0.44
1	3.0	0.33	2.60	0.45
2	3.0	0.33	2.60	0.45
3	3.0	0.34	2.60	0.46
4	3.0	0.34	2.60	0.47
5	2.9	0.36	2.60	0.47
6	2.9	0.36	2.60	0.48
7	2.9	0.37	2.60	0.48
8	2.9	0.37	2.60	0.49
9	3.0	0.35	2.60	0.49
10	3.0	0.36	2.60	0.50
11	3.0	0.37	2.60	0.51
12	3.0	0.37	2.60	0.51
13	2.9	0.42	2.60	0.52
14	2.7	0.50	2.60	0.52
15	2.7	0.50	2.60	0.53
16	2.3	0.68	2.60	0.54
17	1.7	1.54	2.60	0.54
18	1.7	1.60	2.60	0.55
19	1.7	1.62	2.60	0.56
20	1.7	1.62	2.60	0.56
21	1.7	1.64	2.60	0.57
22	1.7	1.60	2.60	0.58
23	1.7	1.62	2.60	0.58
24	1.6	1.75	2.60	0.59
25	1.9	1.25	2.60	0.60

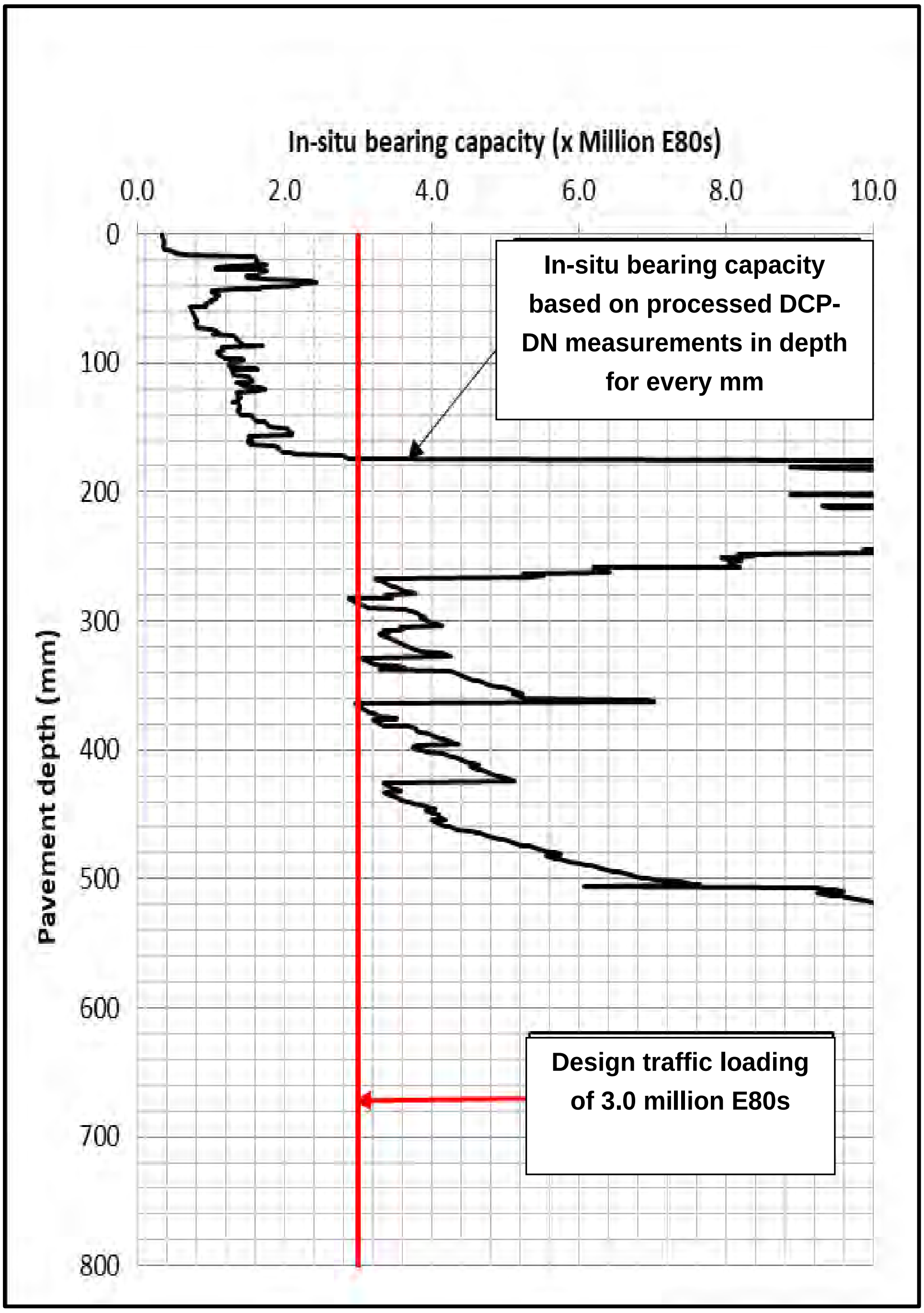


Figure 61 Example: In-situ calculated bearing capacity in E80s of the DCP-DN measured data

Step 6: Determination of DCP-DN design requirements:

To evaluate the adequacy of the measured data in terms of the recommended design method, i.e., the DCP-DN method, the minimum requirements of DCP-DN need to be determined as a function of the:

- Design traffic loading (refer to Chapter 5.3.2), and
- Applicable Climatic Zone, the Weinert N-value or the Thornthwaite's* Moisture Index (refer to Table 35) to determine the climatic adjustment factor (C_f) applicable to the road.

The required DCP-DN values in depth are easily determined using Equation (5.3). The required DCP-DN values are superimposed on the measured data to establish the materials in depth (if any), not meeting the design DCP-DN values. Figure 62 shows the design DCP requirements for design traffic loadings of 3.0 MESA and 1.3 MESA superimposed on the processed data shown in Figure 62**.**

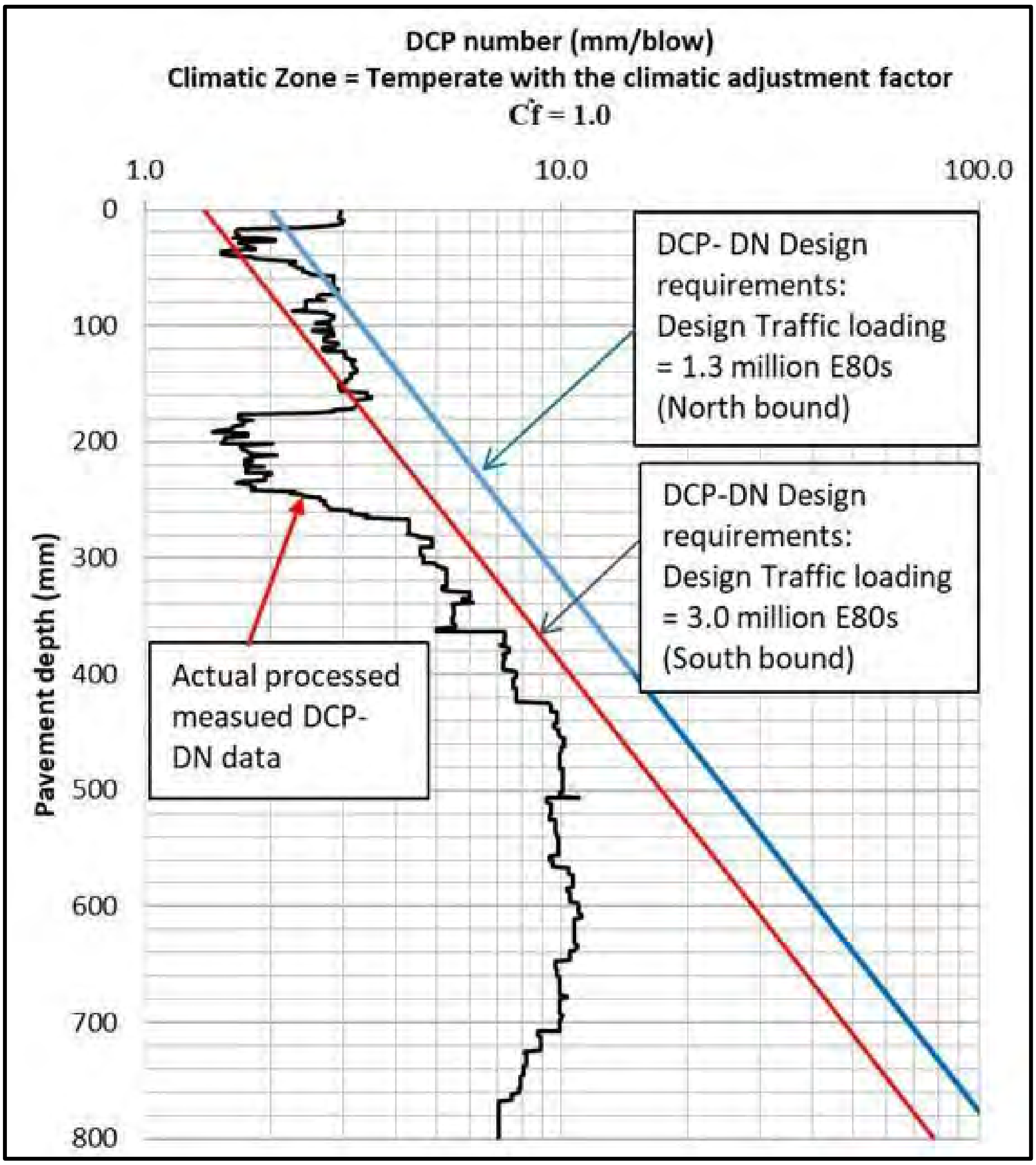


Figure 62 DCP-DN design requirements

All DCP-DN measurements in depth to the right of the applicable design line for the estimated design traffic loading do not meet the design requirements. For example, from Figure 62 it is seen that, in this case, the top 170 mm of the uniform pavement section does not meet the design requirements (in terms of DCP-DN measurements) for a design traffic loading of 3.0 MESA. Various options can now be considered by the design engineer to address the problem.

Step 7: Designing strengthening options (Refer to flow-diagram Figure 55):

The example shown in Figure 63 is used to discuss the various options available to the design engineer using this DCP-DN approach.

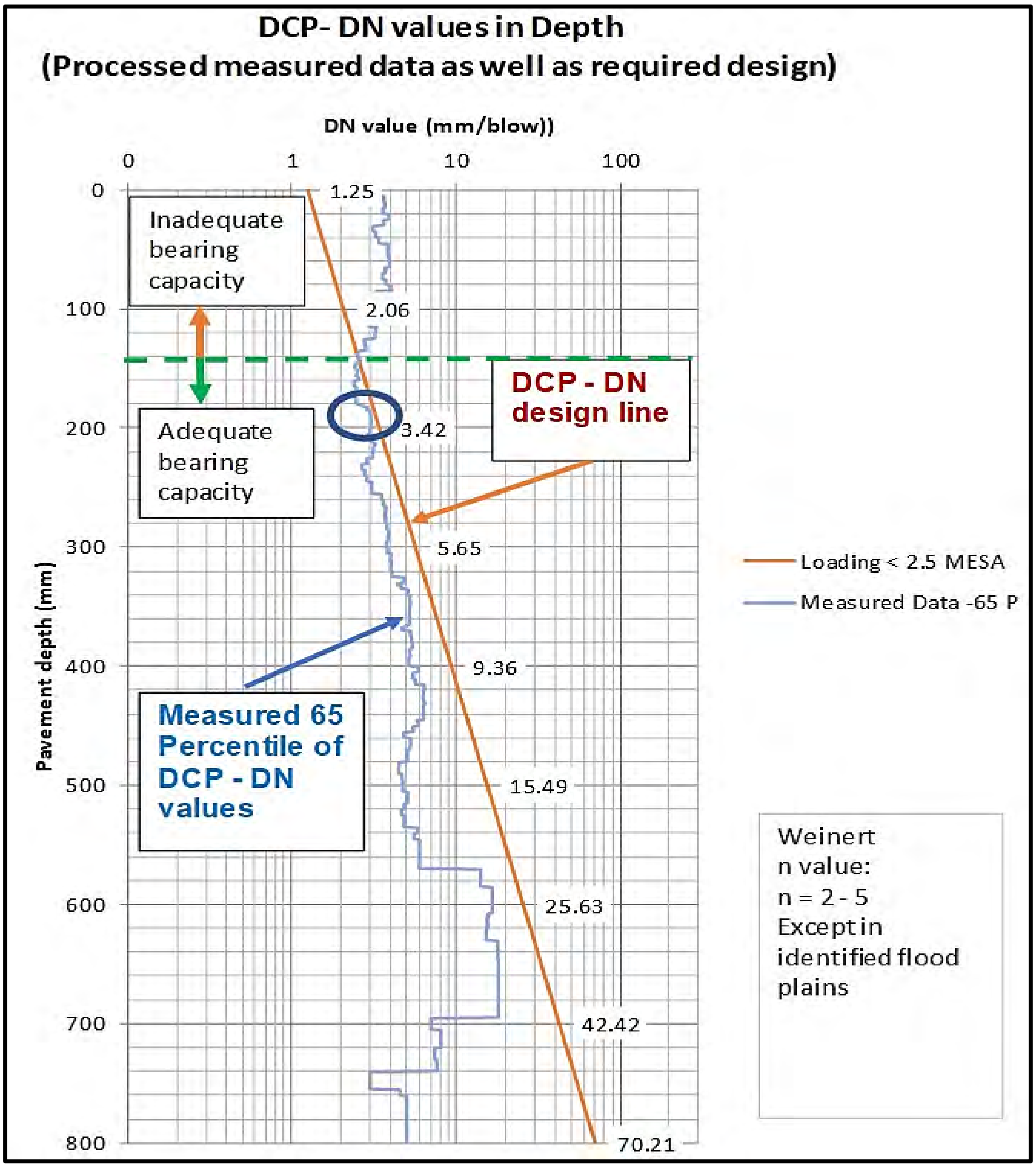


Figure 63 Example: Measured DCP-DN data superimposed on design requirements

From Figure 63 it is seen that the top 150 mm of the existing road does not meet the required design criteria. However, at a depth of between 180 mm and 200 mm (highlighted in the figure) the measured data and the required DCP-DN data almost coincide. Given the various assumptions built into the estimation of the expected design traffic loading and the general lack of historic data, this section of the pavement structure could be considered at risk.

The following design options should be considered by the design engineer:

1. Improvement of the in-situ material using an applicable stabilising agent – the required thickness will be determined taking into consideration the improved load-spreading ability of the stabilised material as discussed and shown in a following example;
2. Protection of the unsuitable top part of the road through the importation of suitable NAGM meeting the appropriate strength requirement;

3. A combination of Options 1 and 2 with the importation of naturally available materials of marginal quality, mixing and in-situ stabilisation of unsuitable thickness of the top of the road, or
4. Sourcing suitable commercial materials of a quality meeting the materials design specifications.

The effect of these options on the recommended DCP-DN approach will be as follows:

- Option 1 will result in the strengthening of the top of the pavement structure with improved load spreading abilities with more strength concentrated at the top of the pavement structure. In terms of the DP-DN design method the BN_{100} will show an increase with a displacement of the design requirements in depth;
- Options 2 and 4 will add suitable material to the existing structure with an upward displacement of the design requirements at the higher new level of the pavement structure, and
- Option 3 will be a combination of the scenarios described above.

The various scenarios as described above, are easily addressed using this DCP-DN method approach and will be addressed as identified.

Scenario 1: In-situ stabilisation increases the strength at the top of the pavement structure, effectively increasing the BN_{100}.

This approach enables the BN_{100} (percentage of strength in the top 100 mm of the pavement structure to be easily adjusted with an adjustment factor incorporated in Equation 5.5. This is achieved by multiplying the required DCP-DN values in depth below the level by a factor deemed applicable to an increase in the load-spreading ability of an applicable stabilisation agent, compatible with the in-situ available materials of inadequate DCP-DN properties. Equation 5.5 is adjusted to allow for an increase in the load-spreading ability of the stabilised material as follows:

$BN100_{adjusted}$ value (for stabilisation of material of inadequate quality):

$$DCP - DN = (\frac{BN100adjust}{40.6})(\frac{1}{Cf})(10^{\left(\frac{Depth+1285-194Log(Design\ traffic\ loading)}{457}\right)}) \quad \ldots\ldots\ldots\ldots.. (5.5)$$

Where:

DCP-DN = displacement of the required DCP-DN values below the stabilised layer;

$BN100_{adjust}$ = Adjustment of the BN_{100} as a result of the improved load distribution of a stabilised layer and hence, an appropriate increase in the BN_{100} as a result of the improvement of the load-spreading ability of the stabilised material – In fact, the BN_{100} can be adjusted upward or downward using this approach to investigate the impact of various material options, at the discretion of the pavement design engineer to allow various material options, allowing for the optimum use of naturally available materials.

For example, with an MC-NME stabilisation of the base layer, an increase in the BN_{100} value of 50 per cent (1.5 times the increase in the load-spreading ability of the stabilised granular material) can reasonably be assumed) (Asphalt Institute, 1969). Such an impact on the DCP-DN balance curve is shown in Figure 64. The effect on the required minimum design DCP-DN values is shown in Figure 65, taken from actual measurements for the upgrading of a Category D Road (65^{th} percentile values of actual measurements are shown).

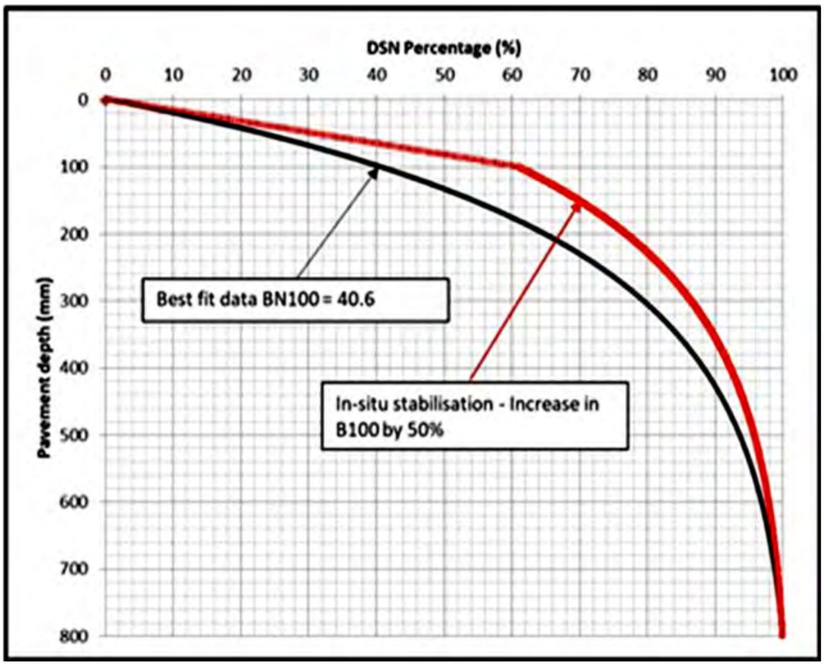


Figure 64 Effect on the DCP balance curve as a result of the BN100 increase by 50 per cent

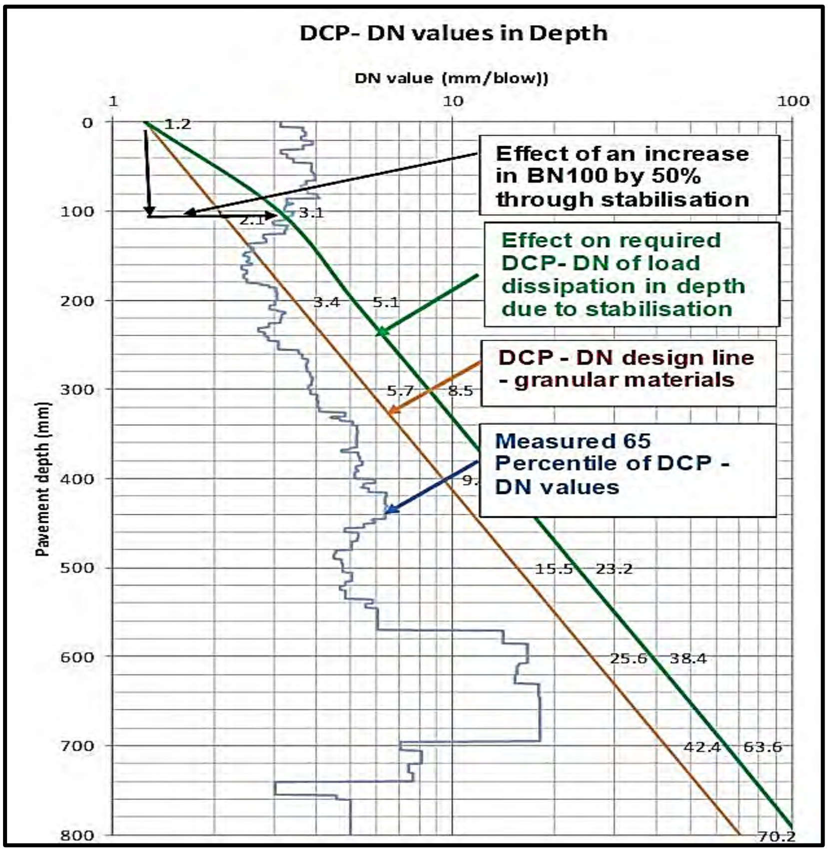


Figure 65 Example: Practical effect of the in-situ stabilisation of materials with increased load-spreading abilities

From Figure 65 it is seen that at least 120 mm of the in-situ material will have to be stabilised for the DCP-DN (adjusted) values to be met. In this example, for practical as well as structural considerations, it will be recommended that the design engineer includes volumes of materials to be stabilised to a depth of 150 mm for inclusion in the BOQ and the material properties specified in a recommended "End Product Specification" as discussed in Chapter 9.

Scenario 2: Importation of naturally available material of adequate quality or the sourcing of commercial material of adequate quality as protection of the material of inadequate quality.

In this scenario, the required design line is adjusted upwards to a height of imported material for the in-situ material to be adequate in terms of the design DCP-DN requirements. The importation of 200 mm of material of adequate quality will result in the following adjustment of Figure 63 as shown in Figure 66, which is achieved through the adjustment of the DCP-DN values by 200 mm – the "0 mm" depth now effectively becomes a depth of 200 mm. The required material properties of any additional layer in terms of DCP-DN values are the requirements at the top of the layer to be constructed.

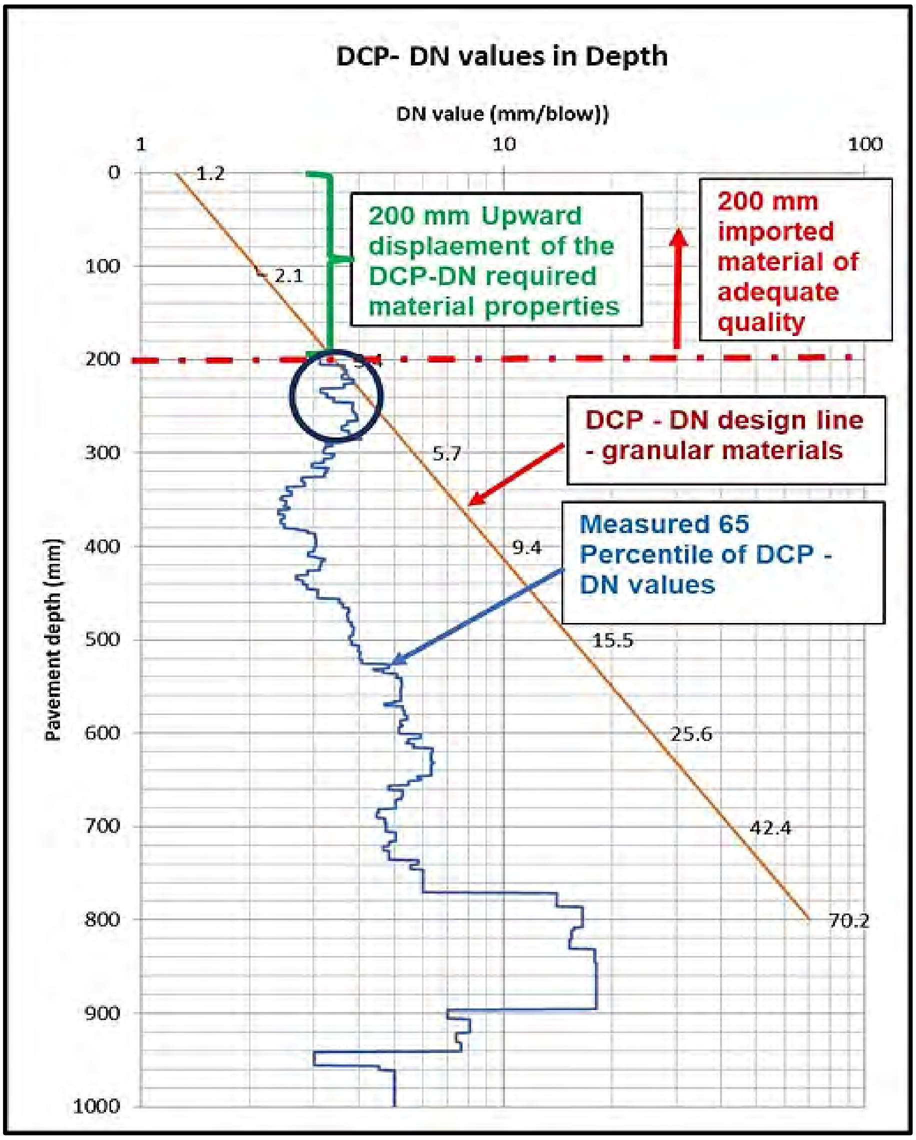


Figure 66 Example: Impact of the importation of 200 mm of adequate quality materials

***Note: Material of adequate quality**. The process of testing the adequacy of local borrow pit materials or increased density of the existing base is described in Section 5.6. It involves the compaction of materials in CBR moulds at different compaction efforts, drying out to different moisture contents and testing the DN in the central portion of the samples.*

Figure 66 shows that the importation of material of adequate quality may barely be enough to give adequate protection to the relatively poor-quality material within the top of the structure. However, the preparation of the top 100 mm and compaction of this relatively weak material may adequately address this problem. Additional material testing of the top 100 mm of the existing road may well provide the necessary confidence to recommend this as a viable option, provided material is available within reasonably close proximity to the road for importation.

A more viable alternative (depending on costs may be the importation of 100 mm of high-quality material to mix with the top relatively weak in-situ material to improve the quality to an acceptable level as shown in Figure 67. Again, the availability of high-quality material and the in-situ material properties of the top 100 mm of the in-situ material will show the viability of such an option.

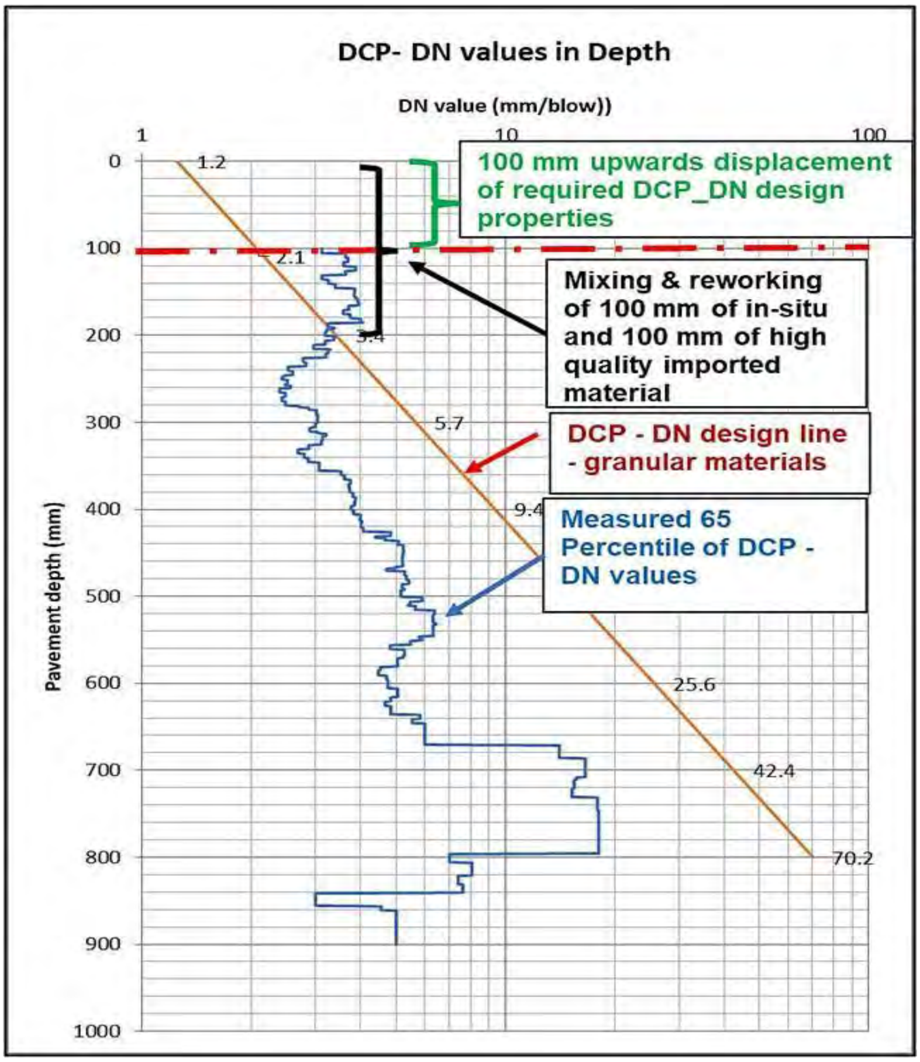
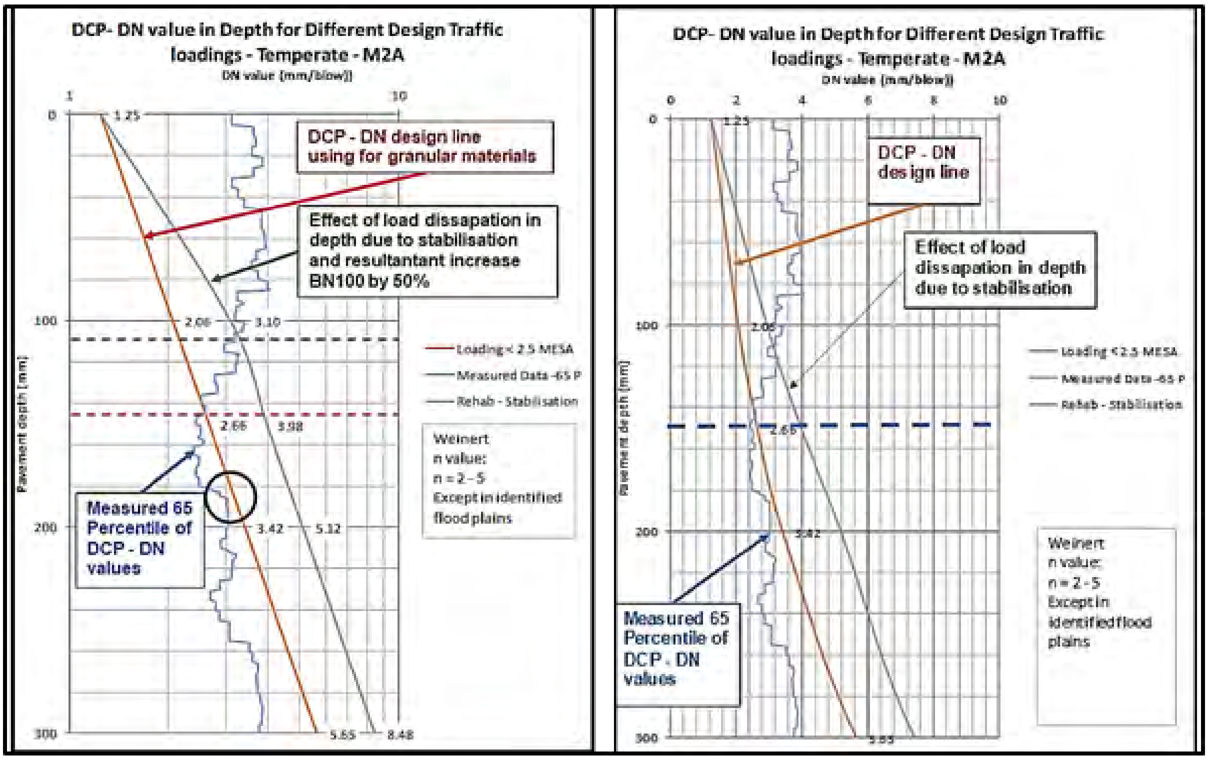


Figure 67 Example: Impact of the importation of 100 mm of high-quality material to mix with the top relatively weak material to create a 200 mm layer with adequate DCP-DN properties

Scenario 3: Combinations of Scenario 1 and 2.

From the previous discussions, it should be clear that a number of options and combinations of options are available for investigation. The duty of the designer is limited to the detailed testing of the materials, the quantification of material volumes to be improved and the identification and cost-effectiveness of the "End Product Specifications" to be met by the tenderer and his suppliers.

Following this procedure of the DCP-DN design method, all information is readily available to the design engineer. More detailed investigations on any section of the pavement structure and the impact of design considerations can easily be done within the spreadsheet. For example, the top part of the pavement section can easily be investigated in much more detail as shown in Figure 68 by simply changing the plot inputs or axis plot criteria.



(a) Top 300 mm in detail (b) Changing horizontal scale to linear

Figure 68 Example: More detailed investigation of certain aspects within the pavement

5.6 Untreated materials testing and behaviour

5.6.1 General

The optimum use of naturally occurring, unprocessed materials is fundamental to the design philosophy for the upgrading of unpaved roads to ensure that an economic design is achieved. A key objective is to match the available construction materials to the road functionality and environment. Conventional specifications tend to limit the use of many naturally occurring, unprocessed materials in the upper pavement layers in favour of more expensive crushed rock or other processed materials.

The use of the DCP-DN design method and recent developments in the use of MC-NME technologies have proven that naturally available materials (previously considered unacceptable) can be used in the upper (base and sub-base) layers of pavement structures without compromising the integrity of the road over its design period. In line with conventional design approaches, all other design aspects such as drainage facilities, quality control during construction and maintenance aspects, as discussed in other sections of this TRH, need to be adhered to.

The management of moisture during the construction and operational phases of a pavement affects its performance, especially when unbound, unprocessed, generally relatively plastic materials are used. It is therefore very clear that emphasis should be placed on minimising the entry of moisture into an LVR pavement to ensure that it operates in an unsaturated moisture content environment. The beneficial effect of doing so is illustrated in Table 38, which shows the variation of a material's strength (CBR/ DN) with moisture content in terms of the Field Moisture Content (FMC) to Optimum Moisture Content (OMC) ratio.

Table 38 Variation of CBR and DN with moisture content

Laboratory Soaked CBR (%)/DN (mm/bl)	**Approximate Laboratory Unsoaked CBR (%)/DN (mm/blow) at varying FMC/OMC Ratios**		
	1.0	**0.75**	**0.50**
80 /3.65	96/3.1	151/2.2	205/1.7
45 /5.7	69/4.1	109/2.8	148/2.2
25 /9.0	54/4.9	85/3.4	115/2.7
15 /13.5	50/5.2	79/3.6	108/2.9
10 /18.5	37/6.6	59/4.6	80/3.6

The fundamental material properties of granular materials will remain unchanged unless the operating conditions change or the material itself is modified. For example, MC-NME stabilisation (as recommended as an option for "marginal" or "unsuitable" materials and discussed in Chapter 6), results in a material with improved qualities. The inherent bearing capacity of the parent granular material is a function mainly of the mineralogy of the granular material and is often removed from conventional granular material classification systems.

All materials except quartz, but more specifically the minerals in shales and non-durable dolerites will deteriorate in quality over time due to weathering as a result of chemical decomposition in the presence of moisture. Given the basic material properties, it is possible, to examine how the strength varies with different combinations of moisture content and density at a specific time. A good understanding of how these interacting variables affect material strength is essential for assessing the adequacy of a material for a specific design scenario. Figure 69 shows a typical output of the materials assessment process described in Appendix D. However, this does not account for chemical weathering over time. Chemical weathering can be address by denying water access to all granular particles within any pavement layer.

Figure 69 illustrates how a material's strength in terms of DCP-DN measurements varies as measured in a laboratory with changes in moisture and density, given specific material properties. The gradient of the curves and the separation between the curves indicate the following about the particular material:

- The steeper the slope of the lines, the greater the sensitivity of the material's strength to changes in density (a function primarily of particle size distribution), and
- The greater the separation of the lines, the greater the sensitivity of the material's strength to changes in moisture (a function primarily of plasticity).

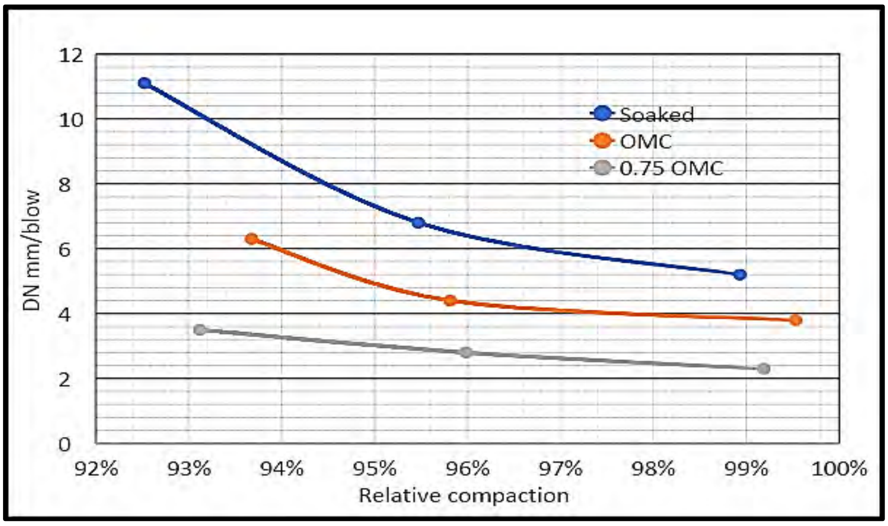


Figure 69 DN/density/moisture relationship for a single material

It follows, therefore, that acceptable:

- DN value (based on the design assumptions) represents a composite measure of the key interacting variables that affect material strength, and
- Grading and plasticity requirements are implicitly controlled by an acceptable DN value and need not be separately specified in the recommended "End Product Specifications"

From the output of the materials assessment process, the following essential design considerations will ensure the optimum use of the naturally available materials:

- Density specifications should be in line with the properties required from the material. The highest possible density specified for the material closest to the direct impact of the stresses induced by the load, i.e. in the base layer. From a practical point of view, the density achievable is partly dependent on the densities of the layer below the pavement layer that is being constructed. In practice, a density specification of more than 3 per cent between layers is not achievable.
- Experience has shown that it normally takes a newly constructed pavement about two full years to reach an equilibrium moisture condition. Appropriate measures should be adopted to keep the subgrade and pavement layer materials at a constant equilibrium moisture condition. This can be achieved by the provision of adequate drainage, both external and internal, as discussed previously and through routine and periodic maintenance. The use of a MC-NME stabilising agent could ensure that the moisture susceptibility of pavement layers so treated is considerably reduced.

5.6.2 Material sampling and testing of in-situ materials

In line with the principle of cost reduction and optimisation of naturally available materials, only materials within the existing pavement structure not meeting the design criteria in terms of the DCP-DN evaluation need to be sampled for further testing. Testing will be limited to determining the potential use of the material within the existing pavement structure as part of the analysis of the various applicable options determined from the DCP-DN evaluation of each of the uniform pavement sections along the length of the road. Materials must be sampled to be representative of the design parameters in line with the DCP-DN values as processed according to the applicable percentile values of the DCP tests done along any uniform pavement section.

Any soils that can cause foundation problems, and adversely affect the performance of roads, must be timeously identified and the necessary precautions implemented. These could cover extensive areas such as in the case of saline or expansive soils or be localised as typically in the case of dispersive soils. These soils are collectively called problem soils and include:

- Expansive soils (e.g. various types of clays);
- Dispersive soils;
- Saline soils;
- Micaceous soils;
- Low-strength soils, and
- Collapsible soils.

Conventional methods of handling such soils should be followed (e.g., Paige-Green, 2008). New available technologies (e.g. a MC-NME consisting of a Nano-Polymer Nano-Silane (NPNS)) can successfully be used with some of these materials to create an equivalent "G5" material in terms of required DCP-DN values. This treatment/stabilisation is discussed in more detail in Chapter 6.

Table 39 gives a guide to the required sample sizes for the most common soil tests applicable to LVRs. The relevant test protocol should be consulted before the collection of samples from the field

Table 39 General guide for sample size requirements for common soil tests

Test		Minimum mass required (kg)		
		Fine	**Medium**	**Coarse**
Classification	Water /moisture content	0.05	0.35	4.0
	Liquid limit	0.5	1.0	2.0
	Plastic limit	0.05	0.1	0.2
	Shrinkage limit	0.5	1.0	2.0
	Bar linear shrinkage	0.5	0.8	1.5
	Particle size distribution	0.15	2.5	17.0
Compaction	DN (per mould)	6.0	6.0	12.0
	Compaction (5 CBR moulds)		80	80
Aggregate strength	Aggregate Crushing Value (ACV)		2.0	
	Aggregate Impact Value (AIV)		2.0	
	Los Angeles Abrasion (LAA)		5 – 10	

Notes: The laboratory definitions of fine and coarse soils differ from those used for engineering soil descriptions.

Fine-grained = not more than 10% > 2 mm (incl. clay, silt and sand)
Medium grained = some > 2 mm, not more than 10% > 20 mm (incl. fine and medium gravel)
Coarse-grained = some > 20 mm, not more than 10% > 37.5 mm (incl. coarse gravel)

In cases where local granular materials would require improvement, sampling should ensure enough material is collected for the necessary testing. Material testing will require the determination of the required material properties to identify the most applicable modifying agent and the volume of the modifying agent most suitable for the specific material. To have enough material available for all laboratory testing, a minimum of 150 kg of material should be collected for testing within each of the different uniform sections.

The depth of sampling must be limited to the depth to which the material is deemed to have inadequate bearing capacity in terms of the DCP test analyses. Materials for detailed laboratory evaluation should be representative of the design percentile value of each of the identified uniform materials and road bearing capacity sections along the route. Sampling positions along the uniform sections should be identified at measuring points that closely represent the applicable percentile values of the DCP tests (DN-values) of the materials with inadequate bearing capacity.

The material should not be contaminated with material underlying the layer of material to be strengthened through in-situ stabilisation. Material properties of deeper underlying material could differ substantially from the material to be treated, resulting in a distortion of tests and incorrect conclusions and chemical application rates. If the uniform material section does not require improvement in bearing capacity, the loose material on the top of the gravel road can be compacted and treated with a high penetration diluted anionic silane-modified nano-polymer applied at 2 litres/m^2, which will serve as a prime before surfacing. Various rates of dilution should be tested in a laboratory to determine an optimum dilution. Normally, dilution rates of 1 to 5 (1-part NPNS to 5-parts of water); 1 to 10; 1 to 15 and 1 to 20 should be tested to evaluate the depth of stabilisation and the hydrophobicity achieved. This treatment can effectively be applied in practice using hand sprayers with little training required.

5.6.3 Identification of and testing of possible naturally available materials in proximity of the road project

Naturally occurring soils, gravel soil mixtures and gravels occur extensively in many parts of South Africa. These unprocessed materials are a valuable resource, as they are relatively inexpensive to exploit compared, for example, to processed materials such as crushed rock, and are often the only source of material within a reasonable haul distance of the road alignment. Thus, to minimise construction costs, maximum use must be made of locally available materials. However, their use requires a sound knowledge of their properties and behaviour in relation to the intended pavement design.

The naturally available materials and their properties are covered in detail in various publications, such as in “The natural road construction materials of southern Africa” (Weinert, 1980).and “Inventory of southern African road construction materials” (Department of Transport, 1990). Users are referred to these documents for a more in-depth understanding of the properties and use of naturally available materials for the construction of road pavement structure.

Prospecting for construction materials is aimed at ensuring that such materials are located as efficiently as possible, instead of the “haphazard or random methods” often used. The art of prospecting involves looking for clues as to the occurrence of useful materials and then digging test pits to see what may be there. Learning to identify features (e.g., landforms, botanical and animal indicators) that point to the presence of different materials from the interpretation of maps and other information is a crucial aspect of the process. The various stages in the materials prospecting process are shown in the flow chart in

Figure 70.

5.6.4 Material sampling and testing of borrow-pit materials

Sampling of borrow-pit materials for detailed laboratory testing should be done according to the minimum following volumes:

- Base: Every 5 000 m^3, and
- Subbase: Every 10 000 m^3.

There is a need to fully understand how the imported pavement materials will perform under a specific design scenario. The process to assess the performance and the risk associated with the design assumptions is essentially the same as for the assessment of the subgrade and in-situ pavement layer materials.

The approach to the evaluation of subgrade/earthworks and pavement layer materials is based on consideration of the following:

1. Knowledge of the key engineering properties of the subgrade/earthworks and pavement materials to detect those materials with deleterious properties associated with "problem soils", such as excessive swell, erodibility, or collapse potential. This is obtained from traditional field observations and classification, grading and other appropriate tests, carried out on at least two bulk samples obtained from each uniform section along the road.
2. The selection of materials in terms of acceptability for specific use in the subgrade or pavement layers is based on engineering judgment related to the results obtained from the materials tests mentions as well as the mineralogy (XRD-scans) (Jordaan and Steyn, 2019b), bearing in mind the preference for the use of locally available natural materials use for the upgrading of the unsurfaced road.

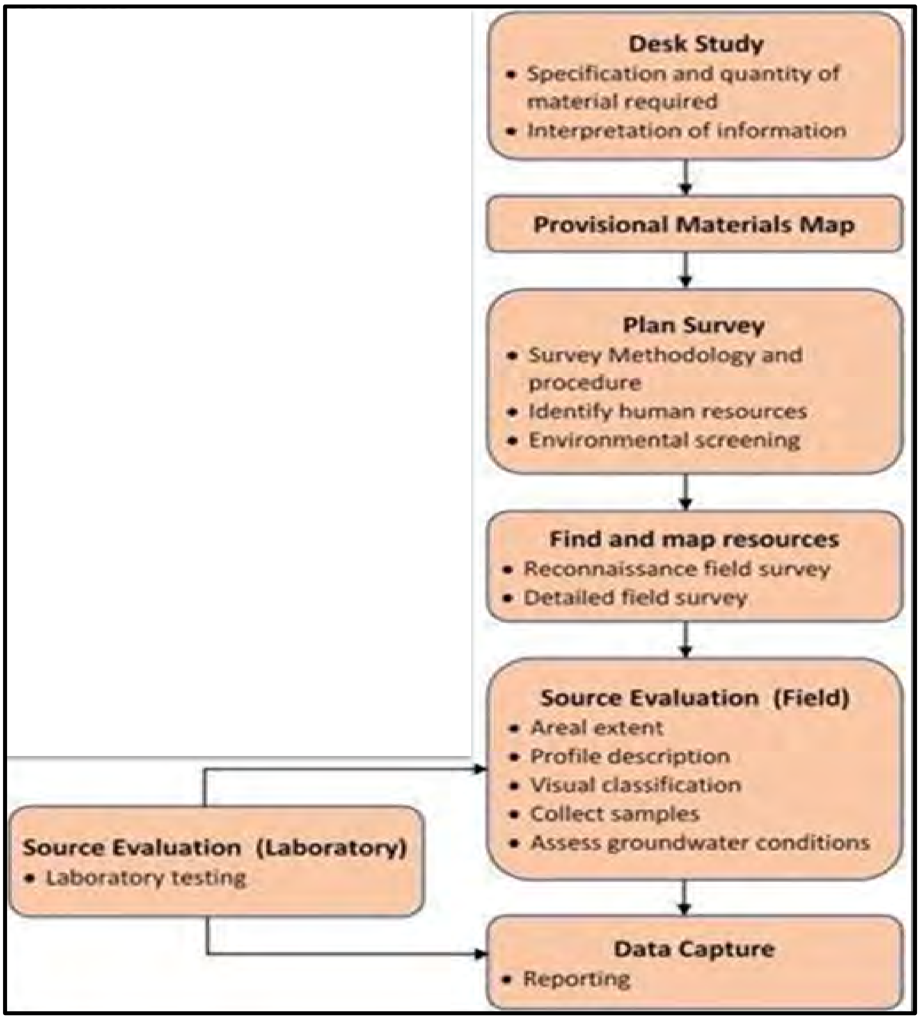


Figure 70 Flow chart showing stages in the materials prospecting process

3. Knowledge of the key parameter required in a pavement layer in terms of the shear strength of the material, which is a function of the material properties, including grading and plasticity. This parameter is strongly correlated with the laboratory DN value of the material, which is determined at the highest practicable density anticipated in the field ("compaction to refusal") and at the anticipated Equilibrium Moisture Condition (EMC) in the pavement of the upgraded road. Thus, the finally specified material selection parameter is a DN value that represents a composite measure of the key interacting variables that affect material strength, i.e., compacted density, moisture content, grading and plasticity. This approach avoids potentially suitable materials being rejected based on one or other of the traditionally specified parameters not being complied with, even though the strength, represented by the DN value, may be adequate. The selected DN value then becomes the "end product specification" irrespective of any of the other material properties.

5.6.5 Laboratory testing

The laboratory testing program is part of a wider materials investigation program to provide all of the information needed to understand the characteristics, potential use and volumes available of construction materials.

The program will comprise the following tests:

- Grading and Atterberg limits;
- Maximum Dry Density (MDD) and Optimum Moisture Condition (OMC);
- Laboratory DN, and
- Others as required (e.g. XRD-scans).

These are mostly traditional testing methods for pavement materials and are covered in various official documents (e.g., draft TRH14, 1985) and require no further discussion.

5.6.6 Materials testing

a. Materials Testing Protocols

Material specifications are based on one particular test protocol applicable to South Africa. It is thus important that the materials are tested in accordance with the relevant test protocol and that tests from different protocols are not used for the same material sample as this could lead to conflicting results and disagreement with the contractor over compliance with the specifications.

For the DCP methods of pavement design, the South African National Standards (SANS 3001) test protocols apply.

It should be noted, however, that the design methods are not affected by the soil test method as long as the proportion of material retained on the 20 mm screen is handled as per the standard method.

b. Standard Tests

Typically, the determination of the basic material properties, i.e., the material grading, Atterberg limits, compaction characteristics and strength (DN or CBR) are the primary laboratory tests. These tests shall be carried out on samples obtained from the road, typically from uniform sections determined from a DCP survey, or from proposed borrow sources to give an early indication of the potential suitability of the material.

The designer needs to be intimately familiar with the basic properties of the materials and how the material behaves under the influence of moisture at varying densities as discussed later. Determination of the grading and Atterberg Limits is, therefore, an important requirement during the early stages of the material investigation.

Standard compaction tests shall be carried out to determine the MDD and OMC of the material. Typically, at least three tests must be carried out on material from the same sample to determine the average values, which are then taken as the representative value for the particular material. It is recommended that each compacted specimen shall be penetrated with the DCP to get a measure of the DN value at the different moisture contents and densities, as illustrated in Figure 71.

The method for determination of material strength is what constitutes the fundamental difference between the conventional and the DCP DN design method described in this TRH document:

- For the DCP-DN method, the potential material strength is determined through Laboratory DN tests, as described in the section on Pavement Design and measured in terms of the DN value, and
- For conventional pavement designs, the material strength is determined through the standard CBR test and measured in terms of the CBR value (normally soaked CBR) – **this method is not recommended in this guideline document.**

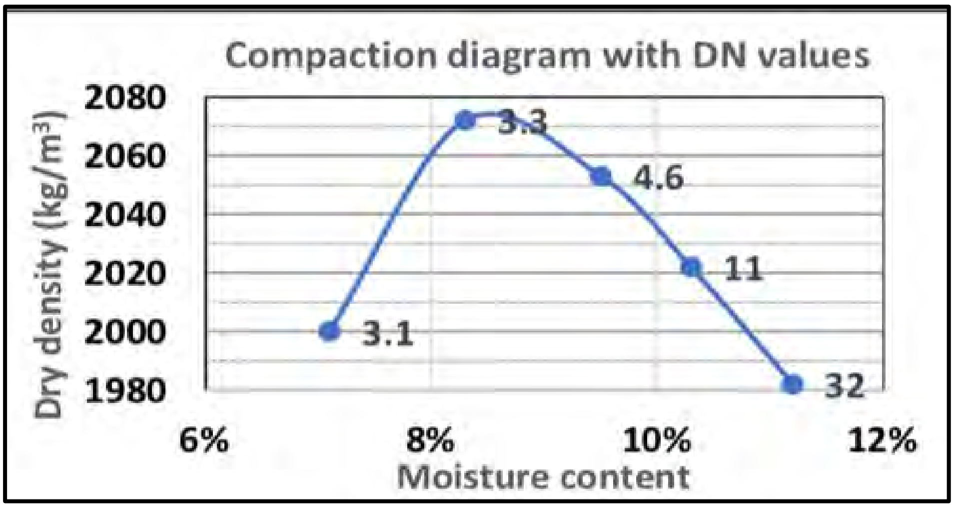


Figure 71 Dry density curve with DN values (mm/blow) determined on each mould

- The information presented in Figure 71 provides the designer with the required knowledge to ascertain under which moisture and density conditions the material will satisfy the design DN requirement. The laboratory testing program required to produce such a figure entails a fairly comprehensive but relatively standard testing program. However, in practice, it will not usually be necessary to carry out the laboratory DN testing program over the full range of moisture contents illustrated in Figure 69 as discussed in the following section. A less comprehensive testing program will generally provide the required information for design purposes.

5.6.7 Construction Material Requirements

The different types of road construction materials required are:

- Common embankment fill;
- Imported (selected) subgrade;
- Subbase and base aggregate;
- Road surfacing aggregate;
- Block or Paving stone (e.g., for cobblestone pavements);

- Aggregates for road or structural concrete;
- Filter/drainage material, and
- Special requirements (e.g., rock-fill for gabion baskets).

In most cases with upgrading an existing gravel road to paved standard, only the base, and perhaps subbase, may require additional material. However, where any re-alignment occurs, material may be required for a range of different layers in the pavement or other applications.

It should also be noted that the majority of low-volume road designs for which this document is relevant would be upgraded from an existing earth or gravel road, which may have been in service for many years. The strength built up in the underlying material must be capitalised on, and as little additional structure as possible should be constructed. Other aspects such as shape, drainage and the recurring repair of localised problem areas have also usually been attended to over the years.

There will, however, always be areas that require full construction or reconstruction, including any realignment to improve the geometry or avoid particular problem areas and areas that may require widening. In these cases, full pavement construction will be necessary, requiring materials for several applications, as identified and discussed in more detail in Appendix D. It is important, however, that any sections of the road that are widened have layers (and layer properties) as close to those of the existing road as possible so that the upgraded road behaves as an integral structure.

5.7 Material improvement/stabilisation and approval

5.7.1 General

Materials on existing roads are often not adequate for the required structural design of the pavement structure. In addition, naturally available materials that comply with the necessary strength requirements are also often not readily available in the area of a roads project. Many natural gravels tend to be coarsely graded and relatively non-plastic. The use of such materials for base courses results in difficulty in obtaining an adequately smooth surface finish for the application of a thin bituminous surfacing.

With the DCP-DN design method, the main objective is to provide a base and subbase layer with the necessary strength to comply with the Layer Strength Diagrams for the different strength categories as discussed. Properties such as grading and plasticity are taken care of in acquiring the necessary strength and it is seldom necessary to make large adjustments to these properties during stabilisation provided that the end-product strength is achieved.

However, where material improvement is considered necessary, this can be in the form of mechanical or chemical stabilisation. The recommended stabilisation method agent to be used is a Material Compatible New (Nano) Modified Emulsion (MC-NME) as discussed in Chapter 6. Mechanical stabilisation and some alternative agents are summarised in Appendix E.

6. Material Design Method Using (MC-NME) Technologies

6.1 Introduction

This chapter deals specifically with the use of Material Compatible New (Nano) Modified Emulsions (MC-NME) and is applicable to both the design of lower-order roads as well as higher-order roads with a design traffic loading exceeding 30 million E80s (30 MESA). In the context of this document an applicable NME stabilising agent will be considered to be Material Compatible (MC). The stabilisation of naturally available materials using NME stabilising agents depends on the mineralogy of the granular materials, the particle sizes of the granular materials, nano-silane modifying agent and the binder properties. The potential bearing capacity of granular materials treated with a NME stabilising agent is mainly a function of the mineralogy of the NAGM and is often not related to traditional material classification systems.

During the Design phase of the investigation, the approved option, following the Concept Development Phase (Phase 1 of the investigation), is taken forward (as approved or recommended by the Implementing Agency), concerning materials design and more detailed testing, as needed. The design concepts allow for an open tender process according to approved procurement procedures in South Africa. The quality of the final product is ensured through the implementation of an “End product Specification”, where the onus is on the contractor to guarantee that the specifications are met using the NME product, as per the required material class for the road as designed.

The structural and material design phases meeting the structural requirements for the surfacing of unpaved roads are divided into two sub-phases as discussed previously, i.e.:

- **Phase 2A: Preliminary Design**, during which material sampling and material characterisation will be done in cases where the naturally available materials do not meet the minimum required bearing capacity as determined from DCP testing or where it is deemed necessary to reduce the risk of environmental aspects through the enhancement of the resistance of the pavement base layer against possible water damage. These tests will be aimed at the optimisation of the use of the naturally available materials to identify applicable NME solutions in terms of the scientific evaluation of material characteristics, and
- **Phase 2B: Detailed Design**, during which the NME solutions are tested with the sampled material to meet the required engineering criteria and to optimise the design of a NME solution for comparison with available alternatives.

6.2 Background

The background to nano-silane technologies is discussed in detail in several publications dating back more than 150 years in the built environment. The uses of these scientifically based products in roads are summarised in the documents contained in the bibliography and not repeated in this document.

The objective of this part of the TRH is to combine all factors relevant to a scientifically based materials design method which can be applied universally, that will enable naturally available materials to be improved (where needed) to:

- Be fully utilised in the pavement design all the pavement layers;
- Meet engineering requirements in terms of fundamental properties, i.e., stresses, strains and durability;

- Meet basic principles of flexible pavement design, utilising NME technologies that are not very sensitive to heavy vehicles that are exceeding legal axel load limits;
- Meet the engineering requirement to negate the high impact of pavement deterioration due to environmental factors, especially affecting LVRs;
- Be construction friendly and tolerable, enabling a wide array of construction methods to be used, and
- Accommodate ease of use to be applied within a low-risk environment without compromising quality.

6.3 Preliminary design

6.3.1 Approach

A flow diagram of the main procedural approach to be followed during Phase 2A: Preliminary design is given in Figure 72.

6.3.2 Objectives

The objectives of this phase of the design for the upgrading of unpaved roads using NAGM with NME technology stabilisation are to:

- Collect material samples along the length of the road for the different uniform sections as identified during Phase 1B: Concept Development – Detailed Assessment, both along the length of the road as well as in identified material sources of naturally available materials, to be used where additional material needs to be imported, sourced as close as possible to the road, and
- Determine the relevant basic material properties of each sample collected, to enable a NME stabilising agent to be designed for the specific materials.

6.3.3 Achieving the objectives

The objectives are achieved following the approach shown in Figure 72. The approach includes:

- Sample each of the uniform material sections to a depth of only the material to be improved as determined from the applicable DCP design curves (samples should consist of at least 150 kg of material per uniform material section for a complete set of laboratory tests);
- Always supplement basic material testing with X-Ray Diffraction (XRD) scans and analyses of the material samples, including detailed clay mineral analysis, according to the recommended protocols (Jordaan and Steyn, 2019);
- Perform a sieve analysis of the materials, discarding any material exceeding 50 mm in size and determine the OMC and MMD, PI, PL and LL of each of the material samples as per standard protocols (SANS 3001), and
- Determine the minimum required engineering properties to be met in terms of minimum tensile and compressive strengths as well as durability, measured as a function of the resistance to the effect of water on the retained tensile and retained compressive strengths (detailed in
- the test protocols).

Similar to the DCP design method, it should again be emphasised that the materials design method to determine a NME stabilising agent is not limited to LVRs. In fact, it allows for the use of NAGM in the base and sub-base layers of roads with considerably higher required bearing capacities

(30 million E80s and higher) as addressed in the materials specifications for different material classes later in this chapter and the “End-Product Specifications” in Appendix E.

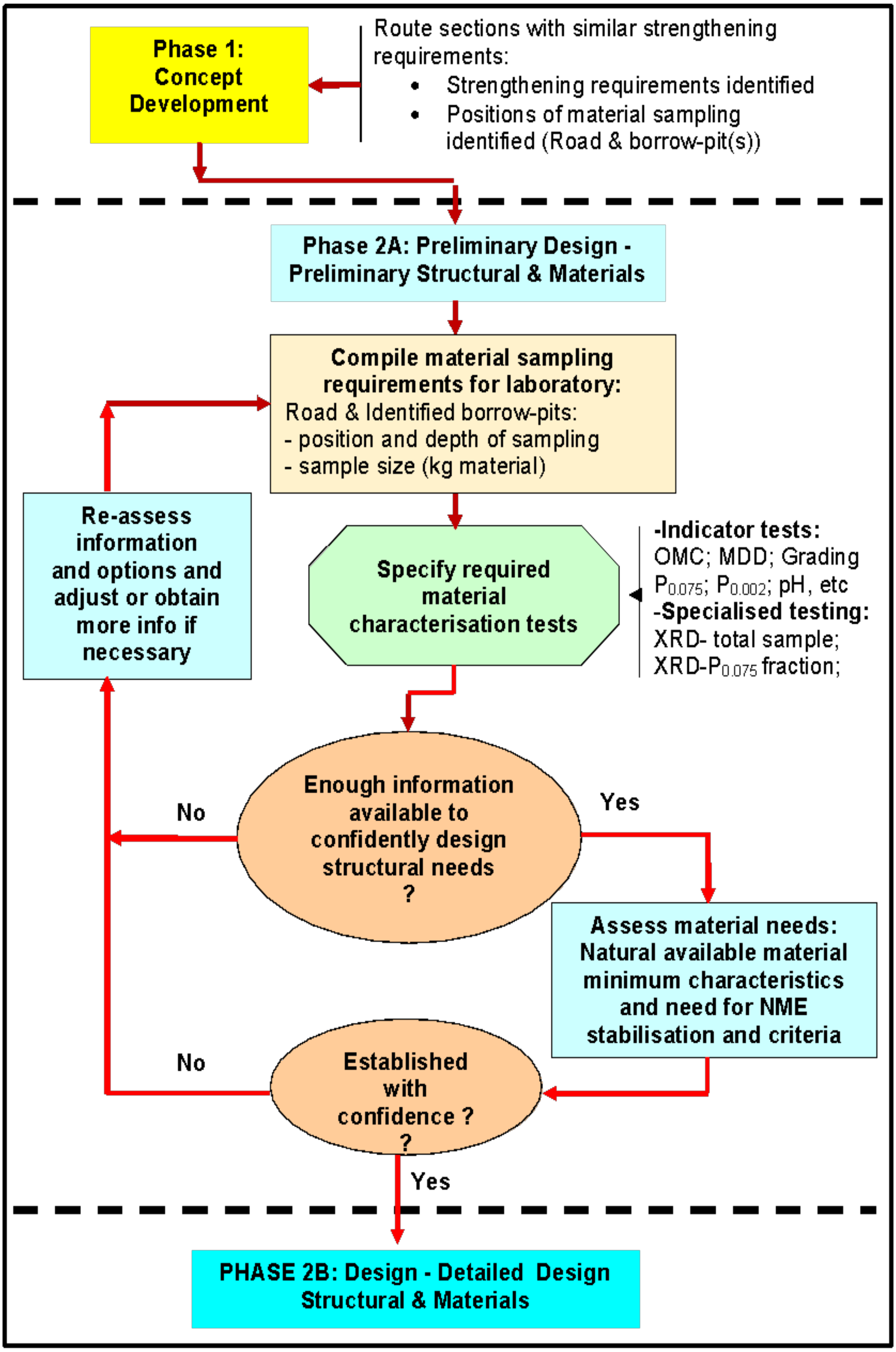


Figure 72 Flow diagram of Phase 2A: Preliminary design towards MC-NME stabilisation

6.3.4 Material sampling and specialised testing

a. Material sampling

Within each of the identified different soil and design sections and possible localised problem sections, enough material needs to be collected for laboratory tests to be performed to optimise the improvement of the material using a NME stabilising agent. Material sampling must be restricted to the depth of the material that requires strengthening. These instructions should be very clear to the laboratories tasked to do the sampling, as the instructions will differ from the "normal" procedures of material gathering. Normal test-pit excavation and material sampling will lead to "contamination" of the material reaching test laboratories, ultimately not being representative of the materials identified to be improved through MC-NME stabilisation.

Material testing will require the determination of the specified material properties to identify the most applicable modifying agent and the quantity of the modifying agent most suitable for the specific material. To have enough material available for all the laboratory testing, a minimum of 150 kg should be collected for testing within each of the different uniform material/design/localised sections and within the identified borrow-pits (i.e., at 3 different areas representative of the materials within each of the identified possible borrow-pits).

Again, it is important to note that the depth of sampling on the road must be restricted to the depth to which the material is deemed to have inadequate bearing capacity in terms of the DCP tests analyses as per Chapter 5. Materials for detailed laboratory evaluation should be representative of the design percentile value of each of the identified uniform materials and road bearing capacity sections along the route. Sampling positions along the uniform material and uniform bearing capacity route sections should be identified at measuring points that closely represent the applicable percentile values of the DCP tests (DN-values) of the materials with inadequate bearing capacity.

Note: *If the uniform material section does not require improvement in bearing capacity, the loose material on the top of the gravel road should be compacted and could be treated with a high penetration Nano-Polymer Nano-Silane (NPNS) applied at a rate of approximately 2 litres/m^2 (of the diluted NPNS), which could also serve as a prime before surfacing. Different solutions, usually 1 part of NPNS to 5: 10; 15 and 20 parts of water should be applied and tested using a DCP (as described) to optimise the design and costs.*

b. Specialised Material testing

i. XRD – scans and analyses

Material samples should be analysed using XRD scans as per the recommended protocol (Jordaan and Steyn, 2019a; Jordaan and Steyn 2019b). In a climatic environment where the decomposition of NAGM due to weathering is the norm, rather than the exception, the identification of the mineralogy of the materials is crucial to determine the impact and suitability of any reactive stabilising agent (including traditional stabilising agents such as cement and lime).

X-Ray diffraction (XRD) scans and analyses of NAGM have a two-fold purpose, i.e., to:

- Firstly, determine/confirm the primary minerals present in the material – this will require an XRD scan of a small piece of the entire rock or soil sample (crushed to a powder – 0.075 mm) obtained from the pavement sections as identified or material sources (borrow-pits) of naturally available materials identified as close as possible to the road to eliminate additional haulage costs, and

- Secondly, (from a point of view of possible in-situ stabilisation options) a more important aspect due to possible adverse reactions and chemical interactions between the stabilising agent and any clay/silt/organic materials that may be present in the material, the mineralogy of the fraction passing the 0.075 mm sieve must be determined. This information will be crucial to identify the presence of possible "problem" minerals that would determine the compatibility with any specific NME stabilising agents (Jordaan and Steyn (2021a). The XRD scan and analyses of the -0.075 mm fraction of NAGM should identify, inter alia, the presence of minerals comprising materials that can potentially cause problems within a pavement structure (fully addressed in Jordaan and Steyn, 2019; Jordaan and Steyn, 2021d):
    - Clay minerals such as Smectite (e.g., Montmorillonite), Kaolinite, Illite, etc. Some of the crystals of the clay particles are smaller than 1 nm in size and the amount of clay (< 0.002 mm) in the percentage of sample passing the 0.075 mm sieve can be crucial to the amount of nano-silane required to effectively protect against the negative impact of these minerals;
    - Mica minerals (e.g., Muscovite), are present in many metamorphic, sedimentary or igneous. Large quantities (>10 per cent) of free mica (especially muscovite) can be detrimental to the performance of material both in an unstabilised state or in combination with cementitious stabilising agents;
    - Calcretes, which require a different modification (Hydroxy Conversion Treatment) (HCT) (Jordaan and Steyn (2021a)) incorporated into the NME to achieve effective chemical bonding of high strength;
    - Other predominant free minerals that could influence the choice of an effective MC-NME stabilising agent, such as iron (Fe), and aluminium (Al) oxides and hydroxides (both often prominent in laterites which are commonly found in most countries subjected to climatic conditions favouring weathering of materials in terms of chemical decomposition);
    - Sulphides and soluble salts;
    - Organic materials including pulverised reef and crushed shell are associated with high concentrations of calcite, and
    - Other minerals, including talc, asbestos, etc. could influence the use and suitability of materials.

All of the identified minerals and observed organic materials could adversely affect the reaction with stabilising agents. This information is crucial with regard to decision taking in terms of the selection, testing and use of an effective stabilising agent that will not result in costly premature failures.

ii. pH measurements

The main aim of pH testing is to determine the "free elements" available on the surface of the stone/gravel /soil that are available to form chemical bonds with the modifying agent to enact strong chemical bonds with the stabilising agent. For example, if bitumen emulsion is used as the stabilising agent, no strong chemical covalent or ionic bonds will form between the material particles and the bitumen particles. Bonding will depend on electrical and mechanical forces between the bitumen molecules and the material assisted by the absorption of the bitumen into the aggregate/material (Weinert, 1980). The addition of the modification acts as an "aggregate adhesive", ensuring that the bitumen (or alternative) chemically binds with the material particles. Some of the strongest bonds in nature are Silicon (Si) – Oxygen (O) bonds, comprising almost two-thirds of the crust of the earth. However, in weathered material, available broken bonds with Silicon may not be in abundance - the most appropriate chemical bonds, with even stronger bond strengths would be Carbon (C) – Oxygen (O) bonds. In such cases, the available "free" elements available to chemically bind with the bitumen through an applicable modifying agent need to be correctly identified as a different modifying agent (i.e., an HCT) will be required to enable chemical bonding (Jordaan and Steyn, 2021a; 2021b).

In remote areas, the pH of the material could be a viable option to indicate the elements on the surface of material properties. Material samples passing the 0.425 mm sieve should be mixed with distilled water and left overnight. A highly accurate pH meter (calibrated at the expected pH) should be used to measure the pH of the mix to two decimal points. Care should be taken during measurements to ensure that the pH measuring device does not come into contact with the glass container. A measurement of a pH less than the neutral value of 7 will indicate the presence of hydrogen ions attached to the clay particles. A pH larger than 7 will most likely indicate more hydroxyl ions attached to the clay particles.

Broken chemical bonds are utilised to form a chemical bond with the stabilising agent with or without (depending on the mineralogy) a HCT of an anionic nano-silane modifying agent. With the correct identification of the available elements on the surface of the materials, strong covalent or ionic chemical bonds can be achieved between the stabilising agent and the material particles with no/little absorption of the stabilising agent. These strong chemical bonds will also render the material water-repellent, preventing future chemical weathering of the material within the pavement structure, thereby enhancing chemical durability. Although not a complete substitute for an XRD analysis, the determination of the pH of the material (at least 3 samples within a borrow-pit or section of road should be tested), can give a reasonable indication of “free broken bonds” on the surface of the material, and hence, of an appropriate modifying agent for test initiations.

Similar to geology and soil maps, the internet may contain some valuable information (although generalised) about the expected pH of the soils in a region (United Nations – FAO, 2005), (JRC, 2013).

Of importance in the determination of the quantity (volume as a percentage of the total volume) of a modifier (e.g., nano-silane modifier), to be added to design a NME stabilising agent to achieve the required level of hydrophobic action (Jordaan and Steyn, 2021c), the grading with specific reference to the finer fractions within the material, needs to be determined with the required accuracy. The percentage passing the 0.075 mm sieve ($P_{0.075}$) and the percentage smaller than 0.002 mm ($P_{0.002}$) (e.g., smectite, kaolinite, illite, etc.) are of high significance.

These $P_{0.075}$ and $P_{0.002}$ fractions of the NAGM mainly control the surface area that needs to be covered by the modifying agent. These fractions will determine the volume of the modifying agent that will be required to achieve hydrophobicity of each material particle and will effectively prevent/limit future access of moisture and water to the clay mineral particle, preventing future in-situ chemical weathering (which can be substantial) and increasing material durability.

Over-and-above the grading measurements, the Optimum Moisture Content (OMC) and the Maximum Dry Density (MDD) of the material, which are of importance for the successful treatment of the material are required. This information is also crucial for use during construction to enable compaction to be done as close as possible to, or just less (as per experience) than OMC. Practical application of MC-NME stabilisation has shown that the best results are normally achieved at a moisture content of about 10 per cent less than OMC, including the total fluid content of an anionic NME stabilising agent.

6.4 Detailed design

6.4.1 Approach

A flow diagram of the main procedural approach to be followed during Phase 2B: Detailed design is given in Figure 73.

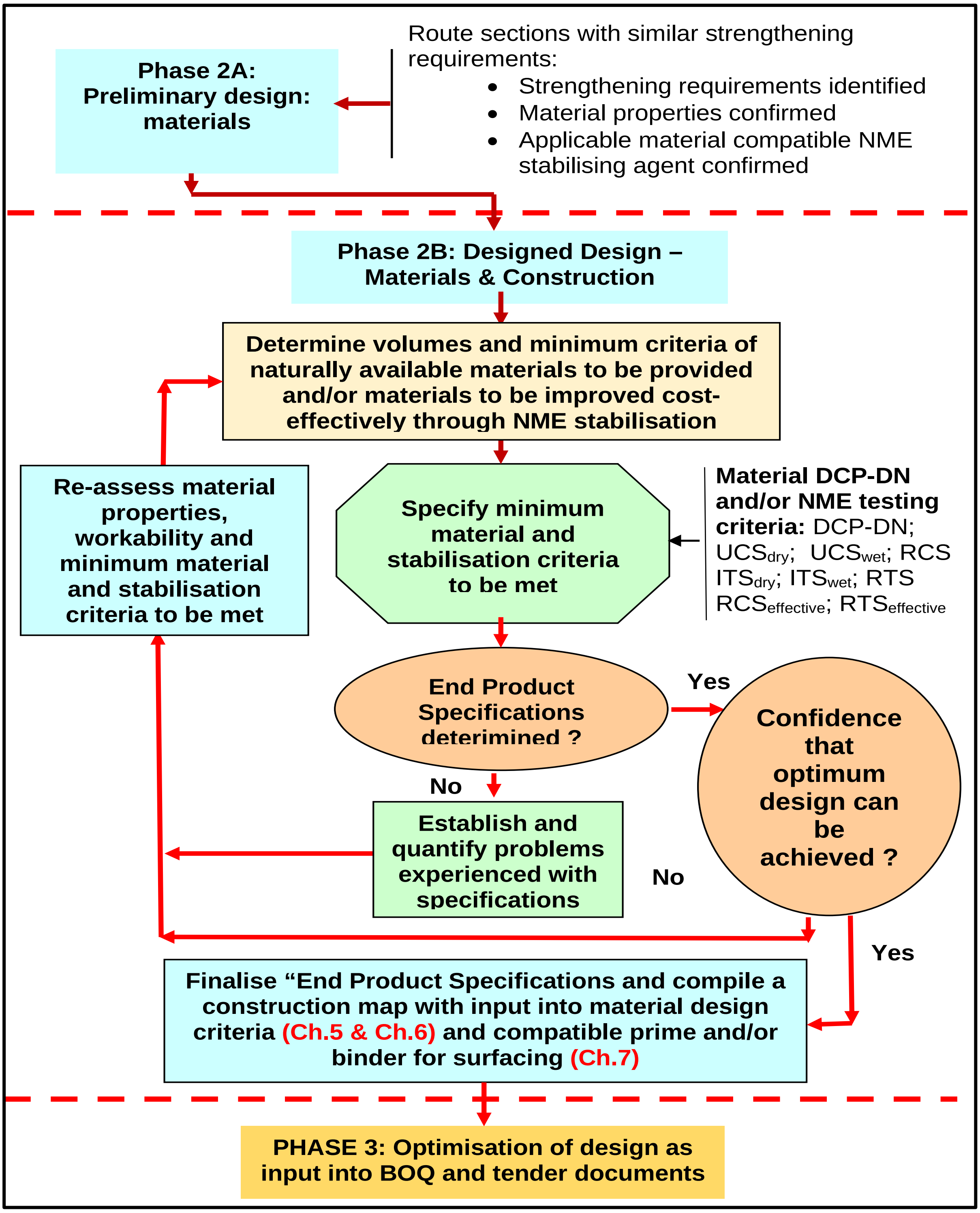


Figure 73 Flow diagram of Phase 2B: Detailed design for using NAGM with MC-NME

6.4.2 Objectives

The objectives of this phase of the design for the surfacing of unpaved roads, using naturally available material with a NME stabilisation are to:

- Optimise the design in terms of the percentage of the NME stabilising agent to be added to the materials expressed as a percentage of the MDD of the materials. The same percentage will not necessarily result in the best Unconfined Compressive Strength (UCS) and Retained UCS versus Indirect Tensile Strength (ITS) and Retained ITS and the design engineer should consider with care the requirements of any specific layer within the pavement structure that are identified for MNE stabilisation;

- Prepare a construction map for the proposed layer works along the length of the road, based on the in-situ variation of the materials as tested,
- Identify and recommend material-compatible primes and/or surfacings (discussed in detail in Chapter 7), and
- Identify applicable construction options

6.4.3 Selection of a MC-NME stabilising agent

The material tests discussed are essential in the selection of the most applicable modifying agent and the selection of a suitable stabilising agent, as shown in Figure 74. The surface area to be covered by the modifying agent (e.g., nano-silane or HCT modified nano-silane), is a function of the type and quantity of primary minerals present in the material to be stabilised. Table 40 gives an indication of the relative surface area of various types of minerals, all of which could influence the percentage of the modifying agent required to achieve the engineering properties required. Durability will only be assured when the level of retained strength is obtained through the neutralisation of the possible negative impact of secondary minerals. Hence, even when the strength requirements are met, adjustments in the NME formula may be needed to ensure that the retained strengths (Retained Compressive Strength (RCT) and Retained Tensile Strength (RTS)) also meet the minimum requirements for the required material class.

Table 40 Differences in surface area of different minerals (m^2/g) (adjusted from PCC, 2009)

Material	Surface area of material (m^2/g)	Comparative surface area - relative to Silicate materials
Glass	0.1 to 0.2	
Quartz (SiO_2)	1 to 2	1
Calcium silicate (Ca_2O_4Si)	2.6	1.3
Calcium carbonate ($CaCO_3$)	5	2.5

Figure 74 gives an example of the selection of an applicable modification and stabilising agent based on the fractions of the finer material within the material. The input in terms of percentage passing the 0.075 mm sieve is based on silicate materials. Should the primary mineral in the example be calcite or any other non-silicate mineral, the effective percentage passing through the 0.075 mm sieve needs to be multiplied by an adjustment factor as given in Table 40 (to a maximum of 100 per cent). An anionic nano-silane modifying agent will require an applicable HCT additive in order to create strong chemical bonds with the granular material.

Also summarised in Figure 74 is the influence of the percentage of problematic materials (as representative of the 0.002 mm fraction) on the selection of an appropriate size modifying agent in combination with the required size of an applicable binder. The influence of the silane modifying agent and binder size in quantified in Figure 75 and detailed in Figure 76 and Figure 78. Other than the fractions identified, the rest of the grading of the available materials has been found not to have a significant influence on the resultant engineering properties (Jordaan and Steyn, 2019b).

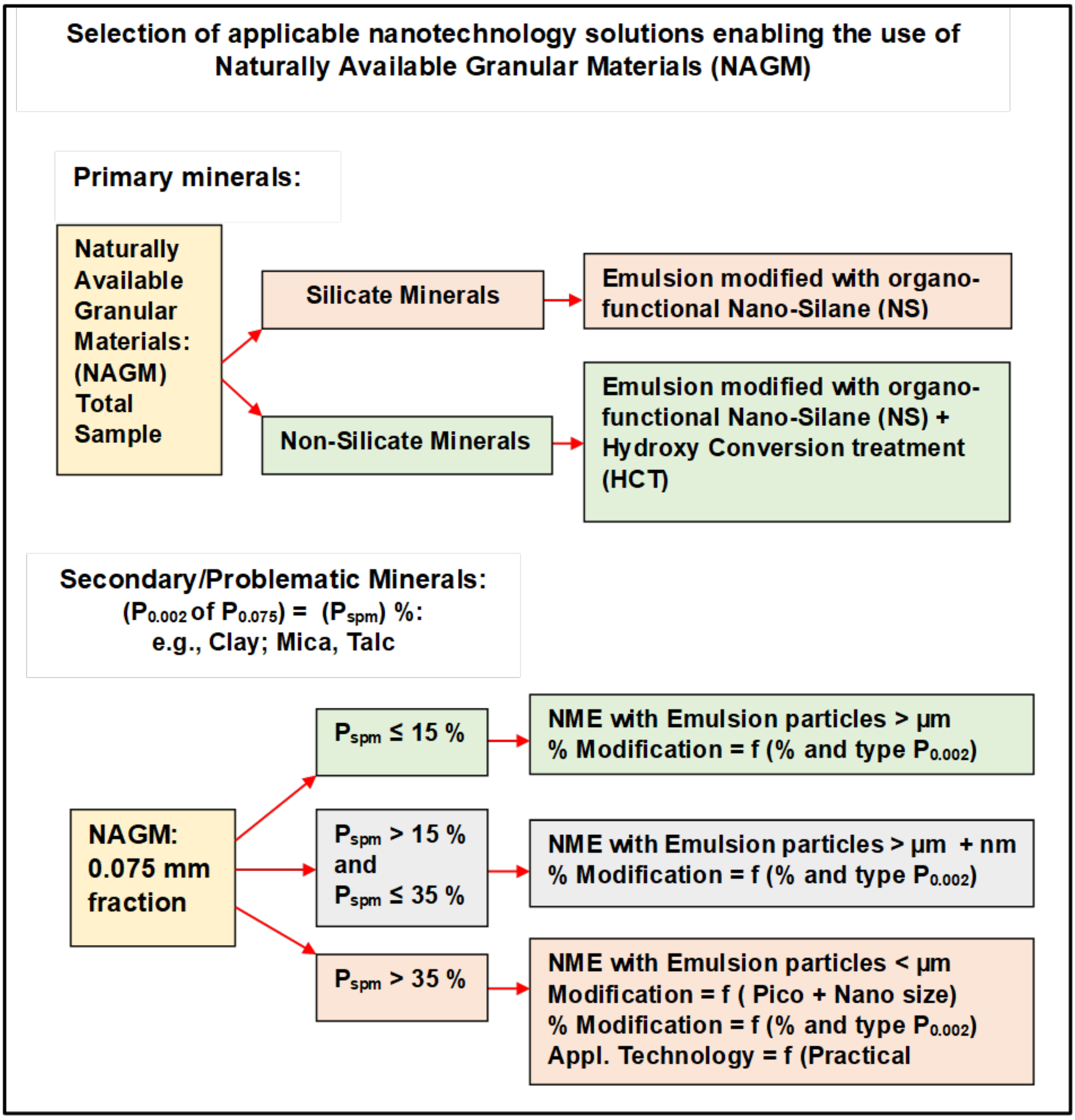


Figure 74 Required information as an input to the selection of a MC-NME

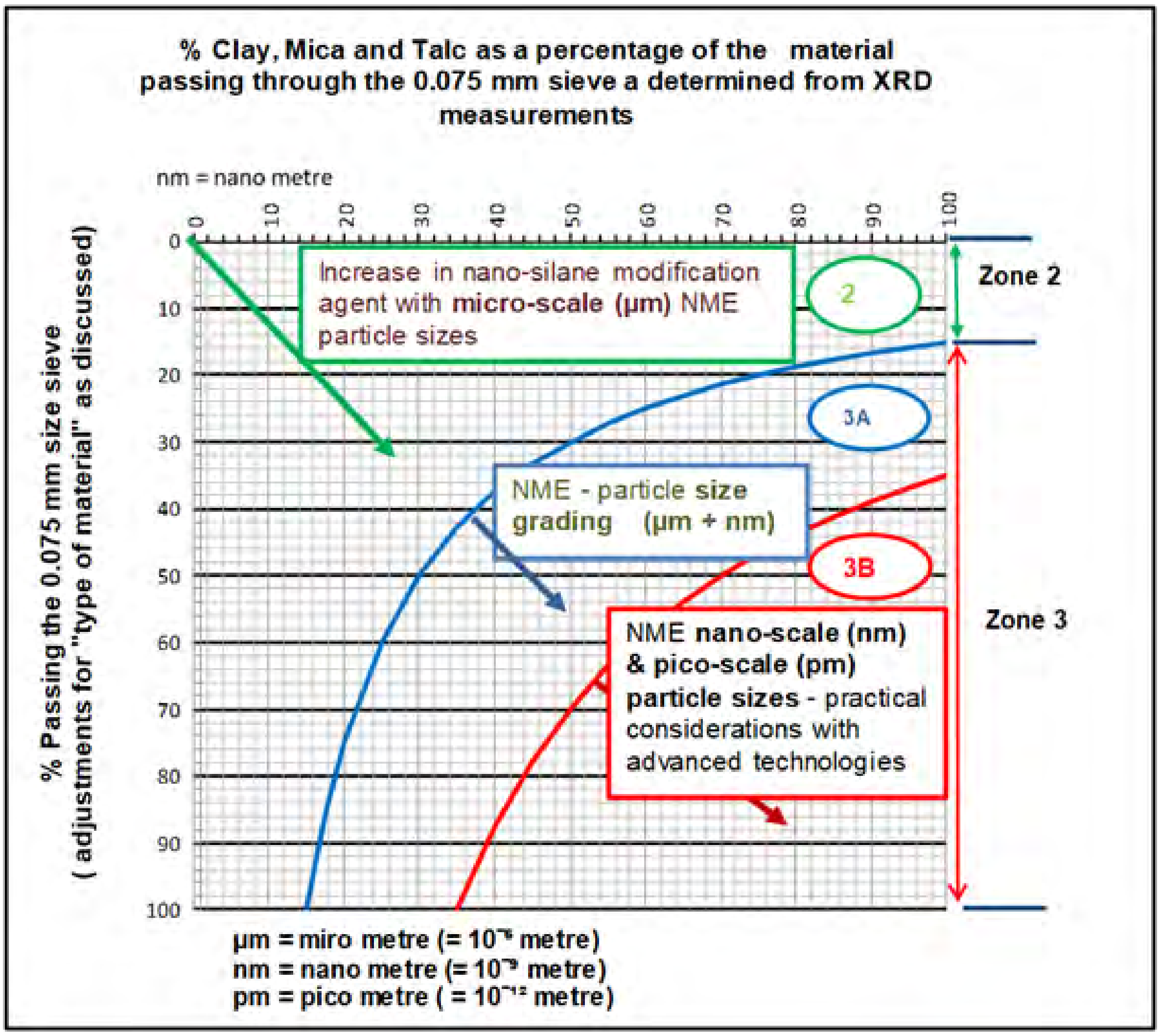


Figure 75 Identification of the most applicable modifying agent and stabilising agent

Figure 76 and Figure 77 give a more detailed indication of the different relative volumes of the modifying agent and the binder respectively required for the optimisation of the NME stabilising agent. The required volumes of the modifying agent and the binder are a function of the surface area of the material particles to be covered which depends on the grading of the material. The area exponentially increases with a decrease in particle size. Hence, the dosage of the NME stabilising agent should be adjusted accordingly to ensure that the modifying agent covers the area of the material particle sizes. Similarly, the binder particle sizes (Figure 78) must be adequate to ensure that the material particles are bound together to meet the engineering strength requirements (tensile and compressive strengths) together with the required hydrophobicity to meet durability criteria when used with a specific material (RCS and RTS).

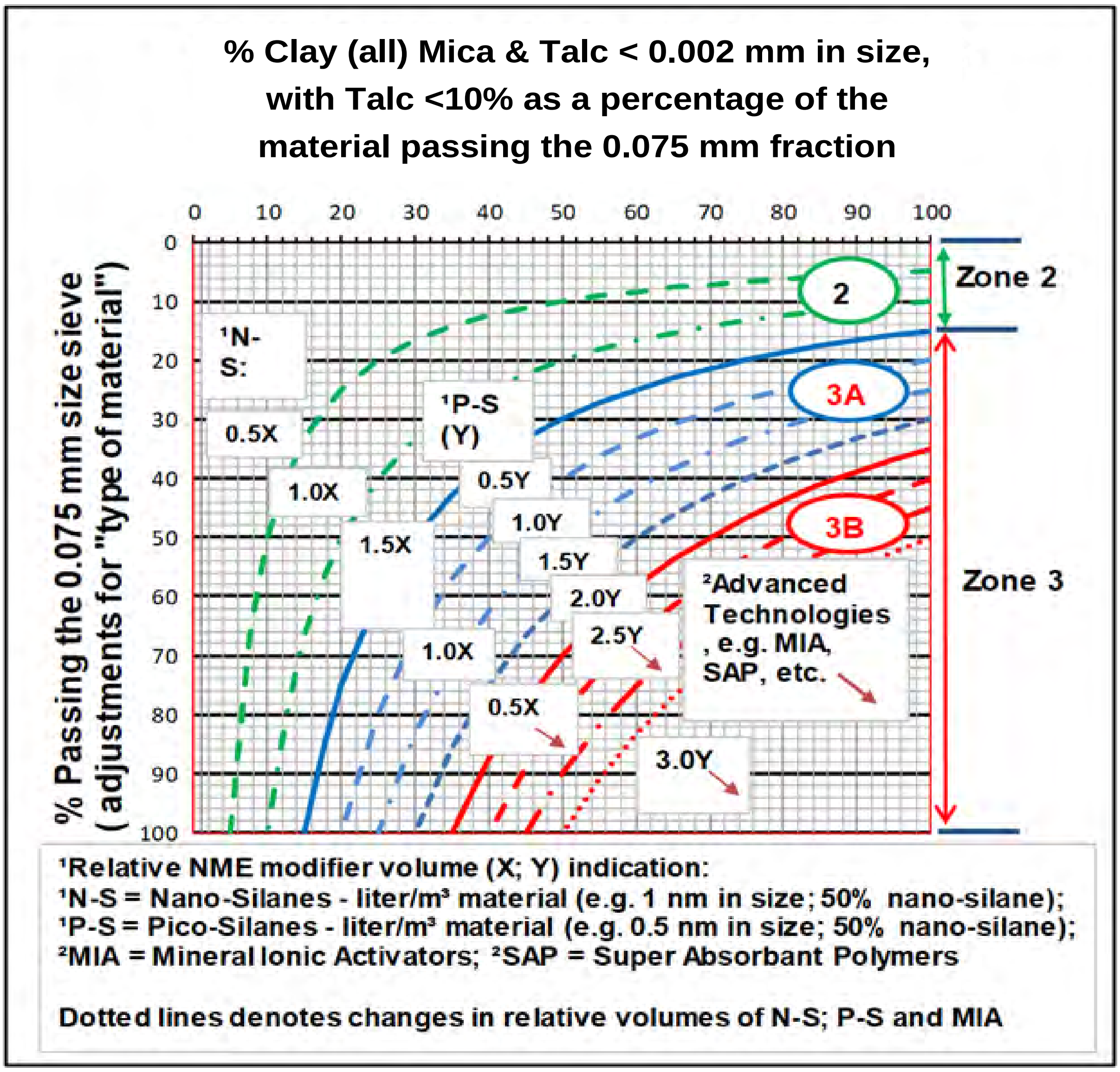


Figure 76 Relative volumes and particle sizes of applicable silane modifications of a MC-NME

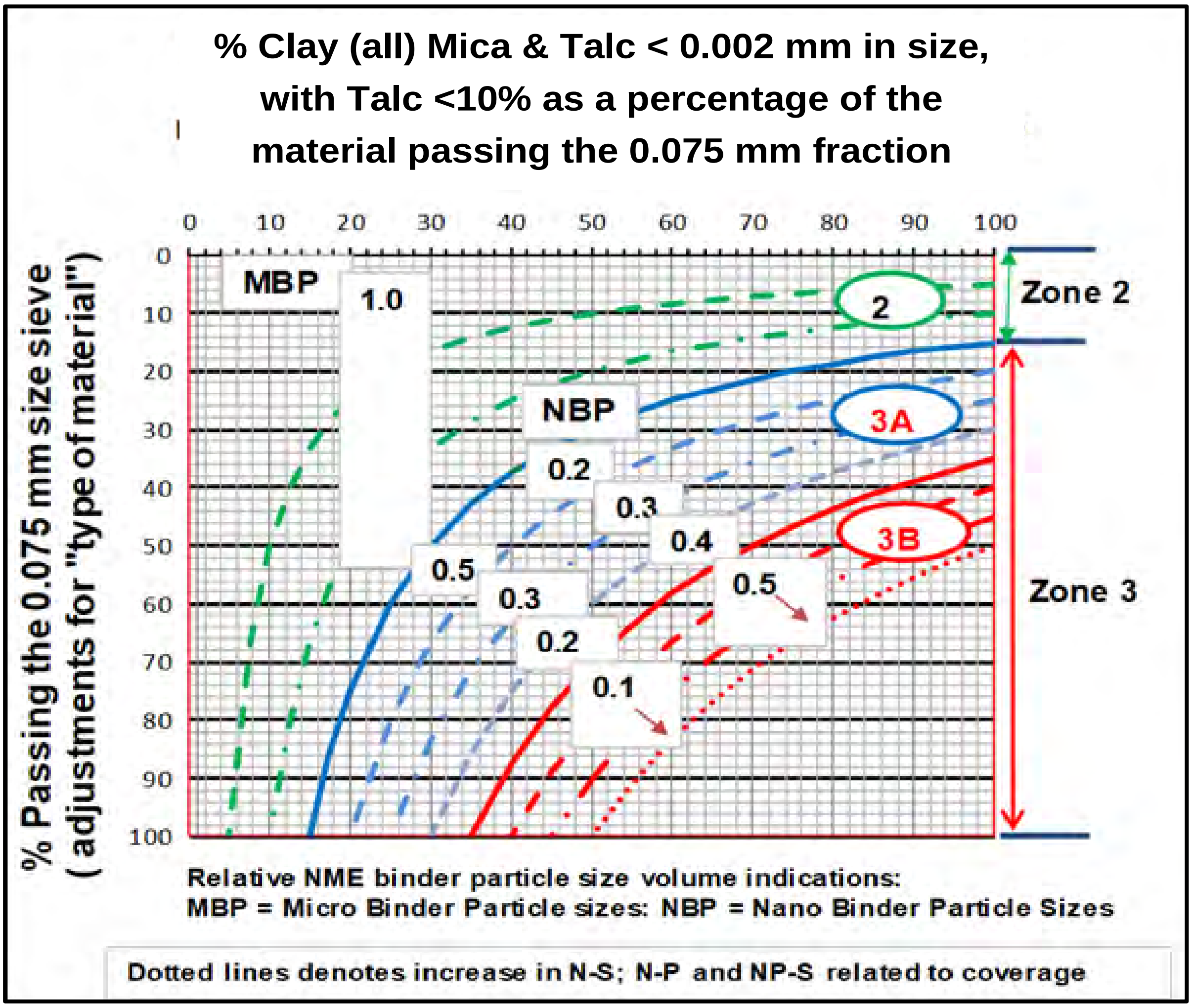


Figure 77 Relative volumes and particle sizes of applicable binders to use in a MC-NME

6.4.4 Engineering requirements

The design of a NME stabilised layer is aimed at the optimisation of the various components of the modified stabilising agent, to ensure that the most cost-effective product is selected for detailed laboratory testing, aimed at meeting the engineering properties required for the designed road pavement structure. The scientific approach developed (discussed in detail in Jordaan and Steyn, 2021c), ensures that a process of trial and error is eliminated together with a risk reduction.

The design and selection of a NME stabilising agent is not a one-recipe fit-all approach. The prime objectives of a modified emulsifying agent are to ensure that the stabilising agent is chemically bound to the material and that a high degree of hydrophobicity is achieved. The mineral composition of the material will determine the available “broken” chains of the elements comprising the material, that are available which can be utilised for these chemical bonds to be activated. An increase in the stabilising agent will also not necessarily lead to an increase in the tensile and compressive strengths of the stabilised material. This is especially the case with highly weathered material containing relatively high percentages of fines. In such cases, the increase in the stabilising agent consisting of particle sizes above a micron could effectively prevent the material particles from binding together. With an increase in the modified stabilising agent, clay particles will then start to “swim” within the stabilising agent, resulting in a reduction in the measured UCS and/or ITS strengths (Jordaan and Steyn, 2019a).

In the case of the structural design for the upgrading of unpaved roads of a road Category D and E, the stabilised material needs to meet the criteria of an NME4 (traffic loading 1.0 to 3.0 MESA) or NME4 – EG5 (Equivalent G5 material in terms of DCP-DN rate of penetration) (discussed in more detail in Appendix E for traffic loading ≤ 1.0 MESA where DCP test results could be sufficient for design purposes as shown in Table 41).Table 41 contains the required design criteria for the different material classes from a NME1 (high class) to a NME4 (low class) as per design requirements for lower-order roads as well as for higher-order roads.

Material samples are prepared and cured for testing as per recommendations contained in the test procedures in the following section as well as specified in the in the "End product specifications" as detailed in Appendix E. It is of importance to note that in Table 41, that the required criteria for materials testing during any design phase in a laboratory is higher than that required during quality control in the field. This adjustment is made to allow for the differences between laboratory and field mix conditions, ensuring that the materials stabilised in the field will meet the required engineering properties after the design has been done under ideal conditions in a laboratory.

6.4.5 Laboratory testing

The main objective of Phase 2B: Detailed Design is to optimise the application rates of the anionic MC-NME through a series of laboratory tests. The laboratory testing of the materials is done to simulate the required engineering properties in terms of the:

- Tensile strength (ITS) (dry and wet), by testing, using the test procedures as detailed, for the rapidly cured stabilised materials after treatment with the NME as per design;
- Compressive strength (UCS) (dry and wet), by testing, using the test procedures as detailed, for the rapidly cured stabilised materials after treatment with the NME as per design, and
- Retained Tensile Strengths (RTS) and Retained Compressive Strengths (RCS) by comparing the wet test results with the dry test results as per recommended protocol. The retained strengths are indicative of the hydrophobicity, achieved with the added modification within the NME. The resistance to the effect of water directly influences the durability of the stabilised layer, preventing or at least reducing in-situ chemical weathering of the stabilised materials within the pavement structure. The RCS is also indicative of the resistance to the formation of potholes in cases where the integrity of the surfacing has been compromised.

In developing recommended test protocols, existing standards for the testing of traditional stabilising agents were strongly relied upon. To compare results, all materials need to be tested and evaluated using test protocols that are the same or taking into account certain limitations associated with specific stabilising agents. For example, the UCS_{wet} and ITS_{wet} of cementitious material (SANS 3001-GR53 and GR54) are tested after soaking in water for 4 hours – the same should apply for the comparison of any other stabilising agent. The whole approach is towards the development and recommendation of test protocols that are universally applicable for the evaluation of any MC-NME stabilising agent and allow fair comparisons of results as required in an unbiased procurement process. In this regard, certain limitations need to be taken into account, e.g.:

- The times and temperature for a rapid curing process for the stabilisation should be standardised allowing for a fair competition between available products. Hence, the rapid curing process should be done at temperatures between 40°C and 45°C (allowing for natural variations in remote or field laboratories as commonly experienced in practice);
- No special treatment of material samples e.g., soaking in the stabilising agent after curing, should be allowed;

Table 41 Requirements for in-situ stabilisation of gravels with a MC-NME stabilising agent

Test or Indicator	Material[1]	Material classification			
		NME1	NME2	NME3	NME4
Minimum material requirements before stabilisation and/or treatment (Natural materials)					
Material spec. (minimum) Unstabilised material: Soaked CBR[2] (%) (CBR as % of MDD)	NG /(CS)	> 45[2] (95%) ACV < 30%	> 25[2] (95%)	> 10[2] (93%)	> 7[2] (93%)
Grading Modulus (GM)	NG	> 1.5	> 1.0	-	-
	GS	NA	> 1.0	-	-
Sieve analysis: % < 0.075 mm ($P_{0.075}$)	ALL	< 25 %	<25 %	< 35 %	< 50 %
XRD scans and analyses: - Total sample - 0.075 mm fraction ($P_{0.075}$)	ALL ALL	Required Required	Required Required	Required Required	Required Required
% Material passing 2 µm ($P_{0.002}$) (e.g. Clay & Mica & Talc) as a % of Material (with Talc <10%) (XRD-scans of the material passing the 0.075 mm sieve are used to determine the % clay, mica and talc in the material – In this case $P_{0.002}$ = $P_{0.075}$ x ($P_{clay, etc.}$ in $P_{0.075}$)	MC-NME stabilisation with micro-meter (µm) emulsion particle sizes				
	ALL	< 15 %	< 15 %	< 15 %	< 15 %
	MC-NME stabilisation with emulsion containing micro-scale as well as nano-scale particles (adjusted according to material grading)				
	ALL	NA	< 35 %	< 35 %	< 35 %
	MC-NME stabilisation with emulsion containing nano-scale and pico-scale particles (grading adjustments) together with technologies addressing workability of materials on site				
	ALL	NA	NA	> 35 %	> 35%
Material specifications after stabilisation and/or treatment					
In-situ density to be required after stabilisation and compaction (% of MDD)	Base	> 100 %	> 100 %	> 98 %	> 97 %
	Sub-base	NA	> 98 %	> 97 %	> 95 %
DCP (DN mm/blow) (Quality control in field testing - base only) (stabilised and compacted = wet; 7 days cured = dry)	DCP-DN	NA	NA	< 2.6(wet) < 2.0(dry)	< 3.5(wet) < 2.3(dry)
Density (% of MDD) (for laboratory testing)		> 100 %	> 100 %	> 100 %	> 100 %
*UCS_{wet} (kPa) (150 mm Φ Sample)	**Design[3]**	**> 2 500**	**> 1 500**	**> 1 000**	**> 750**
	Construction[4]	**> 2 200**	**> 1 200[5]**	**> 700[5]**	**> 450[5]**
Retained Compressive Strength (RCS): (UCS_{wet}/UCS_{dry}) (%)	RCS	> 85	> 75	> 70	> 65
RCS in relation to minimum $UCS_{wet(criteria)}$ = $RCS_{effective}$ = (RCS x (UCS_{wet}/$UCS_{wet(criteria)}$)) (%)	RCS-E	>100	> 90	>85	> 80
*ITS_{wet} (kPa) (150 mm Φ Sample)	**Design[3]**	**> 240**	**> 200**	**> 160**	**> 120**
	Construction[4]	**> 220**	**> 180[5]**	**> 140[5]**	**> 100[5]**
Retained Tensile strength (RTS): ITS_{wet}/ITS_{dry} (%)	RTS	> 85	> 75	> 70	> 65
RTS in relation to minimum $ITS_{wet(criteria)}$ = $RTS_{effective}$ = ((RTS x (ITS_{wet}/$ITS_{wet(criteria)}$)) (%)	RTS-R	>100	> 90	> 85	> 80

[1]CS – crushed stone; NG – natural gravel; GS – gravel soil, and SSSC – sand, silty sand, silt, clay.\
[2]CBR only used as reference to traditionally used test procedures as a broad first indicator
*Definitions: UCS = Unconfined Compressive Strength; ITS = Indirect Tensile Strength);
UCS_{dry}; ITS_{dry} = testing after rapid curing; UCS_{wet}; ITS_{wet} = testing after rapid curing and 4 hours in water (as per test procedure specified for the testing of cementitious stabilising agents (SANS 3001-GR32:2010, 2010));
Design[3] = Minimum criteria to be met in the laboratory during the design phase
Construction[4] = Minimum criteria to be met during construction as part of quality control
[5]Criateria based on reference TG2 (Asphalt Academy, 2009)

- No treatment of the sample compaction moulds to assist with the removal of samples, e.g., the use of oil or grease should be allowed as this could influence the results obtained during the soaking of the sample in water;
- No deviation from the specified method of compaction should be allowed, and
- Rapid curing process pre- and post-treatments before testing must be standardised.

Considering the basic requirements, the following test protocols are currently recommended (Jordaan et al, 2016; Jordaan and Steyn, 2020). These recommendations are repeated due to the influence on test results to be discussed using the recommended design method:

1. The curing and testing process of the 152 mm diameter samples (127 mm high) shall be as follows: The samples are to be prepared as per SANS PART 3001 GR50 and GR51 with some adjustments based on the requirements for a generalised procurement process, with no plastic covering. (Plastic covering is required when cement is included in the mix to assist in the hydration of the cement.) Samples are cured for 24 h in an oven at 22-25°C before being subjected to a “rapid curing” process in an oven for 48 h at 40 °C to 45 °C;
2. After 48 h the samples must be removed from the oven and allowed to cool down for twenty-four (24) hours. This is preferably done in the oven at 22-25°C for 24 h);
3. Three (3) samples must be crushed to determine each of the ITS and UCS values. The average values obtained are called the DRY ITS and the DRY UCS values;
4. Three (3) samples must be placed in a bath of water at a temperature of 22-25°C for four (4) hours (as per the test procedure specified for the testing of cementitious stabilising agents (SANS 3001-GR53 and GR 54 as adjusted)) and thereafter removed from the bath and allowed to drain off excess water before determining the ITS (wet) and UCS (wet) values;
5. The “wet” tests (UCS and ITS) may suffice during the quality control during construction. For the lower-order roads (Category D and E), DCP tests done at randomly selected spots may be approved for quality control by the Engineer (refer to Table 41);
6. During the design phase, 3 samples for each test must be preserved outside the moulds for 28 days. After 28 days the UCS (wet and dry), as well as the ITS (wet and dry), should be tested as per the procedure described above. The results of the 28-day tests should not show a decrease in the respective UCS and ITS test values as tested after the rapid curing process (an increase of up to 30 per cent has been shown after 28 days during laboratory testing for certain materials);
7. It is important to note that sample preparation must be done in strict compliance with the prescribed procedures and NO deviation shall be allowed, including:
   a) The moulds in which the samples are prepared are not to be treated with grease or any other lubricant to facilitate the easy removal of the sample as this could influence the loss (during rapid curing) or increase (during soaking in water) of moisture and hence, the measurements of UCS and ITS both in the dry and wet conditions;
   b) No additional soaking of samples in any “covering” liquid or any other material will be allowed as this will make any comparison and application of test requirements invalid and not comparable with what is practically achievable during construction, and
   c) No deviation from the compaction process prescribed in the SANS specification will be allowed.

The most applicable percentage of the NME stabilising agent to apply is determined through a series of laboratory testing during the detailed material design process. A variation in the percentage (per mass of the material) of the NME stabilising agent should be tested with the naturally available material, to optimise the required stabilising agent as well as the required percentage of the modifying agent. As discussed, careful assessment of the results will be required, understanding the properties of the granular materials (mineralogy) stabilised with regard to the results obtained. Again, it should be noted that, depending on the material characteristics, an increase in the NME stabilising agent application percentage will not necessarily lead to an increase in the measured ITS and/or UCS and/or RTS and/or RCS.

The following ranges, in terms of percentages of the NME stabilising agent (in terms of the mass of the material to be stabilised), are recommended to be tested in a laboratory during the design phase to determine the optimum percentage to be applied. The testing should aim to identify the optimum percentage that best meets the engineering requirements of the specific pavement layer in the most cost-effective manner. The following percentages should give a range normally sufficient for testing during the design stage (material zones with reference to Figure 75 to Figure 77):

- Zone 1 (Not shown in figures): Crushed stone suitable for any layer works: 0.1 to 0.2 per cent per cubic metre by mass (the addition of a small percentage of a NME stabilising agent will assist in the compaction of the material, reducing energy inputs and construction time. In addition, the material particles will be rendered hydrophobic, which will increase the in-situ durability by preventing, or at least considerably reducing, chemical decomposition);
- Zone 2: 0.7 to 1.5 per cent per cubic metre by mass to be stabilised;
- Zone 3A: 0.6 to 1.1 per cent cubic metre by mass to be stabilised, and
- Zone 3B: Specialist design.

The use of reduced percentages of the NME stabilising agent is possible due to the reduced particle sizes achieved through the introduction of the modified emulsification agent as one of the advantages of NME stabilisation (Jordaan and Steyn, 2019a). These smaller particle sizes distribute with ease within the construction water, requiring no more effort than used during the normal construction of granular material layers (with considerably less compaction effort) at a moisture content of about 10 per cent less than OMC.

NAGM within Zone 3B, with a high percentage of fines, may present additional problems in terms of practical construction and challenges in the field. In such cases constraints in terms of constructability (considering available construction equipment), may require a material with larger particle sizes (e.g., building sand, etc.) to be mixed in with the in-situ materials to assist with the construction and effective stabilisation of a pavement layer. Some indications of materials qualifying for special construction practices are demarcated in Figure 78 (shown on a log-log scale).

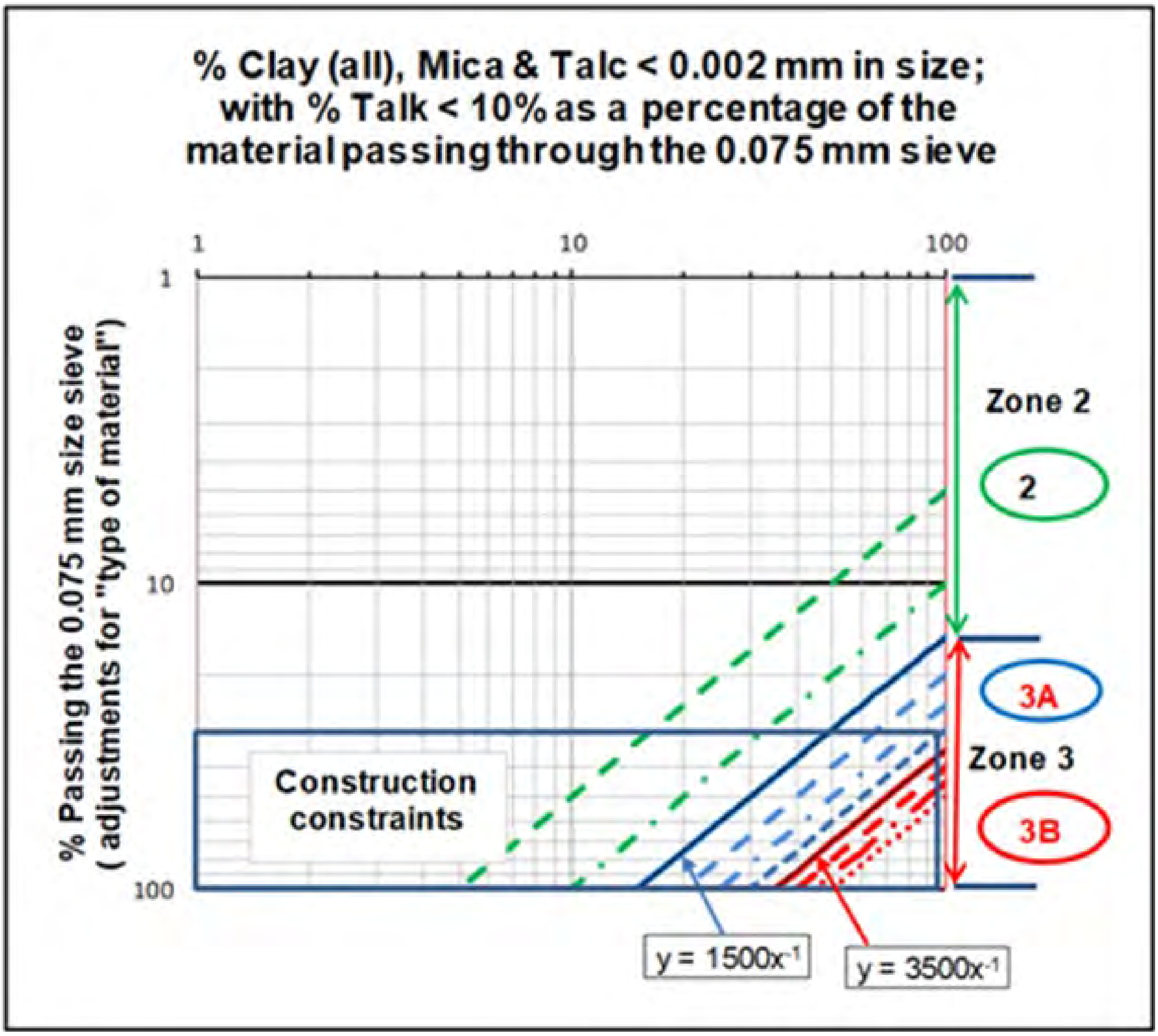


Figure 78 Materials that may present challenges in terms of construction practices

The design of the most cost-effective NME stabilising agent can be considerably simplified by ensuring that the material to be stabilised conforms to the following (from Figure 76 and Figure 77):

$P_{0.075}$ (adjusted as per Table 40) x $P_{0.002}$ (of the $P_{0.075}$) < 3500 ………………………………….. (6.1)

Where:

$P_{0.075}$ = percentage of the material passing the 0.075 mm sieve size, and

$P_{0.002}$ = percentage of the material passing the 0.002 mm sieve size (problematic minerals as a fraction of the material passing the $P_{0.075}$).

Further simplification can be achieved by ensuring that:

$P_{0.075}$ (adjusted as per Table 40) x $P_{0.002}$ (of the $P_{0.075}$) < 1 500 ……………………………………...(6.2)

If the material currently on the road does not conform to the above guidelines, the grading of the material can be changed by blending it with suitable naturally available materials that can most cost-effectively be mixed with the material to ensure that any of the above guidelines be met. Detailed maps, identifying clay, silt, sand and gravel are available on the internet, covering a specific region (JRC, 2015).

6.4.6 Typical applicable NME designs as a function of sub-grade conditions and orientation to traditional design approaches

The concepts of NME design approaches require design engineers to adjust from traditional approaches to material classification systems and the use thereof in terms of material suitability. The actual structural design requirements should be determined for each uniform pavement section along any road using the design concepts based on the DCP-DN approaches as addressed in Chapter 5. The different moisture conditions and climatic zones are also addressed in the recommended DCP-DN approaches. Figure 79 gives a comparison between traditional designs and typical design using NAGM with a MC-NME stabilising agent. This figure is included for purposes of orientation and adjustment of engineers to the effect of MC-NME technologies (Jordaan and Steyn, 2019; Jordaan and Steyn, 2021d).

6.4.7 Construction map

Due to the measured variation in the in-situ bearing capacity of the road, the required structural improvements may also vary. The results of all the analyses and laboratory tests will enable the designer to prepare a required strength profile along the length of the road. Care should be taken not to over-complicate the construction process for the upgrading of any road, especially for emerging contractors. Small variations in required strengthening should be avoided by combining sections with required layer works within the same range. In addition, layer thicknesses should be considered in terms of practical constructability considerations.

6.4.8 Construction options and preferences

a. General

The upgrading of unpaved roads using in-situ materials or any marginal materials stabilised with a NME stabilising agent lends itself towards full compliance with regard to any preferred or prescribed construction method (Jordaan and Steyn, 2021e). Depending on the specific needs of the Implementing Agency or the Funding Agency, the pavement structure and surfacing can be done either fully through labour construction or with some basic equipment (to assist in speeding up of the construction process) or using the most modern construction equipment. When considering labour-intensive construction options, a mixture of equipment with a high labour content usually proves to be the most cost-effective. These requirements are usually a function of external requirements as per the original TOR.

With the emphasis on the creation of employment opportunities and development of SMMEs, recommendations regarding the type of contract are discussed in Chapter 9**.**

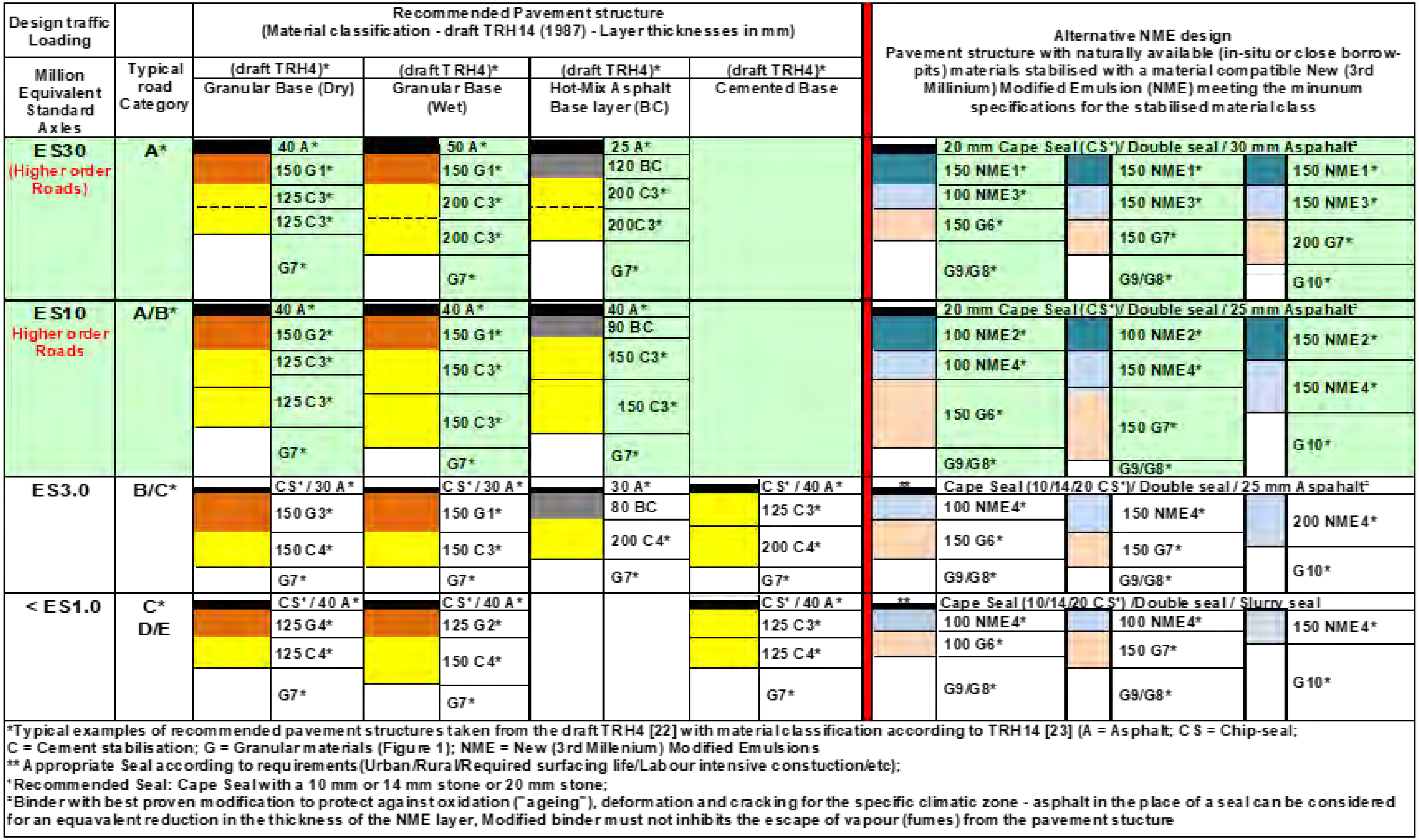


Figure 79 Comparison between traditional designs and NAGM stabilised with MC-NME

b. In-situ stabilisation

The depth to which the in-situ materials need to be stabilised is determined during the structural design process for the different uniform material sections identified along the length of the road. Independent of the requirements and decisions about the level of labour-intensive construction to be implemented, the following basic steps need to be followed:

- The in-situ material needs to be ripped to the required depth;
- Over-size material (usually more than 1/3 of the thickness of the layer but preferably not larger than 40 mm) needs to be removed – this can be done manually, and the stone used for the protection of drainage facilities if required;
- If in-situ recycling with depth control is not used as the preferred construction method, the ripped material needs to be windrowed, enabling the layer below to be compacted to the minimum required DCP penetration rates required for the layer at that depth within an applicable climatic zone. This process will also ensure that the material to be stabilised is constructed to the correct thickness. DCP-DN values (accounting for moisture content) can be used for quick and easy quality control of the compacted layer on which the stabilised layer is to be constructed;
- The material can either be mixed with the stabilising agent by hand and transferred back onto the compacted layer or transferred back and mixed using conventional equipment such as a grader and water cart with compaction equipment, or by a recycler on the road itself. For Category D and E roads, the densities can quickly and easily be determined using the DCP equipment to evaluate the required DCP-DN values for that specific layer, and
- Finally, the top of the base layer should be treated with a diluted (50:50) NME (the same as used for the stabilisation of the layer), to ensure that a firm base layer is achieved with high water resistance and protection against any possible damage, especially if it is to be opened to traffic before the surfacing is applied. Suitable application rates for the treatment of the base layer should be determined using trial sections. An application of ± 2 litres/m^2 of an NME consisting of a NPNS is usually suitable for the priming of an unstabilised base layer. Stabilised base layers will normally require a lesser application rate (± 0.6 litre/m^2).

An example of the construction of the in-situ stabilisation of a local access road using a NME stabilising agent is shown in Figure 80 (Jordaan and Steyn, 2021e). More examples are provided in Appendix F

(a) Ripping by grader;
(b) Scarifying of in situ material using a rotavator to both loosen material to the required depth and expose oversized material for removal by hand;
(c) Ripping of layer to create layer depth exposure for ease of application of the construction water-diluted MC-NME stabilising agent:
(d) Mixing of the MC-NME stabilising agent in a rudimentary water tanker;
(e) Spraying of the diluted MC-NME onto the exposed material for easy mixing:
(f) Mixing of material and cutting to level for compaction;
(g) Compaction of the MC-NME-stabilised base material using small hand operated rollers, and
(h) Applying a MC-NME diluted prime on the stabilised MC-NME base layer by hand.

Figure 80 Construction of a local access road using in-situ materials with a MC-NME

7. Selection and Design of Applicable Surfacings

7.1 Introduction

The surfacing of any road plays a critical role in its long-term performance. It:

- Prevents gravel loss;
- Eliminates dust generated from unpaved roads;
- Improves skid resistance, and
- Reduces water ingress into the pavement once surfaced.

The latter attribute is especially important for LVRs where moisture-sensitive materials are often used.

There are many surfacing options, both bituminous and non-bituminous, that are available for use on LVRs. They offer a range of attributes which need to be matched to such factors as expected traffic levels and loading, locally available materials and skills, construction and maintenance regimes, and the environment.

The main purpose of this chapter is to provide a broad overview of:

- The various types of bituminous and non-bituminous surfacings available for use on LVRs;
- Considerations and factors that affect the selection of an appropriate surfacing, and
- A simplified guideline for surfacing type selection

7.2 Surfacing Options

7.2.1 General

The main surfacing types identified for use on Low Volume Sealed Roads (LVSR) are shown in Figure 81.

Variations and further alternatives include:

- Reclaimed bituminous surfacings e.g., asphalt millings, slurry from hydro cutting operations;
- Roller-compacted concrete;
- Various forms of concrete blocks e.g., geocells, grass blocks, and
- Track applications as an alternative to full-width applications.

Although the non-bituminous surfacings are highly effective in specific situations, they are mostly used in the urban environment or, for spot applications e.g., very steep grades, construction/farm implement crossings or in situations where suitable materials for bituminous surfacings are not available.

The use of bituminous surfacings for upgrading in the African context is estimated to be more than 95 per cent, with bituminous surface treatments being the preferred option on rural low-volume sealed roads (estimated at more than 80 per cent).

A summary of the different surfacing types is provided in Appendix G highlighting advantages and concerns.

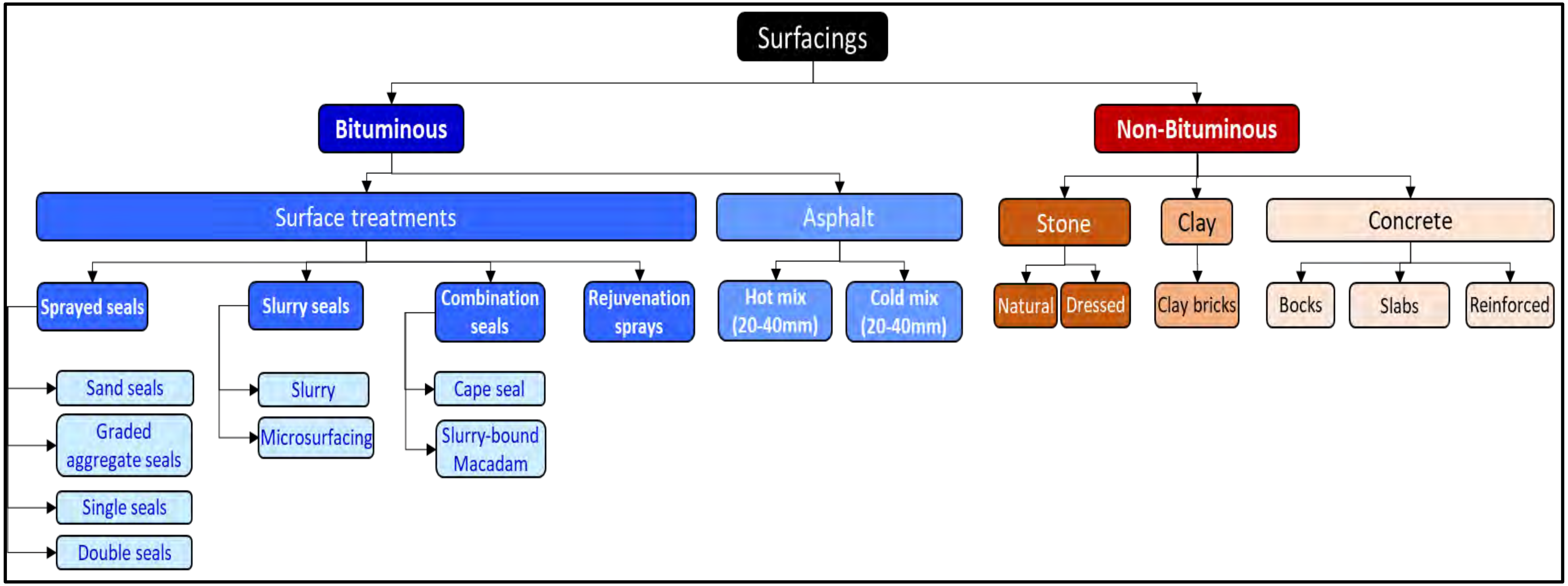


Figure 81 Surfacing alternatives for LVRs

7.2.2 Bituminous Surfacings

Bituminous surfacings for purposes of this Guideline are divided into surface treatments or seals (often referred to as surface dressings) and asphalt surfacings, as shown in Figure 81.

This section highlights the most common bituminous surfacings used with information obtained and or adapted from SABITA Manual 40 and Cook et al, (2013). All surface treatments are sensitive to the quality of the base, quality of construction, materials used and timeous maintenance. In general, as pointed out in reference documents, very thin surfacings e.g., thin slurries, single sand seals and single seals are not recommended for initial construction surfacings.

Different types of bituminous surface treatments are discussed in this section, highlighting specific benefits and risks when used as initial construction seals.

Note: More detail for the selection of appropriate bituminous surfacings can be found in guideline manuals e.g., SABITA Manual 40.

Important Notes:

1. Due to safety issues, the world trend is to move away from hot bituminous binders (Applied at 170 to 200°C) and specifically hot binders, cutback with Low Flashpoint Solvents (LFS). Adding paraffin (kerosene), diesel or other solvents on site is considered unacceptable. The impact of this is that some surfacing types e.g. thick graded aggregate seals are considered high-risk applications as the best binders to use are soft cutback binders that migrate up into the aggregate matrix over a period of time under the action of traffic;
2. The use of emulsions (applied at 60 to 80ºC) is promoted for all surface treatments
3. Continuous research has led to the modification of binders to improve performance in terms of durability, flexibility and ability to retain macro texture (for skid resistance purposes). **However, conventional binders such as cationic spray grade emulsion and 70/100 Pen bitumen are easier to use, cheaper and suitable for LVRs;**
4. Whereas standard emulsions (Slow and rapid setting) are sensitive to run-off on steep grades and particularly sensitive in high rainfall areas, high viscosity emulsions and shear thinning emulsions are now available and used at grades steeper than 10 per cent and in high rainfall areas, and
5. Recent research and development confirm several benefits with the use of MC-NME slurries. Provisional End Product Specifications are provided in 7.7.6. Additional information on MC-NME slurries are provided in Chapter 8.5.

7.2.3 Surface treatment types

The various surfacing types are fully described in APPENDIX G

7.3 <u>Important considerations for surface type selection and design</u>

7.3.1 Environmentally optimised design

International guideline documents highlight the fact that different surface types could be used along a route to optimise available funding (Figure 82). As an example, on very steep grades concrete or segmented blocks should be used as bituminous surface treatments are difficult to construct and do not perform well.

Although the focus of this document is to provide guidelines for the upgrading of unpaved roads to appropriate surfaced standards, it should be noted that unpaved roads with suitable material (natural or modified) could be cost-effective solutions to provide an appropriate level of service in certain environments.

The Rural Access Index (RAI) was originally developed as a poverty indicator for rural access and measures “the proportion of the rural population who live within 2 km of an all-season road”. The term “all-season” implies that the road can be used throughout the year and includes unpaved roads.

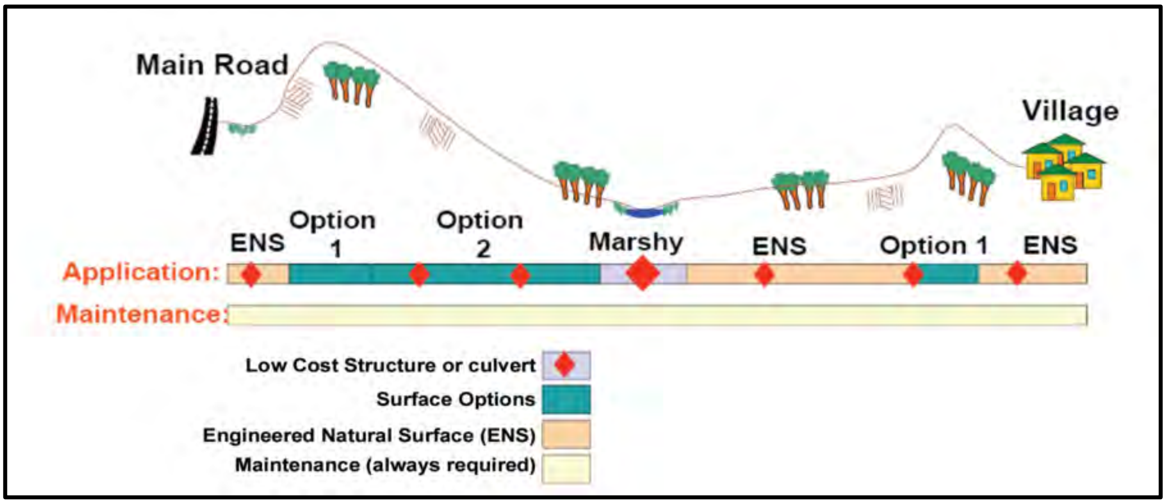


Figure 82 Alternative surface types effective for different situations

7.3.2 Optimal use of local materials

Although some material specifications have been relaxed in new national guideline documents e.g. SABITA Manual 40, there is still scope for further relaxation based on research and experience locally and in other countries.

7.3.3 Maximising local labour and development of SMMEs

Following the main objectives of this project the guideline must address the following:

- Transformation of the South African construction and engineering sectors as well as broad-based black economic empowerment. Two of the strategic opportunities highlighted are “Harness existing professional skills and support the growth of new skills” and “Use technology and innovation to improve capacity, mobility and road safety.”, and
- National policy priorities are to generate low-skilled work opportunities and support the development of SMMEs.

7.3.4 Maintenance considerations

The selection and design of appropriate surfacings must consider the maintenance capability of local authorities and recommend life-cycle strategies for maintenance. Activities for routine and periodic maintenance should be, as far as possible, suitable for execution through local labour and SMMEs.

7.3.5 Risks

Guidelines for the selection of surfacing types and binder types (in the case of bituminous surfacings) must consider:

- Safety of workers and the public during construction.

- The road user, and
- Road performance.

7.4 Key factors influencing selection

Key factors identified for the selection of appropriate surfacings for low-volume surfaced roads are:

- External stresses expected. This includes:
  - Probability of water overflowing and provision for erosion protection/ or not;
  - Probability of landslides and the risk of damage due to removal of material;
  - Induced vehicle stresses e.g. traffic volumes, turning/breaking/ actions, probability of material spillage, leaking of solvents (oil) at bus stops, damage due to farming equipment;
- Gradient of the road both in terms of:
  - Constructability;
  - Speed of stormwater runoff (Urban environment);
- Condition and macro texture of the base/substrate before surfacing;
- Material availability and costs;
- Available skills/equipment and complexity of surface types (Risk of poor performance);
- Climatic conditions, which include:
  - Rainfall intensity, duration;
  - Ambient temperatures during construction and expected operational road surface temperature;
  - Microclimate changes along the route e.g. shady areas with reduced temperature;
  - Humidity affecting the curing of emulsions;
- Environment (urban or rural) with factors influencing decisions as follows:
  - Handling of stormwater on or off the surface;
  - Topography and speed of water flow eroding surfacings;
  - Developing areas with risk of building materials and construction activities on the road;
  - Probability of greywater on the road;
  - Population density with risk of people crossing during or shortly after construction, influencing the use of hot binders and surfacing type e.g., slow setting slurries;
  - Social requirements e.g., the use of streets as playgrounds for children;
  - Population stresses e.g., risk of barricades, fires on the road etc.;
- Maintenance capability of the local authority to do repairs and to resurface when required, and
- Noise and skid requirements, which are mainly functions of the posted speed limit, macro texture and material properties.

Each of these factors should be considered either in the surface type selection, the binder type or both.

7.5 Simplified selection process

7.5.1 General

The selection process comprises two phases namely:

- Phase 1: First level decision to determine which surface type would be appropriate taking into consideration:
  - External stresses expected on the road surface;

  - o Gradient;
  - o Macrotexture, and
  - o Material availability.
- Phase 2: Second level decision considering:
  - o Suitability for labour enhanced construction;
  - o Maintenance capability of the authority;
  - o Costs, and
  - o Risks.

7.5.2 Phase 1: Performance evaluation

a. Key factors

The key physical factors that exert a strong influence on the choice of appropriate surfacing for an LVR are:

- External stresses expected;
- Gradient of the road;
- Expected macro texture after construction, and
- Material availability.

b. External stresses

Table 42 defines the severity of external stresses that affect the choice of surfacing.

Table 42 External stress categories

Very high	High risk of water overflowing, high risk of farm or industrial equipment damage, high risk of landslides and subsequent material removal
High	High occurrence of heavy vehicles turning/ breaking, a high probability of loose material on the road surface and a slight probability of the risks mentioned under “Very high”. Stormwater is accommodated on the road at steep grades in the urban environment.
Mild	Occasional turning/breaking of heavy vehicles, the possibility of loose material and very low probability of risks mentioned under “Very high”
Low	Very low risk of damage due to external stresses mentioned above

c. Gradient

Table 43 indicates the categories of gradient that affect the choice of surfacing.

Table 43 Construction gradient

Very steep	> 8%
Steep	6 to 8%
Flat - Mild	0 to 6%

d. Macrotexture

The macrotexture of a pavement refers to the visible roughness of the pavement surface and is defined as texture ("bumps and dips") in a pavement with a wavelength (distance from "bump" to "bump) ranging from

0.5 mm to 50 mm. The macrotexture is measured by determining the volumetric texture depth (SANS 3001-BT11).

Single and double surface dressings are particularly sensitive to coarse textures in the underlying layer due to the applied binder running into the voids of the existing surface and not properly adhering to the surfacing aggregate. Slurry is often applied as a pre-treatment (Void fill) to obtain a uniformly fine texture before the final surface dressing is applied.

Table 44 categorises macrotexture in terms of texture depth as a basis for selecting an appropriate type of surfacing.

Table 44 Texture depth by type of macrotexture

Macrotexture	Volumetric Texture Depth (mm)	Typical Base Type
Very coarse	> 3	WBM or excessively brushed crushed stone
Coarse	1.4 to 2.9	Well-brushed crushed stone
Medium	0.8 to 1.3	Well-graded natural gravel
Fine	< 0.7	Fine-graded natural gravel

Note: In most cases, the volumetric texture depth on roads constructed with natural or treated gravel should be less than 1.3 mm.

e. Material availability

Different to the potential utilisation of local materials in large quantities for the pavement structure, good-performing bituminous surfacings, except for graded aggregate seals (Otta seals), require crushed rock meeting set specifications.

The availability of clay bricks, rock pavers, graded angular sand, screened gravel suitable for Otta seals and single-sized sand should be taken into consideration in the final selection of the surfacing type (Table 45 to Table 47).

Table 45 High external stresses

External Stresses	Gradient	Base texture	Material availability											
			Clay Bricks	Rock pavers	Graded angular sand	Crushed stone							Graded gravel	Single sized sand
Very high	Very steep	Any texture			Concrete		Concrete							
	Steep	Any texture			Concrete		Concrete							
	Mild - flat	Any texture			Concrete		Concrete							
High	Very steep	Any texture			Concrete or ICB	ICB	Concrete							
	Steep	Any texture	√	√	Concrete or ICB	ICB	Concrete	40 AC						
	Mild - flat	Any texture	√	√	Concrete or ICB	ICB	Concrete	40 AC						

ICB = Interlocking Concrete Blocks

CB = Non-interlocking concrete blocks

20 - 30 mm AC = Thin asphalt

AC = Asphalt Continuous graded (Hot, Warm or Cold)

Slurry II = Slurry or Microsurfacing (Aggregate Grade II)

Slurry III = Slurry or Microsurfacing (Aggregate Grade III)

Cape = Cape Seal

SB Macadam = Slurry-bound Macadam

Sand blinding = Could substitute 2nd aggregate layer on double seal

Table 46 Mild external stresses

External Stresses	Gradient	Base texture	Material availability: Clay Bricks	Rock pavers	Graded angular sand	Crushed stone							Graded gravel	Single sized sand
Mild	Very steep	Very coarse			Concrete or ICB	ICB	Concrete	40 AC	SB Macadam					
		Coarse												
		Medium to fine												
	Steep	Very coarse	√	√	Concrete or ICB	ICB	Concrete	30 - 40 AC	SB Macadam	Slurry III + Cape		Slurry III +12mm slurry II	Otta seal	Improve slurry workability or Sand blinding
		Coarse								Cape		12mm slurry II		
		Medium								Cape		12mm slurry II		
		Fine								Cape				
	Mild - flat	Very coarse	√	√	Concrete or CB or ICB	CB or ICB	Concrete	20 - 30 AC	SB Macadam	Slurry III + Cape		Slurry III +12mm slurry II	Otta seal	Improve slurry workability or Sand blinding
		Coarse								Cape		12mm slurry II		
		Medium to fine								Cape				

ICB = Interlocking Concrete Blocks

CB = Non-interlocking concrete blocks

20 - 30 mm AC = Thin asphalt

AC = Asphalt Continuous graded (Hot, Warm or Cold)

Slurry II = Slurry or Microsurfacing (Aggregate Grade II)

Slurry III = Slurry or Microsurfacing (Aggregate Grade III)

Cape = Cape Seal

SB Macadam = Slurry-bound Macadam

Sand blinding = Could substitute 2nd aggregate layer on double seal

Table 47 Low external stresses

External Stresses	Gradient	Base texture	Material availability											
			Clay Bricks	Rock pavers	Graded angular sand	Crushed stone							Graded gravel	Single sized sand
Low	Very steep	Very coarse												
		Coarse			Concrete or ICB	ICB	Concrete	30 - 40 AC	SB Macadam					
		Medium to fine												
	Steep	Very coarse								Slurry III + Cape	Slurry III + Double Seal	Slurry III +8 mm slurry II		
		Coarse	√	√	Concrete or CB or ICB	CB or ICB	Concrete	20 - 30 AC	SB Macadam	Cape	Slurry II + Double Seal	Double Slurry II	Otta seal	Improve slurry workability or Sand blinding
		Medium to fine								Cape	Double Seal			
	Mild - flat	Very coarse			Concrete or CB or ICB					Slurry III + Cape	Slurry III + Double Seal	Slurry III +8 mm slurry II		
		Coarse	√	√		CB or ICB	Concrete	20 - 30 AC	SB Macadam	Cape	Slurry II + Double Seal	Double Slurry II	Otta seal	Improve slurry workability or Sand blinding
		Medium to fine			Double sand seal					Cape	Double Seal	Double Slurry II		

ICB = Interlocking Concrete Blocks	AC = Asphalt Continuous graded (Hot, Warm or Cold)	Cape = Cape Seal
CB = Non-interlocking concrete blocks	Slurry II = Slurry or Microsurfacing (Aggregate Grade II)	SB Macadam = Slurry-bound Macadam
20 - 30 mm AC = Thin asphalt	Slurry III = Slurry or Microsurfacing (Aggregate Grade III)	Sand blinding = Could substitute 2nd aggregate layer on double seal

7.5.3 Phase 1 Selection process

Table 45 to Table 47 provide guidance for the selection of a suitable surfacing.

Chip seals are sensitive to the macro texture of the base layer. If the texture is very coarse, small aggregate will fall into the voids, resulting in vehicle tyres making contact with the base aggregate. Table 48 provides guidance regarding the maximum volumetric texture depth, measured on top of the base layer, for different chip seal types to perform well.

Table 48 Recommended maximum Volumetric Texture Depth (VTD) for different seal types

Seal Code	Description	Recommended Limiting VTD (mm)
S2(10)	Double seal with 10 mm aggregate and sand	1.1
S2(14)	Double seal with 14 mm aggregate and sand	1.35
S4(10)	Cape Seal with 10 mm aggregate and one layer of slurry	1.55
S4(14)	Cape Seal with 14 mm aggregate and one layer of slurry	1.95
S4(20)	Cape Seal with 20 mm aggregate and two layers of slurry	2.75
S2(14/7)	Double seal with 14 mm aggregate and a layer of 7 mm aggregate	1.35
S2(14/5)	Double seal with 14 mm aggregate and a layer of 5 mm aggregate	1.35
S2(20/10)	Double seal with 20 mm aggregate and a layer of 10 mm aggregate	1.95
S2(20/7)	Double seal with 20 mm aggregate and a layer of 7 mm aggregate	1.95
S8(14)	Slurry-bound Macadam seal with 14 mm aggregate (25mm)	3.0

The required maximum Volumetric Texture Depth (VTD), as per SANS 3001-BT11, could be specified in the contract documentation. (95^{th} percentile)

Notes:

In addition to the above, the VTD along a uniform section should not vary more than 30 per cent from the mean.

7.5.4 Surfacing Selection Phase 2: Additional Considerations

a. Suitability for labour enhanced construction

All alternatives provided are suitable for labour-enhanced construction. Due to costs and mainly low to mild external stresses on the majority of LVRs, surface treatments will be the appropriate surfacing type in most cases.

b. Maintenance capability of the responsible authority

Following a SABITA study of appropriate bituminous surfacings for low-volume roads, the conclusion was drawn that the institutional capacity and capability of the responsible authority to maintain their roads has a major impact on the selection of appropriate surfacings.

Any bituminous surfacing has a limited life, highly influenced by oxidative hardening. If routine maintenance and reseals are not applied in time it will result in complete failure and the need for pavement rehabilitation within a short period (This is of prime importance with initial seals and even more important for granular base pavements). Therefore, if the responsible authority has poor or no institutional capacity for regular maintenance, the only option is to select more expensive/ stronger seals such as a 20 mm Cape seal or a 40 – 50 mm asphalt surfacing for new construction (Table 49).

Table 49 Recommendations related to maintenance capability

Maintenance capability	Recommended bituminous surfacing
High (Can perform any type of maintenance whenever needed)	Any bituminous surfacing
Medium (Routine maintenance, patching and crack sealing on regular basis, but no formal maintenance management system)	Only seals with double application of binder and stone, thick slurry, slurry-bound Macadam and asphalt
Low (Patching done irregularly, no committed team, no inspection system)	As above excluding double chip seals but still inclusive of double graded aggregate seals
None	Only thick asphalt (40mm) or Slurry-bound Macadam using 20mm aggregate

c. Costs

When a flexible pavement type is selected, and a choice must be made between different bituminous surfacings. Comparative costs and expected effective lives of different surfacing types are provided in Table 50.

Note: The current cost of a 14 mm single seal (2024) with a 70/100 pen bitumen is approximately R 45 per m^2. This does not include:

- Overheads including establishment, P&Gs, safety and environmental requirements, traffic accommodation and risks;
- Consultant costs including investigation, design, quality assurance and contract administration;
- Laboratory costs;
- Cost of pre-treatment (e.g., pavement repairs), and
- Line marking.

Cognisance must be taken that the cost of labour-intensive construction is usually higher than normal mechanical processes. However, the additional cost could be offset by poverty alleviation and skills development.

Table 50 Comparative costs of bituminous surfacings

Seal Code	Description	Binder	Cost ratio to 14mm single seal	Average estimated life	Labour enhanced construction	Comments
S3 (S <10)	Graded aggregate seals - Single application (<10mm) (6 mm sand seal)	MC3000	0.69			*NR-ICS
		Cat 65%	0.73			*NR-ICS
S3D (S <10)	Graded aggregate seals - Double application of single sand seal (10-12 mm)	MC3000	1.24	8	Medium	**BA-Dist; ***RI & TC
		Cat 65%	1.31	8	Good	****NS-SG[1]; ***RI & TC
S3 (S 10+)	Graded aggregate seals - Single application (10mm or more) (10mm)	MC3000	1.16	8	Medium	**BA-Dist
S3 (D 10+)	Graded aggregate seals - Double application (16-20mm covered with sand seal)	MC3000	1.80	12	Medium	**BA-Dist
	Double Otta seal (Local natural aggregate)	MC3000	2.00	14	Medium	**BA-Dist
S7 (<10mm)	Thin Microsurfacing or Slurry seal (3 mm texture slurry)		0.87			*NR-ICS
	Thin Microsurfacing or Slurry seal (6 mm coarse slurry)		1.32			*NR-ICS
S7 (>10mm)	Thick Microsurfacing or Coarse slurry seal (10 mm microsurfacing)		2.10	8	Not suitable	*****A-CSM
	Thick Microsurfacing or Coarse slurry seal (15 mm microsurfacing)		2.50	10	Not suitable	*****A-CSM
S1 (7)	Single seal with 7 mm aggregate	70/100	0.60			*NR-ICS
		Cat 65%	0.87			*NR-ICS
S1(10)	Single seal with 10 mm aggregate	70/100	0.92			*NR-ICS
		Cat 65%	1.08			*NR-ICS
		S-E1	1.01			*NR-ICS
S1(14)	Single seal with 14 mm aggregate	70/100	1.00			*NR-ICS
		Cat 65%	1.11			*NR-ICS
		S-E1	1.25			*NR-ICS
		S-R1	1.49			*NR-ICS
S1(20)	Single seal with 20 mm aggregate (16 mm)	S-R1	1.63			*NR-ICS
S2(10)	Double seal with 10 mm aggregate and sand	Cat 65%	1.24	8	Good	***NS-SG
		SC-E1	1.41	10	Good	***NS-SG
S2(14)	Double seal with 14 mm aggregate and sand	Cat 65%	1.52	10	Good	***NS-SG
		SC-E1	1.61	12	Good	***NS-SG
S4(10)	Cape Seal with 10 mm aggregate and one layer of slurry	SC-E1 (t)	1.59			*NR-ICS
S4(14)	Cape Seal with 14 mm aggregate and one layer of slurry	Cat 65% (t)	1.75	12	Good	***NS-SG
		SC-E1 (t)	1.79	14	Good	***NS-SG
S4(20)	Cape Seal with 20 mm aggregate and two layers of slurry	70/100	2.25	15	Medium	**BA-Dist
		Cat 65%(t)	2.41	15	Good	***NS-SG
		S-E1	2.40	16	Medium	**BA-Dist
S2(14/7)	Double seal with 14 mm aggregate and a layer of 7 mm aggregate	70/100	1.70	10	Medium	**BA-Dist
		S-E1	1.82	12	Medium	**BA-Dist
S2(14/5)	Double seal with 14 mm aggregate and a layer of 5 mm aggregate	70/100	1.65	11	Good	**BA-Dist
S2(20/10)	Double seal with 20 mm aggregate and a layer of 10 mm aggregate	70/100	1.98	13	Very Low/High risk	**BA-Dist
		S-E1	2.10	15	Very Low/High risk	**BA-Dist
		S-R1 / S-R2	2.30			******N-LVR-IS
S2(20/7)	Double seal with 20 mm aggregate and a layer of 7 mm aggregate	S-E1	1.94	14	Medium	**BA-Dist
S2(20/7/7)	Double seal with 20 mm aggregate and two layers of 7 mm aggregate	S-E1	2.10			******N-LVR-IS
S8(14)	Slurry-bound Macadam seal with 14 mm aggregate (20 - 25 mm)	60% Anionic	2.55	14	Very Good	
S8(20)	Slurry-bound Macadam seal with 20 mm aggregate (30 -40 mm)	60% Anionic	3.20	16	Very Good	
AC[2]	Asphalt layer with suitable grading and thickness (Continuous 15mm) within 50km of plant		2.55	14		Refer note (2)
	Asphalt layer with suitable grading and thickness (Continuous 30mm) within 50km of plant		3.32	16		Refer note (2)
	Asphalt layer with suitable grading and thickness (Continuous 40mm) within 50km of plant		3.90	18		Refer note (2)
*NR-ICS	Not recommended for initial construction seal					
**BA-Dist	Binder application only with distributor					
***RI & TC	Risk at intersections and tight curves					
****NS-SG	Not suitable on steep grades >6%[1]					
*****A-CSM	Application only with continuous slurry machine					
******N-LVR-IS	Not used for LVRs as initial seals					

Comments

General	Refer SABITA Manual 40 for more detailed information regarding limitations of different surfacing types under different conditions
	Modified binder products
	Homogenous polymer modified binders increase life with approximately 25%
	NME products might increase effective life considerable. Scientific proof required before selection
	Rejuvenation sprays could increase effective life of double seals with 3 years if applied at approximate mid-life (Cost ratio to 14mm single seal =
	Resurfacing: For life-cycle strategy analyses apply a 14mm single seal with SC-E1 binder at end of initial seal life
(1)	High viscosity emulsions, shear-thinning emulsions or double bar system rapid setting emulsions could be applied with distributors at steep grades
(2)	Hot mix asphalt not recommended for hand placement. Cold mixes suitable for hand placement but with reduced life expectancy (Approximately 60% of hot mixes). Obtain cost estimate for site

d. Risks

i. Risks related to skid resistance

Since the skid resistance of smooth-textured (fine) surfaces decreases much more rapidly with an increase in vehicle speed than that of rough-textured (coarse) surfaces, it is more important to provide a rough-textured (coarse) surface for rural high-speed roads than for urban roads/streets. Smooth-textured surfaces are desirable for the urban environment since they are both easier to clean, generate less noise and are more user friendly for pedestrians.

There is a limit to the coarseness of the texture of the surface because of the nuisance of tyre noise, its effect on riding comfort and the risk of windshield damage by large loose stones.

For LVRs the maximum posted speed is often less than 80 km/h (< 60 km/h in the urban environment) requiring approximately 0.5 to 0.7 mm macro texture depth. This could be achieved by all recommended bituminous surfacings.

In case of operational speeds above 100 km/h graded aggregate seals, sand seals and fine slurry seals are not recommended.

ii. Risks in the urban environment

Stormwater is often carried on the road to sub-surface drainage systems. With steep gradients, the speed of the water is such that rapid erosion of single and double-chip seals can occur. In developing areas with building aggregates stockpiled, the soil wash aggravates the deterioration of chip seals. Cape seals, micro surfacing and asphalt layers are the most appropriate surfacings in these situations.

iii. Particular risks related to surface treatment construction

Any single or double seal could be constructed by hand, using hand spray equipment, applying the aggregate by hand and compaction with light pedestrian-type rollers. However, the key to good performance lies in the quality of workmanship, with the risk increasing dramatically with poor base finishing and an increase in traffic volumes.

There are excellent examples of good-performing seals, constructed by hand and/or with the aid of light equipment.

Guidelines for the construction of various seal types are provided in SABITA Manual 12: Labour Absorptive methods in road construction using bituminous materials.

iv. Risk classification when using emerging contractors or for labour-intensive work

Different risks could apply to labour-intensive seal construction e.g.:

- Safety: The use of hot bituminous binders. The lowest risk is to use cold binders (Emulsions);
- Base quality: Single and double seals cannot be properly compacted with pedestrian-type rollers on base layers with surface irregularities. A poorly compacted base will result in premature failure of the seal;
- Seal constructability: Provided safety with handling hot binders can be maintained and the base is properly constructed without irregularities, Table 51 provides some indication of risk levels related to specific treatments and binder types, and
- The risk of poor performance increases dramatically with inexperienced contractors, often not having the proper equipment or experienced staff on site to control the various processes.

Although there is no excuse for poor quality work, the selection of lower-risk surfacing types and binders could reduce the risk of construction defects and, thus, minimise premature failures and/or poor longer-term performance.

Table 51 Risk Levels for Labour Intensive Seal Work and emerging contractors

Risk category	Seal/treatment type	Binders
Low	Rejuvenation	Anionic stable grade emulsions or Invert cutback emulsions
	Slurry Texture by hand	Anionic stable grade emulsions
	Boxed-in slurry layers with suitable grading for selected thickness	Anionic stable grade emulsions
	Sand, grit or graded aggregate seals	Cationic spray grade emulsion or MC3000
	Single seals with cover sprays and grit blinding	Cationic spray-grade emulsion
Medium	Single seals with cover sprays	Conventional binders
	Cape seals	Any binder except MC3000 or bitumen rubber
	Double seals (Stone & 1/3 configuration)	Hot homogeneous polymer-modified binder
	Precoated single and double seals with additional cover spray	Conventional binders
High	Precoated single and double seals, even with cover sprays	Hot homogeneous polymer-modified binder
Very high	Precoated single and double seal	Bitumen rubber
	S2 20/10 or S2 20/7/7 double seals	Any binder combination

Note: If MC3000 is used, it is recommended that the product be applied by an experienced supplier and not by an inexperienced contractor.

7.6 Prime coats

The main purpose of a prime coat is to promote and maintain adhesion between the surfacing and the base.

Standard specifications (COTO 2020) allow different products to be evaluated on the completed base against specific criteria. The factors influencing the selection of an appropriate product are:

- Penetration depth;
- Drying time;
- Softening of the base;
- Permeability, and
- Carbonation (in case of stabilised layers).

Note: More detail on prime coats can be obtained from SABITA Manual 26: Guidelines for primes, bond coats and stone precoating fluids.

Warning:

- Not all commercially available prime coats will adhere to NME stabilised base layers. It is recommended that the same NME used for the stabilisation of the base be applied in a 50:50 dilution as a prime. The application rate of the diluted NME should be similar to that of a normal prime (± 0.8 litre/m^2). Test sections should be constructed at the start of the contract to confirm application rates as some variations are possible among different products. Before specifying or applying any other prime, the adhesion to the base should be evaluated, and
- Although all hot binders should adhere well to an NME prime, cationic spray grade emulsions may not adhere well to such a prime. The adhesion of the seal binder to the primed base should be evaluated on a small trial section before sealing on a primed NME stabilised base is done.

In cases where the existing base is of adequate quality and only requiring shaping and recompaction, an NME consisting of a Nano-Polymer Nano-Silane (NPNS) could be applied to ensure that a firm base layer is achieved with high water resistance and protection against any possible damage, especially if it is to be opened to traffic before the surfacing is applied. An application of 2 litres/m^2 is suitable for the priming of an unstabilised base layer.

7.7 Surfacing Design

7.7.1 Introduction

This chapter provides information for the design of surface treatments and asphalt surfacings for low-volume roads. Different good practice guidelines could be downloaded from the following website:

https://www.sabita.co.za/non-members-manuals-and-dvds/

Concrete and segmented block surface types contribute significantly to the structural strength of the pavement. The design of such pavements is not covered in this TRH24.

The selection of appropriate surfacings is based on the expected performance thereof and life-cycle strategy costs. If not properly designed, constructed and maintained according to best practice, the costs and benefits used in the life-cycle strategy analysis become meaningless. As stated in (DOT 2011), although projects must be designed to maximise labour-based techniques and the use of local materials:

- Projects must be designed to include the development of community assets (e.g. water resources, quarries, sports fields, and public facilities) without incurring additional costs, and
- The use of labour-based construction methods **must not compromise** national and provincial road standards.

7.7.2 Design of surface treatments

a. Principles applied for seal design on LVRs

Principles applied for seal design on LVRs have been adopted from SABITA Manual 40.

https://www.sabita.co.za/wp-content/uploads/2021/12/latest-manual-40.pdf

Provided the base is not too soft (< 4 mm Corrected Ball Penetration), a range of binder application rates can be accommodated for all seal types on LVRs (< 2000 Equivalent Light Vehicles (ELVs)). The principle is explained in Figure 83 (TRH3 2007 simplified design method). For a Corrected Ball Penetration (CBP) value = 3 mm on an LVR (ELV< 2000) with an Average Least Dimension (ALD) of 8 mm, the application rate could vary between approximately 0.97 litre/m^2 and 1.12 litre/m^2 to maintain a texture depth of more than 0.7 mm.

Note: 0.7 mm macro texture depth is sufficiently safe for speeds up to 80 km/h.

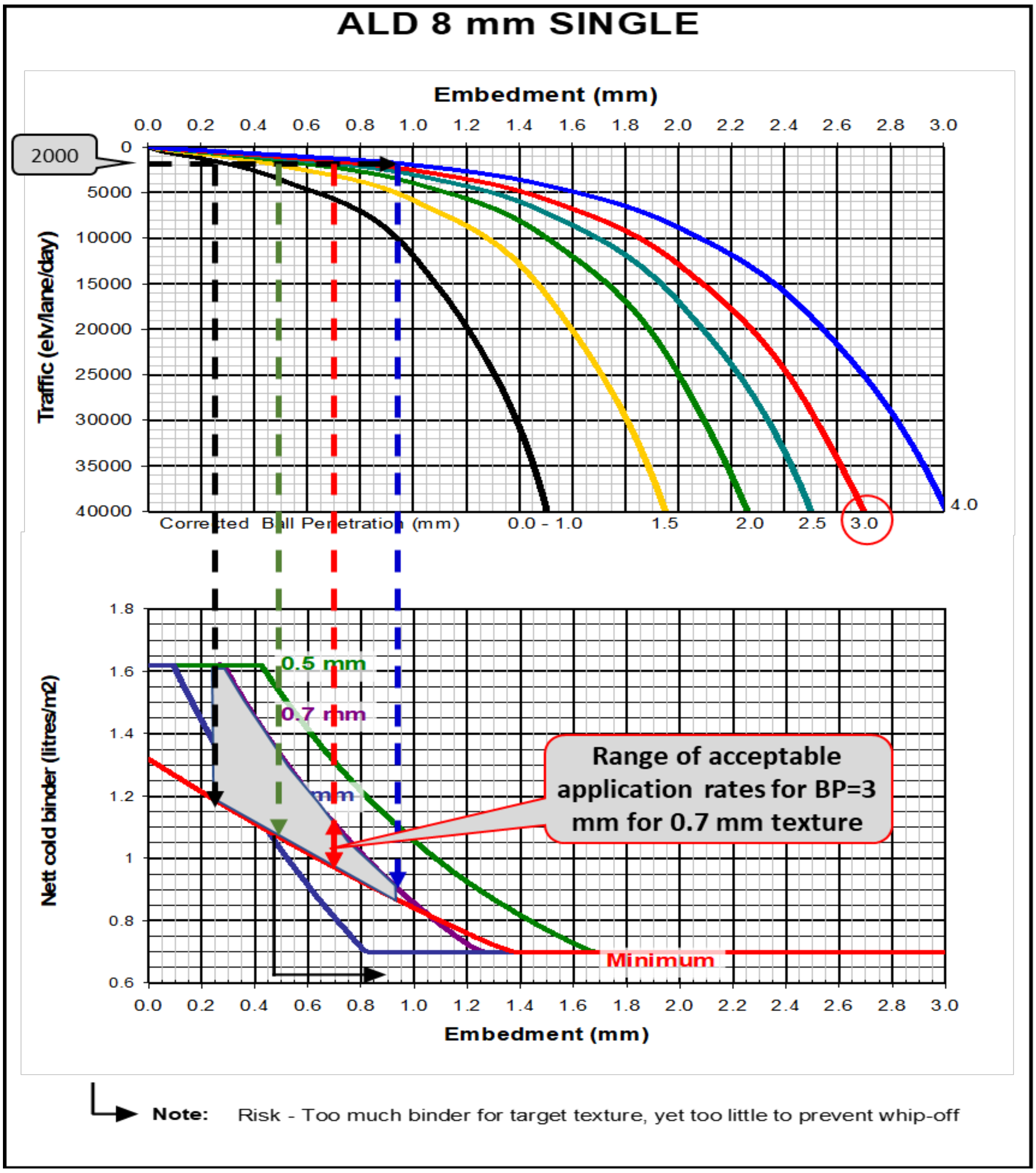


Figure 83 Higher range of acceptable application rates for harder substrates

The margin of success, not to lose aggregate while maintaining macro texture becomes very small when the substrate is soft (CBP > 4 mm).

b. Material specifications

i. Binder specifications

No relaxation for bituminous binder specifications is recommended. The specifications stated in COTO 2020 must apply.

ii. Aggregate specifications

Provision has been made in COTO 2020 to relax specifications for LVRs less than 300 vpd. A summary of material property specifications for LVRs is provided in Table 52.

Table 52 Seal aggregate specifications for LVRs

Hardness		**Limiting Value**
	Dry 10 % FACT [kN] (min)	130
	Wet 10 % FACT [kN] (min)	100
Polishing stone value (PSV)		
Aggregate position in seal	Exposed aggregate (min)	48
	Underlying aggregate (min)	45
Flakiness		
	20 mm nominal size (max)	30
	14 mm nominal size (max)	30
	10 mm nominal size (max)	35
	7 mm nominal size (max)	35
ALD		
Nominal Aggregate Size (mm)	20 (min)	**10.8**
	14 (min)	**7.4**
	10 single layer (min)	**5**
	10 second layer (min)	**NA**

For specifications on grading, shape and durability, please refer to COTO 2020.

7.7.3 Single seal design

Single seals are only recommended as reseals and not for initial construction seals. As an initial seal, variations in the base finish, areas not covered with the full binder application and potential lack of sufficient compaction, result in a too-high a risk for good performance. For the design of single reseals, refer to SABITA Manual 40.

7.7.4 Double seal design

Double seals refer to seals constructed with at least two applications of binder and two applications of aggregate. The most important input requirements are:

- Expected traffic per lane soon after construction (ELV per lane per day with 1 heavy vehicle = 40 light vehicles);
- ALD of the aggregate layers;
- Hardness/ softness of the base - Corrected Ball Penetration (CBP);
- Coarseness of the base – VTD, and
- Speed of heavy vehicles.

Table 53 provides the approximate total net cold conventional binder required for different double seals.

Further steps in the design process are as follows:

- Decision to apply a cover spray (normally a cationic 65 per cent emulsion diluted with 30, 40 or 50 per cent water and applied at 0.8 to 1.0 litre/m^2). If the cover spray is used, then 50 per cent of the residual binder from the cover spray must be subtracted from the total net cold conventional binder calculated (refer to SABITA Manual 40 for reasons to subtract 50 per cent);

- The remaining binder must now be split between the tack coat (first binder application) and the penetration coat (second binder application). Current recommendations suggest a 50/50 split between the two applications;
- In the case of using modified binders, the net cold modified binder application is now determined for each layer using Table 54, and
- The spray application rate is then determined by converting the cold binder application rates to hot-applied application rates using Table 55.

Table 53 Approximate residual conventional binder (net cold binder) for Double seals

LVRs < 2000 ELVs																
Double seals		**14/7**			**14/5**			**14/Sand**			**10/Sand**			**20/7**		
Substrate hardness (CBP)		Hard < 1mm	2 mm	Soft 3 mm	Hard < 1mm	2 mm	Soft 3 mm	Hard < 1mm	2 mm	Soft 3 mm	Hard < 1mm	2 mm	Soft 3 mm	Hard < 1mm	2 mm	Soft 3 mm
HV Speed	**VTD (mm)**															
>40km/h	Coarse (>1.3)	2.75	2.30	1.95	2.20	1.85	1.60	1.70	1.35	1.10	1.35	1.05	0.70	2.95	2.65	2.40
	Med (0.8)	2.60	2.25	1.95	2.20	1.85	1.60	1.65	1.35	1.10	1.30	1.00	0.70	2.90	2.60	2.40
	Fine (0.3)	2.45	2.15	1.95	2.00	1.75	1.60	1.50	1.25	1.10	1.15	0.95	0.70	2.75	2.55	2.40
< 40km/h	Coarse (>1.3)	2.65	2.20	1.85	2.10	1.75	1.50	1.60	1.25	1.00	1.25	0.95	0.60	2.85	2.55	2.30
	Med (0.8)	2.50	2.15	1.85	2.10	1.75	1.50	1.55	1.25	1.00	1.20	0.90	0.60	2.80	2.50	2.30
	Fine (0.3)	2.35	2.05	1.85	1.90	1.65	1.50	1.40	1.15	1.00	1.05	0.85	0.60	2.65	2.45	2.30

Note: The shaded cells indicate that the required binder application rate is too low for proper coverage

Table 54 Conversion from conventional binder to modified binder

CONVERSION FACTORS TO MODIFIED BINDER (LVRS , 2000 ELVs))									
Binder type	**70/100**	**S-E1**	**S-E2**	**S-R1**	**S-R2**	**Cationic 65%**	**Anionic 60%**	**SC-E1**	**SC-E2**
Single seal	1	1.3	1.4	1.8	1.7	1	1	1.15	1.2
Double seal	1	1.1	1.2	1.6	1.7	1	1	1.05	1.1

Table 55 Conversion from cold binder to temperature at application (Cold to hot)

CONVERSION FACTORS FROM COLD TO HOT APPLICATION									
Binder type	**70/100**	**S-E1**	**S-E2**	**S-R1**	**S-R2**	**Cationic 65%**	**Anionic 60%**	**SC-E1 or SC-E2 65%**	**SC-E1 or SC-E2 70%**
Conversion factor	1.09	1.08	1.06	1.07	1.07	1.55	1.68	1.55	1.44

7.7.5 Slurry seal design

The recommended simplified method for conventional emulsion slurry, as described in SABITA Manual 40, is considered applicable for lower volume roads (typically < 3000 vpd), provided the aggregate is well-graded and within the recommended envelopes.

7.7.6 MC-NME Slurry design and specifications

Material (crusher dust) is sourced, tested for conformance and XRD analysis carried out.

The information is provided, together with a sample of 250 kg, to an NME supplier to develop a formulation and dosage to meet the end-product specifications as provided in Table 56.

The design of NME slurry follows the formal approach as recommended in SABITA Manual 40.

In addition to the requirements for conventional slurries and microsurfacings, Indirect Tensile Strength (ITS) and High-Pressure Permeability (HPP) tests are conducted.

Table 56 NME Slurry End-Product Specifications

Test	Preparation	Test method	Measurement	Criteria
Wet Track Abrasion Test	ISSA Technical Buliten No.100	ISSA Technical Buliten No.100	Mass loss (Max)	800 g/m^2
Indirect Tensile Strength (Wet)	20 mm Briquettes prepared according to SABITA Manual 40. Soaked for 2 hours at 25^{o}C	ASTM D 6931-07	ITS (Min)	850 kPa
High Pressure Permeability	20 mm Briquettes prepared according to SABITA Manual 40.	HPP Methodology. University of Stellenboch (V1.0)	Permeability (Max)	5 ml/min

7.7.7 Cape seal design

a. Single seal component

The design for Cape seals could be done according to SABITA Manual 40, taking into account at least the following important parameters:

- Traffic (ELVs per lane per day);
- ALD of the aggregate;
- Softness of the substrate (Corrected Ball penetration);
- The Volumetric Texture Depth (VTD), and
- Heavy vehicle speed.

The approximate conventional net cold binder application rates for different conditions are shown in Table 57. The shaded cells indicate a high risk of poor performance.

Table 57 Approximate residual conventional binder for Cape seals

LVRs < 2000 ELVs										
Cape seal size		20mm			14 mm			10 mm		
HV Speed	Macro texture (mm)	Hard <1mm	1 - 3mm	Soft 3-4 mm	Hard <1mm	1 - 3mm	Soft 3-4 mm	Hard <1mm	1 - 3mm	Soft 3-4 mm
>40km/h	Coarse (>1.3)	1.80	1.45	1.15	1.20	0.95	0.75	0.95	0.75	0.55
	Med (0.8)	1.70	1.40	1.15	1.20	0.95	0.75	0.90	0.70	0.55
	Fine (0.3)	1.50	1.30	1.15	1.00	0.85	0.75	0.75	0.65	0.55
< 40km/h	Coarse (>1.3)	1.70	1.35	1.05	1.10	0.85	0.65	0.85	0.65	0.45
	Med (0.8)	1.60	1.30	1.05	1.10	0.85	0.65	0.80	0.60	0.45
	Fine (0.3)	1.40	1.20	1.05	0.90	0.75	0.65	0.65	0.55	0.45

Conversions for the use of modified binders and from cold to hot application should be done according to the recommended conversion factors provided in SABITA Manual 40.

Notes:

- Good practice suggests always applying a diluted emulsion cover spray, regardless of whether the aggregate is precoated. In this case, different from single seals, the full residual (net cold) binder component from the cover spray should be deducted from the total binder volume to obtain the tack coat application rate;
- The stable mix-grade emulsion used in the slurry seal may also be used for the cover spray. If available, this may be the most desirable. A mixture of equal parts of 60 per cent stable grade emulsion and water applied at a rate of 0.8 to 1.2 litre/m^2 is recommended;
- Compatibility of the water to be used with the emulsion for the cover spray should be checked. Water which is fit for drinking is usually suitable for the dilution of cationic (spray grade and stable mix) and anionic stable mix emulsions. In all cases the water should be added gradually to the emulsion;
- Where emulsion is used for the tack coat, the calculated spray rate may exceed the maximum permissible spray rate of 1.5 litres/m^2 (to prevent run-off). In such cases, the first spray should be reduced to 1.5 litres/m^2 and the rest of the binder should be sprayed in the second spray in a ratio of emulsion to water not exceeding 1.2 litres/m^2;
- The maximum emulsion spray rate should be reduced with steep gradients, smooth surface textures (< 0.5 mm) and very coarse surface textures (>1.5 mm), and
- In exceptional cases, where diluted emulsion cannot be used for the cover spray, the undiluted emulsion may be used.

b. Slurry component

For low-volume roads and aggregates within the COTO specifications, a mix consisting of 100 parts aggregate to 20 parts stable grade emulsion (60 per cent) by mass is recommended. The cement/lime content should be between 1 and 1.5 parts. The water content may be varied, but it will normally be about 15 parts to give a flow of 30 to 40 mm using ASTM test method D 3910.

Approximate slurry spread rates for the different Cape seal types are provided in Table 58. This could vary based on the true shape and spread of the single-sized aggregate, the softness of the substrate and the construction process. During construction, the first layer of slurry is levelled off with the top of the stone. Trafficking this layer will result in compaction of the slurry and reduce the volume to approximately 80 to 85 per cent. In the case of an open spread 20 mm aggregate, this will result in a coarse macro texture and high road noise. A final layer of finely graded slurry is then applied, again level to the top of the stone.

Table 58 Slurry Spread Rates

Single seal size (mm)	1st Layer (m^2/m^3)	2nd Layer (m^2/m^3)
20	185 to 195	360 to 370
14	195 to 205	
10	330 to 340	

The use of a MC-NME slurry as part of the Cape seal (Chapter 7.7.6) can add additional benefits in terms of flexibility, permeability and adhesion to the stone.

7.7.8 Sand seals

Generally, single sand seals are not recommended as initial seals for roads on which the traffic exceeds 750 ELV per lane per day.

Should a sand seal be selected as the initial seal, it is recommended that a double sand seal be constructed or that provision be made to reseal the road within three years. Timeous reseal, even with another sand seal, could result in a service life of the second seal above ten years.

- There is no specific design method for sand seals. A nominal bituminous binder application rate of 1.0 litre/m^2 residual binder is recommended;
- As a rule of thumb, the hot binder is applied at the following rates:
  - o Penetration grade bitumen 1.1 to 1.3 litres/m^2;
  - o Cut-back bitumen 1.2 to 1.4 litres/m^2, and
  - o Emulsion 1.4 to 1.6 litres/m^2.

The selected application is a function of the purpose of the seal, the porosity and texture of the existing seal, the grading of the sand, the prevailing temperature and the expected traffic.

Thereafter the sand is applied at a rate of between 200 and 100 m^2/m^3 and rolled for one to two weeks, depending on the traffic. The excess sand is swept back towards the wheel tracks to prevent fattiness and pick-up until no further sand is retained by the binder.

7.7.9 Graded aggregate seals (Otta seals)

The seal consists of graded aggregates (natural gravel or crushed rock) in combination with soft (low-viscosity) binders. From experience, three different aggregate gradings have been defined, namely “Open”, “medium” or “dense”.

Depending on the circumstances, a single or double layer of aggregate is constructed after which a sand cover seal is generally applied. The total thickness of a single Otta seal is approximately 16 mm. A single Otta seal with a sand cover layer is normally used with AADT < 100 vpd.

Key aspects for a successful Otta seal are:

- Using a soft binder that can work itself up into the aggregate layer;
- Maximum particle size (Preferred 16 mm - Maximum 19 mm);
- Dust content (<0.075 mm) (Preferred <10 per cent - Maximum 15 per cent), and
- After-care in the form of brooming material back into the wheel tracks during the first hot season.

From experience, suitable binder application rates have been determined and provided in Table 59.

Table 59 Binder Application Rates for Otta Seals

Hot bitumen spray rates for an un-primed base course (litre/m^2)					
Type of Otta Seal		Grading			
		Open	Medium	Dense	
				AADT<100	AADT>100
Double	1st layer	1.6	1.7	1.8	1.7
	2nd layer	1.5	1.6	2	1.9
Single with sand cover seal	1st layer	1.6	1.7	2	1.9
	Fine sand	0.7	0.7		0.6
	Crusher dust or coarse river sand	0.9	0.8		0.7
Single		1.7	1.8	2	1.9
Maintenance reseal (single)		1.5	1.6	1.8	1.7
Notes: Reduce application rate by 0.2 litre/m^2 for the first layer on a primed base course Increase application rate by 0.3 litre/m^2 if the aggregate water absorption is more than 2 per cent					

Recommended aggregate spread rates are provided in Table 60.

Table 60 Aggregate Spread Rates for Otta Seals

Type of seal	Aggregate spread rates (m^2/m^3)		
	Open grading	Medium grading	Dense grading
Otta seals	77 to 63	77 to 63	63 to 50
Sand cover seals	100 to 83		

7.7.10 Asphalt design

a. Hot mix asphalt

i. Rural areas

SABITA Manual 35 provides guidelines for the design of hot-mix asphalt. For low-volume roads with primarily light traffic, the manual recommends a Level 1 design.

Cognisance should be taken that road sections where asphalt is considered more appropriate and cost-effective than surface treatments are normally subjected to high external stresses e.g., heavy vehicle turning actions, clearing of landslides, etc.

Warm-mix asphalt provides several benefits when working in remote areas with long haul distances. SABITA Manual 32 provides guidelines for the design of these mixes.

ii. Urban areas

SABITA Manual 27 provides guidelines for thin (20 to 30 mm) asphalt layers, suitable for LVRs in the urban environment.

The key design objectives should ensure that the functional requirements associated with relatively light traffic in residential or other low-speed environments are met. These are:

- Low permeability, through limited and dispersed voids, to protect underlying layers – often granular bases – from the ingress of water;
- Compactability, given the rapid cooling of thin layers and, hence the limited compaction windows. Two compositional aspects that would require attention are appropriate maximum aggregate sizes and binder grades;
- A surface texture to provide sufficient skid resistance associated with low speeds (< 80 kph). Because of the generally low prevailing speeds to be accommodated, the skid resistance would be derived from the micro-texture of the asphalt, and
- A compliant consistency, being sufficiently flexible and durable to accommodate the transient deflections associated with light, mainly granular, pavement structures rather than meeting structural requirements e.g., stiffness (i.e., load-spreading capacity) and resistance to permanent deformation.

b. Cold mix asphalt

i. Introduction

Cold Mix Asphalt for surfacing is a cold-laid mixture of continuously graded aggregates and bitumen emulsion.

Specifications for the design of cold mix asphalt have not yet been formalised and documented in South Africa for reference purposes. However, international guidelines have been adapted for South African conditions with the assistance of experienced practitioners.

ii. Binder selection

Different emulsion formulations could be used for this purpose. Binders suitable for cold mix asphalt are shown in Table 61.

Table 61 Binders suitable for cold mix asphalt

Emulsion type	Comments
Slow setting 60% anionic emulsion	Due to slow-setting characteristics, the mix can take a long time to cure. During this period, it will be susceptible to washout by rain.
Slow setting 65% - 70% cationic emulsion	Works well with most aggregates and gives adequate working time before setting.
Micro-surfacing grade emulsion (Rapid setting polymer modified cationic emulsion)	Continuously graded premixes prepared with MS grade emulsions must be mixed with aggregate that is heated to 100 to 110 °C in either a drum, continuous type mixer or a concrete mixer fitted with a heating device such as a gas burner. The water component of the emulsion evaporates during the mixing process. The mix should ideally be stockpiled for about 10 days before use, to ensure that any residual water evaporates.
New (Nano) Modified Emulsions (MC-NME);	Due to the hydrophobic characteristic of mixes, the permeability of mixes reduces dramatically. Properties of nano polymers from different suppliers could vary significantly, leading to new proposed end-result specifications

iii. Aggregate requirements

The grading requirements for crushed aggregate are shown in Table 62 and Table 63 and the strength requirements in Table 64.

From a practical perspective: The reactivity of the aggregate with the emulsion varies between different parent rock types. Thus, trial mixes must be made up to ensure that no “balling” of the emulsion with the fines in the aggregates occurs (cationic emulsions are particularly sensitive with mostly negatively charged aggregate in South Africa) as this would prevent proper coating of the coarse aggregates. If “balling” occurs, the fines content must be reduced towards the lower boundary of the recommended grading envelope.

Table 62 Grading requirements for slow-setting emulsion mixes

Sieve size (mm)	Percentage by weight passing
14	100
10	80 to 95
7.1	58 to 85
5	40 to 68
2	19 to 40
1.18	12 to 28
0.425	6 to 16
0.3	4 to 13
0.15	2 to 9
0.075	1 to 7
Sand equivalent min. 40	
Flakiness Index Max 30%	

Table 63 Grading requirements for medium-setting emulsion mixes

Sieve size (mm)	Medium grading	Fine grading
14	100	-
10	82 to 100	100
5	54 to 75	64 to 88
1	25 to 42	35 to 54
0.3	11 to 23	16 to 28
0.15	7 to 16	8 to 18
0.075	4 to 10	4 to 12
Typical compacted thickness (mm)	25 to 50	20 to 40

Table 64 Aggregate strength requirements

Aggregate strength requirements	AADT at the time of construction	
	<100	**>100**
Min Dry 10% FACT	90 kN	110 kN
Min Wet/Dry strength ratio	0.60	0.75

iv. Design requirements

Design requirements as published in ILO 2013 for cold mixes are provided in Table 65. The degree of compaction during construction is assessed using the permeability of the layers as determined by the modified Marvil permeability test described in Sabita Manual 27. The permeability shall be ≤ 2 litres/hour.

Following research and performance testing of material treated with MC-NME, provisional end-result specifications have been developed as shown in Table 66.

Table 65 Properties of Compacted Cold Mixes

Test	Requirement
Modified Marshall Stability at 50 blows, 24 hr oven cure at 40oC and 1 hr soak (kN)	Min 3.0
Voids in Total Mix (%)	3 to 8
Flow (mm)	2 to 5
Stability loss after immersion (%)	Max 50
Aggregate Coating (%)	Min 50

Table 66 Proposed specifications for MC-NME-treated material

Test or Indicator	Material[1]	Material classification			
		NME1	NME2	NME3	NME4
Material specifications after treatment					
UCSwet (kPa) (rapid curing + 4 h in water)	**150 mm Φ Sample**	> 3 200	> 1 750	> 1100	> 750
UCSdry (kPa) (rapid curing)	**150 mm Φ Sample**	> 4 000	> 2 500	> 1 600	> 1200
Retained Compressive Strength: UCSwet/UCSdry (RCS) (%)		> 85	> 75	> 70	> 65
ITSwet (kPa)(rapid curing + 4 h in water)	**150 mm Φ Sample**	> 240	> 180	> 120	> 100
ITSdry (kPa) (rapid curing)	**150 mm Φ Sample**	> 280	> 220	> 160	> 130
Retained Cohesion: ITSwet/ITSdry (%)	**All**	> 85	> 75	> 70	> 65
Typical vertical Effective Elastic Moduli (MPa)*		600 - 300	400 - 200	300 - 100	200 - 80
UCS_{dry}; ITS_{dry} = testing after rapid curing;					
UCS_{wet}; ITS_{wet} = testing after rapid curing and 4 hours in water;					
UCS_{soaked}; ITS_{soaked} = testing after rapid curing and 24 hours in water					

For LVRs, the requirements for MC-NME4 should suffice.

7.7.11 Proprietary products

Proprietary products for cold mixes could be used if they meet the Agremént specifications (SABITA CMA, 2020).

The dense graded, cold-laid bituminous paving mixtures shall consist of:

- A uniform mixture of coarse and fine aggregates, having approximately the same bulk density, with or without mineral filler. The maximum aggregate size shall not exceed 14 mm, and
- A bituminous binder of undisclosed composition, the base bitumen of which complies with SATS 3208 or its replacement as a national standard.

Requirements for specific properties are shown in Table 67.

Table 67 Performance criteria for proprietary cold mixes

Property	Test method/procedure	Requirements
Resistance to permanent deformation	Sabita Manual 39 – ASP 4.	Min. number of passes to 12 mm rut depth: 15 000
Permeability		
Air voids:	Sabita Manual 39 – ASP8	≤ 4 %

Air permeability:	Sabita Manual 39 – ASP5	Fundamental air permeability ≤ 1 X 10^{-8} cm^2
Durability		
Binder film thickness:	Sabita Manual 35, Section 5	≥ 5 µm
Tensile Strength Ratio (TSR)	ASTM D 4867	≥ 0.70
Surface texture		
Coarse aggregate Polished Stone Value (PSV)	SANS 3001–AG11	≥ 45

7.8 Non bituminous surfacing options

7.8.1 Block or Paving Stone

Paving stones (blocks or cobbles) can be produced by cutting or breaking large natural boulders. Each stone should be a strong, homogenous, isotropic rock, free from significant discontinuities such as cavities, joints, faults and bedding planes. Rocks such as fresh granite, basalt and crystalline limestone have proven to be suitable materials. Quartzite rock is not suitable, nor is any rock that polishes or develops a slippery surface or abrades under traffic.

The material infilling the spaces between the cobblestones should be a loose, dry, natural or crushed stone material with a particle size distribution equivalent to well-graded coarse sand to fine gravel. It must be clean and free from clay coating, organic debris and other deleterious materials.

7.8.2 Clay bricks and cement blocks

Burnt clay bricks and concrete blocks are potentially useful surfacing materials. Both of these can provide good riding quality and sufficient skid resistance and are highly labour-intensive in their construction. Problems due to poor construction or insufficient support can be easily maintained with only the localised areas showing distress requiring removal and resetting, after correcting the causes of the problems. The blocks/bricks must have adequate strength and be durable.

7.8.3 Aggregates for Concrete

Concrete aggregate comprises two components – a coarse fraction and a fine fraction. The fine aggregate is usually naturally occurring sand, with particles up to about 2 mm in size. The coarse aggregate can be natural gravel or, more commonly, crushed or hand-broken stone with a range of sizes from about 5 mm to 20 mm (or sometimes larger).

Aggregates must be entirely free from soil or organic materials such as grass and leaves, as well as fine particles such as silt and clay; otherwise, the resulting concrete will be of poor quality. Some aggregates, particularly those from salty environments, may need to be washed to make them suitable for use.

Both the coarse and fine aggregates need to contain a range of particle sizes and are mixed in such a way that the fine aggregates fill the space between the coarse aggregate particles. A ratio by volume of one-part fine aggregate to two parts coarse aggregate is generally used. Aggregates can be crushed and screened by hand or by machine.

8. Required Maintenance Actions

8.1 Introduction

All roads require regular maintenance to ensure that their basic function is fulfilled for the duration of their design life. Achieving this will depend on the implementation of suitable maintenance strategies, with operations selected and carried out in a planned manner.

Important maintenance concepts are discussed in Appendix H.

8.2 Definitions

Maintenance comprises a range of activities necessary to keep a road and associated structures at the required level of service as intended during the design and phase as constructed.

Road maintenance could be categorised as follows:

Routine maintenance also referred to as "reactive" maintenance, comprises ad-hoc treatments that are applied to a pavement, structures and the road reserve to keep the assets functioning properly. Routine maintenance is carried out on roads when specific signs of deterioration are observed. Routine maintenance works are divided into the following categories:

- Non-Pavement: Include day-to-day activities that are undertaken outside of the road surface such as cleaning drains and culverts, vegetation control, line marking, guardrail repair, road sign repair, etc., and
- Pavement: Include day-to-day activities responding to minor pavement defects caused by a combination of traffic and environmental effects, for example, crack sealing, patching, edge repair, shoulder regravelling and blading.

The need for routine maintenance could be identified through formalised regular inspections and public incident reporting through a Maintenance Management System (MMS).

Periodic maintenance also referred to as preventative or corrective maintenance, comprising periodically scheduled activities that are aimed at restoring the level of service provided by a road before major repair to the road formation or structure is required. The need for periodic maintenance is generally identified through formalised annual inspections, analysis and prioritisation as part of a Pavement Management System (PMS), Gravel Road Management System (GRMS) and a Bridge Management System (BMS).

Emergency maintenance is limited to the immediate work required to reopen a road after it has been damaged by an unexpected event, making it safe for use by the road user and preventing further damage to the road. This includes the removal of debris, undertaking temporary repairs, providing a detour or bypass or similar works. Repairs carried out under Emergency maintenance are generally temporary and will require permanent works to be included from within the existing budget or programmed in future periodic or upgrading programs. Emergency maintenance is considered the most critical component of maintenance and therefore an allowance must be made each year to cover these works.

Note: Proper and responsible designs, good quality of construction, continuous routine maintenance and specifically timeous periodic maintenance, drastically reduce the need for emergency maintenance

Rehabilitation of a road, in the context of Low Volume Sealed Roads, means activities that are aimed at restoring a surfaced road that has deteriorated beyond the point at which periodic maintenance can restore it to effectively function, generally requiring major repair to the structure of the road formation and the pavement and road surfacing. These activities can include recycling existing layers and/or replacing worn or deteriorated layers with layers of equivalent strength and structure as the original road.

8.3 Maintenance planning

8.3.1 Introduction

Maintenance planning aims to identify the need for maintenance works and potential improvements of the network to achieve or maintain standards. In conjunction with road planning, appraisal and design processes, it attempts to optimise the overall performance of the road network over time. At a practical level, it aims to ensure that the correct activities are performed on the network at the right time, and to the desired quality. The process comprises a series of management functions and relates to both short-term and long-term decisions, and concerns both the whole network and individual lengths of road.
Key elements in the planning process are:

- Road network inventory and location referencing;
- Data collection (Condition assessment);
- Condition description and performance monitoring;
- Treatment (remedial measure) selection;
- Activity prioritisation;
- Budgeting and resource requirements;
- Work scheduling, and
- Contracting.

8.3.2 Condition assessment and activity prioritisation

a. General

To apply the correct maintenance treatment at the appropriate time, it is necessary to assess the condition of the road and to identify those defects that need to be corrected.

The information and detail gathered for routine maintenance and periodic maintenance activities and prioritisation thereof could differ significantly and are also different for network-level planning, and project-level investigations.

At the network level, condition assessments are undertaken visually and through instrumental measurements of riding quality, rutting and texture depth for higher-order roads. The recommended frequency for visual assessment is one to two years and for instrumental surveys three to five years.

b. Assessments for periodic maintenance and rehabilitation purposes

Knowledge of the condition of roads (assets) and their performance is essential as all management decisions regarding maintenance, rehabilitation and renewal revolve around these two aspects.

Condition data elements selected must be appropriate to describe the current condition, to apply selected performance prediction models and to select appropriate remedial measures.

The processes and recommended methodologies are described in:

- TMH 22: Road asset management manual;
- TMH 13: Automated road condition assessments;
- TMH 9: Manual for visual assessment of road pavements:
    - Part A: General;
    - Part B: Flexible pavements;

- Part C: Concrete pavements;
- Part D: Block pavements, and
- Part E: Unpaved roads;
- TRH12: Flexible pavement rehabilitation investigations and design, and
- SABITA Manual 40, Part D: Seal type and binder selection.

8.3.3 Assessments for routine maintenance purposes

Routine maintenance embraces a wide variety of different activities that are employed in response to the appearance of different defects. They are normally planned on the following basis:

- A reactive (i.e., condition responsive) basis in response to a defect exceeding a certain condition state, and
- A cyclic (i.e., programmed) basis where work is undertaken at a set frequency or a particular time of the year, the interval often varying because of environmental as opposed to traffic responses.

Assessments for routine maintenance purposes are relatively quick, executed by drive-over, occasional stops and recording whether standards are met or not and allocating a priority or urgency to the selected relevant activity. A practical way to allocate an “urgency” rating for low-volume roads is to evaluate these roads in terms of functionality criteria such as accessibility, safety, mobility and impact on pavement performance as presented in Table 68 and where applicable, estimate quantities.

Table 68 Urgency rating for routine maintenance

	Unacceptable		**Requires attention**	**Acceptable**
Urgency	**A**	**B**	**C**	
Accessibility	No Access	Difficult access with normal saloon car	Possibility of getting stuck	
Safety/ Risks	Risk of life loss or serious accidents	High risk of accidents	Risk of vehicle damage	
Mobility		Unacceptable slow movement or damage to sensitive agricultural produce due to poor surface condition	Uncomfortable driving, potential damage to sensitive agricultural produce and time loss e.g. due to poor road signs	
Performance impact		Seriously impacts the performance of the road	Impacts on the performance of the road	

Depending on the type and structure of routine maintenance contracts, the different activities could be separated e.g., for a small community-based project where skill levels are low, and equipment limited, only specific activities could be selected. This would mean that only the relevant defects are assessed on a high frequency (e.g., one-week intervals).

In the case of large area-based routine maintenance contracts, all elements that might trigger routine maintenance activities should be assessed.

Assessment items could be grouped as follows:

- Road reserve maintenance (Table 69);
- Paved roadway maintenance (Table 70);
- Unpaved roadway maintenance (Table 71);
- Drainage facility maintenance (Table 72);
- Bridge structure maintenance (Table 73);
- Miscellaneous structure maintenance (Table 74), and
- Maintenance of road furniture, signs and markings (Table 75).

The priority/urgency is marked by the assessor.

Table 69 Road reserve maintenance

Road Reserve	Vegetation Control	Grass Cutting		Creeper Grass		Bush Clearing		Trees Trimming		Trees Removal				Other Vegetation	
		Routine	Periodic	Routine	Periodic	Routine	Periodic	Routine	Periodic	Routine	Periodic			Routine	Periodic
	Animal Control	Fence Repair		Gate Repair		Cattle Grid Repair								Other Animal	
		Routine	Periodic	Routine	Periodic	Routine	Periodic							Routine	Periodic
	Litter and Obstacles	Litter		Obstacles		Dead animals		Abandoned vehicles/scrap		Anthills		Signs/encroachments		Other Obstacles	
		Routine	Periodic	Routine	Periodic	Routine	Periodic	Routine	Periodic	Routine	Periodic	Routine	Periodic	Routine	Periodic
	Slope Maintenance	Erosion prevention		Erosion Repair										Other Slope	
		Routine	Periodic	Routine	Periodic									Routine	Periodic

Table 70 Paved roadway maintenance

Paved Road Way	Routine	Rut & Depressions		Pothole/Edge		Unpave shoulder		Crack sealing		Bleeding				Other Paved routine	
		Routine	Periodic	Routine	Periodic	Routine	Periodic	Routine	Periodic	Routine	Periodic			Routine	Periodic
	Periodic	Fog Spray		Reseal		Overlay		Shoulde regravel		Shoulder reshape				Other periodic	
		Routine	Periodic	Routine	Periodic	Routine	Periodic	Routine	Periodic	Routine	Periodic			Routine	Periodic

Table 71 Unpaved roadway maintenance

Unpaved Road Way	Routine	Dragging		Sand cushion Maintenance		Dry grading/ Light blading		Pothole Patching		Erosion Runnels Repair		Dust prevention		Other routine	
		Routine	Periodic	Routine	Periodic	Routine	Periodic	Routine	Periodic	Routine	Periodic	Routine	Periodic	Routine	Periodic
	Periodic	Wet Grading		Reshaping		Regravelling		Sand Cushioning							
		Routine	Periodic	Routine	Periodic	Routine	Periodic	Routine	Periodic					Routine	Periodic

Table 72 Drainage facility maintenance

Drainage Facilities	Culvert Maintenance	Culvert cleaning		Culvert In/Outlet		Culvert Repair		Marker post		Post Reflector				Other culvert	
		Routine	Periodic	Routine	Periodic	Routine	Periodic	Routine	Periodic	Routine	Periodic			Routine	Periodic
	Drainage maintenance	Drain cleaning		Unlined Erosion		Unlined reshape		Drain lining repair		Lining Repair				Other drainage	
		Routine	Periodic	Routine	Periodic	Routine	Periodic	Routine	Periodic	Routine	Periodic			Routine	Periodic
	Erosion Protection Works Maintenance	Stone Pitching Repair		Concrete Repair		Gabion Repair		Scour and Chutes Repair		Berm Repairs				Other protection works repair	
		Routine	Periodic	Routine	Periodic	Routine	Periodic	Routine	Periodic	Routine	Periodic			Routine	Periodic

Table 73 Bridge structure maintenance

Bridge Structures	Bridge Routine Maintenance	Deck cleaning		Weep hole cleaing		Wearing course		Rails/parapets						Other routine	
		Routine	Periodic	Routine	Periodic	Routine	Periodic	Routine	Periodic					Routine	Periodic
	Bridge Periodic Maintenance	Rust & Paint		Bearings clean		Bearings replace		Steel replace/repair		Erosion repair		Concrete repair		Other drainage	
		Routine	Periodic	Routine	Periodic	Routine	Periodic	Routine	Periodic	Routine	Periodic	Routine	Periodic	Routine	Periodic
	Waterway Maintenance	Debris/ Obstacles		Waterway erosion		Waterway desilting								Other waterway	
		Routine	Periodic	Routine	Periodic	Routine	Periodic							Routine	Periodic

Table 74 Miscellaneous structure maintenance

Miscellaneous Structures	Drift & Causeway Maintenance	Structure damage		Waterway		Drift reshaping		Marker post		Post Reflector		Stone pitching repair		Other drift	
		Routine	Periodic	Routine	Periodic	Routine	Periodic	Routine	Periodic	Routine	Periodic	Routine	Periodic	Routine	Periodic
	Retaining Wall Maintenance	Minor repairs		Weep hole		Vegetation clearing								Other retaining wall	
		Routine	Periodic	Routine	Periodic	Routine	Periodic							Routine	Periodic
	Railway Crossing Maintenance	General repairs												Other Railway	
		Routine	Periodic											Routine	Periodic

Table 75 Maintenance of road furniture, signs and markings

Furniture, Signs and Markings	Road Furinture Maintenance	Guardrails		Kerbstone		Kerb maintenance		Distance marker						Other furniture	
		Routine	Periodic	Routine	Periodic	Routine	Periodic	Routine	Periodic					Routine	Periodic
	Road Sign Maintenance	Sign cleaning		Repainting		Sign repair		Sign replace						Other signs	
		Routine	Periodic	Routine	Periodic	Routine	Periodic	Routine	Periodic					Routine	Periodic
	Road Marking Maintenance	Repainting		Reflective studs										Other marking	
		Routine	Periodic	Routine	Periodic									Routine	Periodic
	Rumble Strips and Speed Humps	Rumble strips		Speed humps										Other speed	
		Routine	Periodic	Routine	Periodic									Routine	Periodic

8.4 Maintenance Delivery Models

Labour-based maintenance has proved to be cost-effective globally for several years. Guidelines are readily available (Johannessen, 1999; PIARC 2001; Donnges et al 2007). Cook et al. (2013) described several general options for the actual delivery of the maintenance, including:

- Direct public works (Force Account);
- Large contractor;
- Small local contractor or SME;
- Contracted local groups;
- Village Groups, and
- Single contracts (Length-men).

Each of the above has its advantages and disadvantages depending on the physical, climatic and financial environment (Johannessen, 1999). Overarching some of the above is a decision on the contracting model to be used; traditional BoQ based or some form of a performance-based contract. This latter option is being increasingly favoured by donors (Salomonsen and Diachok 2015; Silva et al, 2011).

The contractor in an output or Performance-Based Contract (PBC) for road maintenance is paid on a monthly or quarterly basis for maintaining the road at a specified service standard. The resulting condition of the road is defined by performance criteria rather than on an input basis as occurs under traditional maintenance contracts where payment is based on the volume of work (Bull et. al 2014). These performance criteria are basic and easily measurable, targeting the principal defects to be addressed (e.g., maximum number, size and depth of potholes; maximum height of vegetation; maximum allowable degree of blockage of the drainage system). This is in contrast to the BoQ-based approach where the contractor is paid strictly in terms of the time and resources used as per a submitted list of costed items.

Whilst there are undoubted advantages for the performance-based approach, there remain significant challenges for its implementation at the LVR level in terms of Client/Contractor experience, particularly in terms of appreciation of risk, for example from climate impacts. To be effective a PBC-based LVR initiative is only applicable for "maintainable roads"; that is roads that are generally fit for purpose and have only minor defects which can be rectified using routine or periodic maintenance, without significant rehabilitation.

8.5 Implementation of New Technologies

8.5.1 General

The goals and objectives of rural road development include the implementation of new technologies to “do more for less”.

The international market is flooded with proprietary products claiming huge benefits. Although true in many cases, procurement rules prevent authorities from utilising such products unless they adhere to either generic material specifications, Agrément certification or, end-product specifications.

The development of Nano Modified Emulsions (NME) both with a Bitumen Emulsion (BE) basis or a Nano Polymer Nano Silane (NPNS), opened new possibilities to the cost-effective maintenance of surfaced roads as well as to gravel preservation of the shoulder materials (or, for that matter on unsurfaced roads). These options includes:

- MC-NME precoating of stone (chips) used in single or double seals;
- Alternatives to fog sprays, i.e., “clear seals” consisting of a 1 to 10 mixture of a Nano Polymer Nano Silane (NPNS) with water applied to existing surfaced pavement;
- MC-NME mixtures to mix locally at ambient temperatures for pothole repairs, and
- MC-NME mixtures for surfacing slurries, also as part of a Cape seal.

8.5.2 MC-NME precoating of stone (chips) used for single or double seals

Limited trail sections have been done since 2018, replacing traditional precoating mixes with a MC-NME pre-coating on actual reseal projects in a comparative study. The use of the MC-NME resulted in zero stone loss, compared to a 2 per cent to 4 per cent stone loss using traditional precoating additives.

These results are in expectation with the chemical bond created between the aggregate and the binder when using the MC-NME precoating agent. With traditional precoating agents, adhesion is established through a bit of binder absorption and the filling of crevasse in the stone (ships). The selection of a suitable MC-NME pre-coating agent should be done similar to the selection of a suitable NME stabilising agent as discussed in Chapter 6.

8.5.3 NME (NPNS) “clear seals” as alternative to diluted bitumen emulsion fog sprays

The development of a “clear seal” consisting of an NME – NPNS have been shown to potentially be a game -changing technology (Jordaan and Steyn, 2022; Jordaan and Steyn, 2023; Horak, et al, 2024) for cost-effective preventative maintenance, protecting existing surfacings through waterproofing in cases where

- Existing surfacing exhibiting micro cracking’s where water-proofing will prevent water ingress and accelerated deterioration of pavement layers;
- Existing pavement structures showing distress in terms of pothole forming and deformation due to water ingress, where immediate interim intervention is urgent required to limit distress in preparation for a more permanent solution in terms of, for example, an NME slurry with a zero HPP, restoring some irregularities and providing a surface with no water penetration, and
- Protection of gravel shoulders (and surfacings against erosion and the effect of rolling wheel abrasion.

The clear seal normally consists of the dilution of 1 litre of NPNS in 10 litres of water where some minor distress (micro cracking may be evident and can be adjusted to a 1 to 20 litre dilation where only porous surface void filling may be done. When little or no surfacing distress is evident, the NPNS can be dissolved in a water truck with the required water and distributed or applied by hand in cases where significant differences in surface condition are present. Application rates depend on the condition of the existing surfacing and applied until saturation is achieved. Figure 84 shows application of a NPNS "clear seal" by hand to saturation, ensuring waterproofing of the surfacing layer (a), as measured using the Marvil apparatus (b)

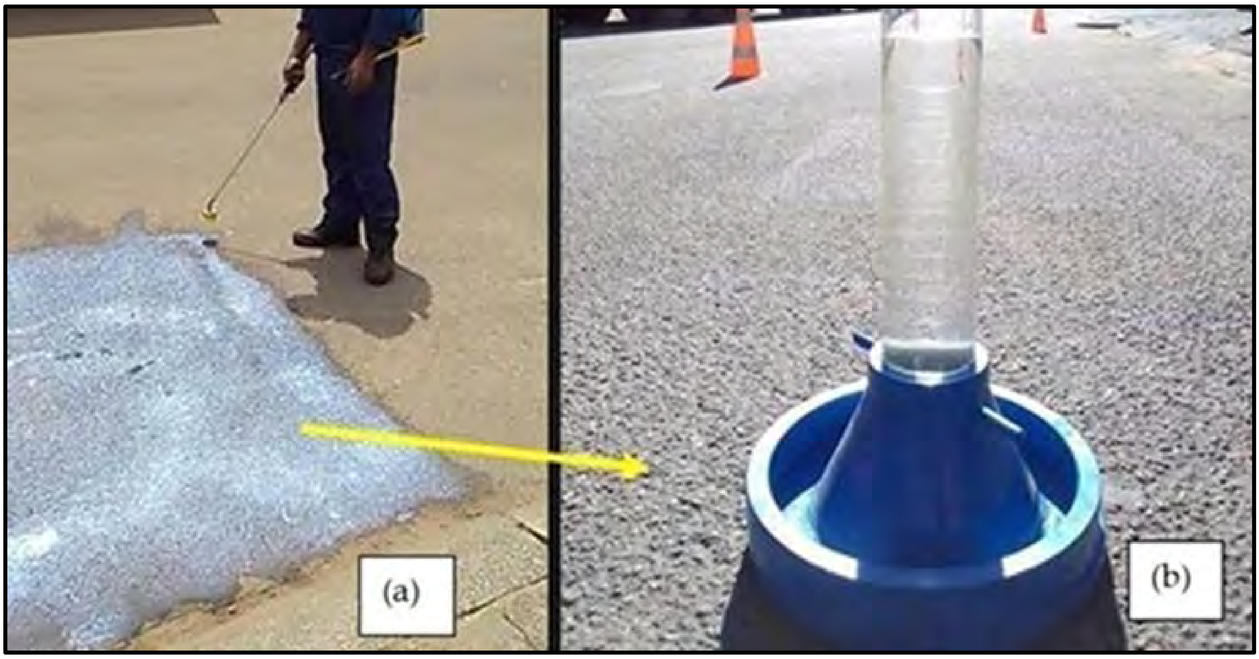


Figure 84 Hand application of a NPNS "clear seal and permeability measurement

Figure 85 Application of a NPNS clear seal from a flow-bin on the back of a trailer

The application of a NPNS clear seal offers several advantages in comparison to alternative enrichment using diluted bitumen emulsions. The particle sizes of a good Nano Polymer varies between 40 and 80 nm with an associated particle size of a high-quality Nano Silane of less than 1 nm, while a bitumen emulsion particle is between 1 and 5 µm in size. A particle sizes of a rejuvenating agent will result in a temporary surface sealant with benefits ranging from 1 to 2 years. The considerably smaller particle sizes of a NPNS clear seal penetrates micro cracks in depth, rendering it waterproof for effective sealing lasting considerably longer. Due to the small particle sizes of the NME-NPNS clear seal no change in the skid resistance has been shown. The clear seal application will dry within 1 hour, with no need for the repainting of road traffic markings.

Quality control on site can easily be done with each batch of clear seal delivered, by testing the product using a Marshal mould filled with building sand (fine sand). The application of a comparative application rate on the top of the building sand in the Marshall mould should result in the penetration of the NPNS clear seal to the full depth of the Marshall mould. After 48 hours in an oven at 40 – 45ºC, the bottom of building sand at the full-depth of the Marshall mould should be bound together and water applied to the bottom of the material should show droplets forming as an indication of the waterproofing achieved throughout the depth of the Marshall mould with the building sand.

At this stage, no comparative data comparing conventional rejuvenators (fog sprays) against NPNS clear seals are available. However, the proven water repellent characteristics of the Nano Silanes together with the considerably smaller particle sizes of the nano polymer binder (25 to 125 times smaller than a typical bitumen particle) makes this an alternative that warrants more comprehensive consideration for implementation.

8.5.4 MC-NME pot-hole mixes using locally available granular materials

Pothole mixes using MC-NME liquid to mix with locally available granular materials, considerably reduces costs, can be used at ambient temperatures, provide a waterproof solution and is labour intensive. The same principles contained in Chapter 6 for the development of a MC-NME stabilising agent for the stabilisation of NAGM, are also applicable to MC-NME pothole mixes. The End Product Specification for a pothole mix is also a function of the traffic loading (refer Table 41).

8.5.5 Protection of gravel shoulders against erosion and gravel preservation

The NME (NPNS) technology has shown great promise to penetrate gravel to a depth of at least 60 mm (using a standard Marshall mould of 60 mm in thickness as discussed in Appendix E, Item F1014. This aspect has also been demonstrated in practice, where flood waters have caused no damage to compacted NME layers subjected to high flood conditions (Jordaan and Steyn, 2022b).

The potential impact and cost implications of this technology require more thorough investigation in terms of potential use for gravel preservation on shoulder materials and on unpaved roads.

8.5.6 MC-NME slurries as a maintenance option

The use of NME slurries have already been discussed as a surfacing option in Chapter 7.7.6, including preliminary End Product Specifications. The relatively high flexibility achieved without any cement additive, together with a zero HPP water test makes this an attractive option for use as a preventative maintenance option, especially on highly flexible rural roads or even within urban environments faced with severe pavement surfacing deterioration and vehicle turning actions. This option is also labour intensive, working at ambient temperatures, presenting authorities with relatively cost-effective option to address immediate problem areas along road networks, while creating numerous labour-intensive work opportunities and opportunities for the development of SMME's. In such cases it is advisable that local authorities go out on tender directly to available suppliers using the recommended "End Product Specifications. Successful suppliers meeting the minimum required engineering properties will supply the MC-NME liquid directly to the authority for distribution within its jurisdiction to labourers and/or SMME's.

The application of NME slurries as a maintenance option using a continuous slurry machine (10 -12 mm), could improve riding quality on roads by eliminating some unevenness (Figure 86).

Figure 86 Application of a 12 mm MC-NME slurry using a continuous slurry machine

Trials were conducted to evaluate the ease of mixing MC-NME slurry with small equipment and application by hand. A uniform thickness with smooth surface was obtained without any difficulty (Figure 87).

Figure 87 Mixing and hand application of a 12 mm MC-NME slurry

8.5.7 Sequence of maintenance actions addressing highly distressed roads

Large portions of rural and urban road networks are exhibiting severe distress. Faced with limited resources, authorities need to address current problems effectively using available technologies within the restriction of funding regimes. Using the above-described technologies, a combination of the action may provide options not previously available as temporarily relief. The sequence of events to improve the severely distressed roads is illustrated in Figure 88 (Jordaan and Steyn, 2023).

Although many of the aspects are still in a test phase, the proven hydrophobic characteristics of a good nano silane together with various actions as shown, makes this option an improvement to the "do nothing" option.

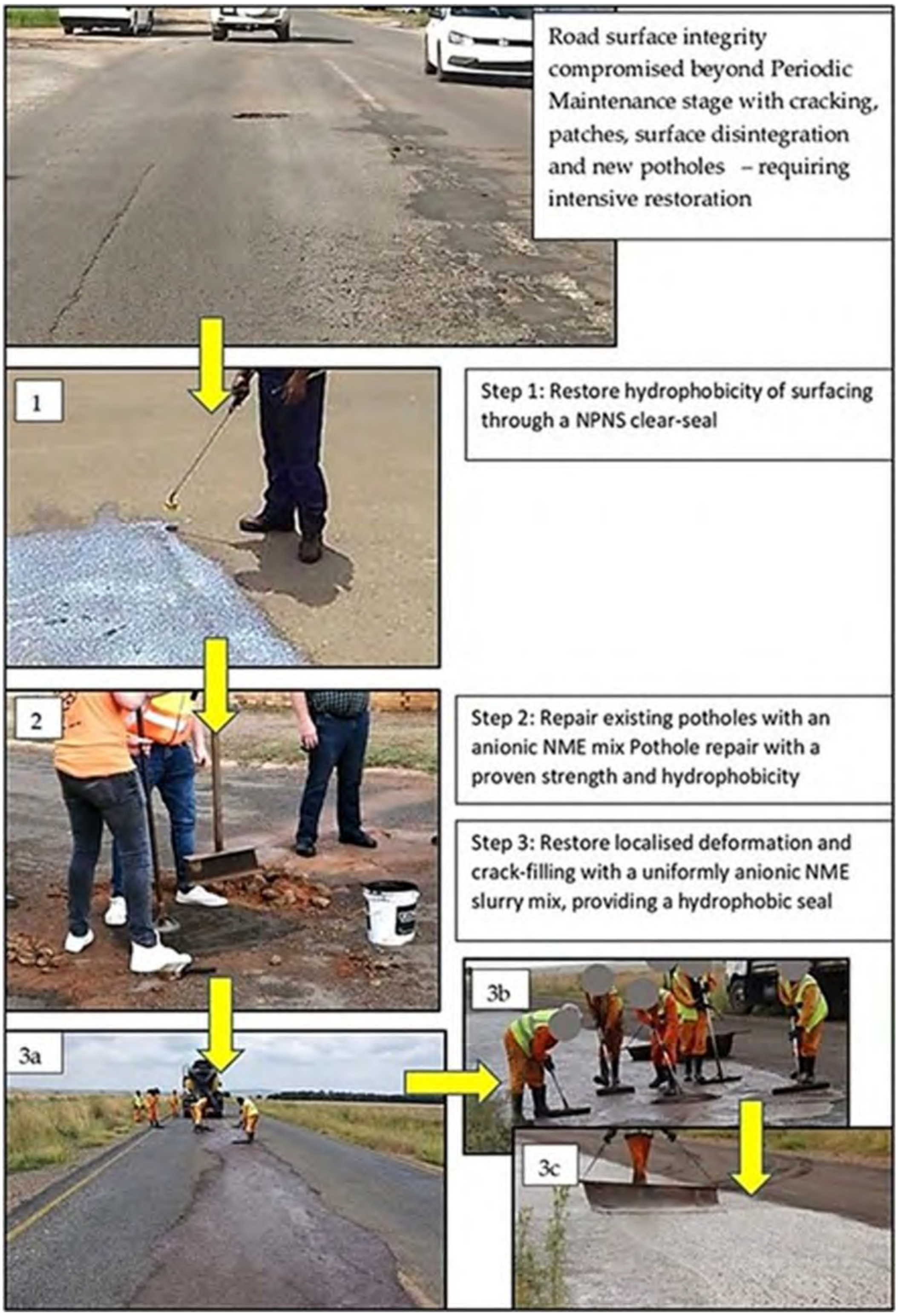


Figure 88 Sequence of events to restore severely distressed roads

8.5.8 Drive towards end-product specifications

To stimulate innovation in the local industry and to allow suppliers to compete on a level playing field it is essential to develop end-product specifications for maintenance treatment products. This requires both fundamental and practical research.

Significant work in the utilisation of nanotechnology has led to end-product specifications for treating local marginal materials for road pavement layers (Jordaan and Steyn, 2020). However, specific research is required to quantify the cost-effectiveness and to develop/finalise end-product specifications for maintenance treatments e.g.:

- Cold mixes for pothole and edge repairs;
- Additives to improve properties of slurry mixes i.e., tensile strength, and permeability;
- Additives for improved binder- aggregate adhesion, and
- Rejuvenators.

Whereas the specifications for MC-NME4 materials (refer Table 41) could be applied to cold mixes, the effect of different additives on the short- and longer-term rheological properties of bituminous binders e.g., ageing or excessive softening, is not properly quantified.

Regarding rejuvenators, the standard practice for decades in South Africa has been to apply a diluted anionic stable-grade emulsion. Performance studies confirmed an increased surfacing life of three to four years. Research by suppliers led to the development of proprietary products, which proved to extend the effective service life of surface treatments by up to four years (Figure 89). Based on the proven performance, generic specifications were developed for invert emulsions that could be used as rejuvenators and were incorporated in COTO 2020.

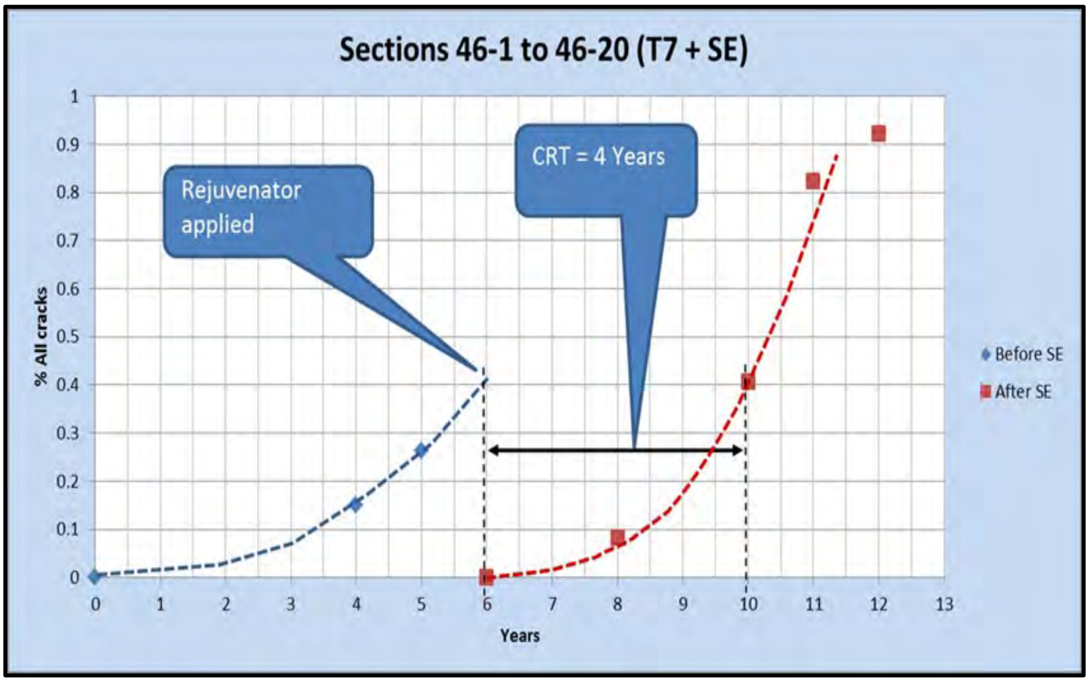


Figure 89 Rejuvenator extending effective service life for four years (SABITA Manual 40)

Continuous research with nano silane products has highlighted that additional benefits could be obtained to improve the flexibility of aged binders while dramatically reducing the permeability of existing seals (Jordaan, 2021). Due to the different properties and characteristics of products from different suppliers, suitable parameters must be identified to measure the effectiveness and to set appropriate specifications.

9. Method of Contract for Upgrading of Unpaved Roads

9.1 Introduction

9.1.1 Purpose

This Chapter is specifically aimed at recommending sound procurement processes to be followed, meeting the objectives to be achieved within the existing legal framework, while ensuring that all specifications are being met in terms of infrastructure development in support of the people of South Africa without compromising quality and durability.

9.1.2 Objectives

The objective is to recommend a contract procurement and project management programme that will enable the objectives of the project to be maximised within the current legal framework, i.e., to:

- Enable the labour content of the works to be performed through the specification of the construction processes aimed at the maximisation of labour-enhanced procedures, and
- Manage projects in such a way as to allow SMMEs to develop and fully participate in all aspects of the road construction works.

Considering the objectives, it is realised that tasks for the execution of normal road construction projects within any specific implementing authority will require adoption that may range from considerable to relatively minor, depending on the original mandate of the authority i.e., from National to Regional to Municipality. All Road authorities will have adopted management procedures and quality control procedures to enable projects to be performed according to strict regulations and standards applicable to the road networks they were mandated to manage in support of the greater well-being of the South African economy as a whole. With the roles hanging considerably in terms of the accommodation of the Upgrading of Unpaved Roads, these specifications, criteria and management procedures may need considerable adaption, depending on the road authority involved.

Nevertheless, all adaptations must be done within the existing legal framework, enabling road authorities to fully adhere to the requirements of the fiscal auditing authorities and meeting the checks and balances required to obtain a clean audit in terms of procurement regulations, expenditure and associated accountability. It follows that the recommendations of the “Type of contract” to be adopted must fully allow any authority to still be able to obtain clean audits as per existing fiscal requirements.

The recommended procurement approach for the Upgrading of Unpaved Roads is aimed at addressing the objectives of the programme, ensuring that all the procurement requirements are met in full. Any recommended procurement process must allow for:

- Optimisation of labour content of projects without compromising the applicable standards and the required integrity of the road pavement structure,
- Opportunities for the development of viable SMMEs, ensuring financial support (e.g., through sessions for the direct payment through sessions of, e.g. equipment and material suppliers) and technology transfer to ensure that the applicable specifications and design criteria are met, and
- Full access for all material suppliers of MC-NME stabilising agents (where required) to compete on an equal basis based on the test procedures and material specifications as provided.

9.2 Recommended procurement procedures

The main components and the main responsibilities of the various role-players in the recommended procurement process are highlighted in Figure 90.

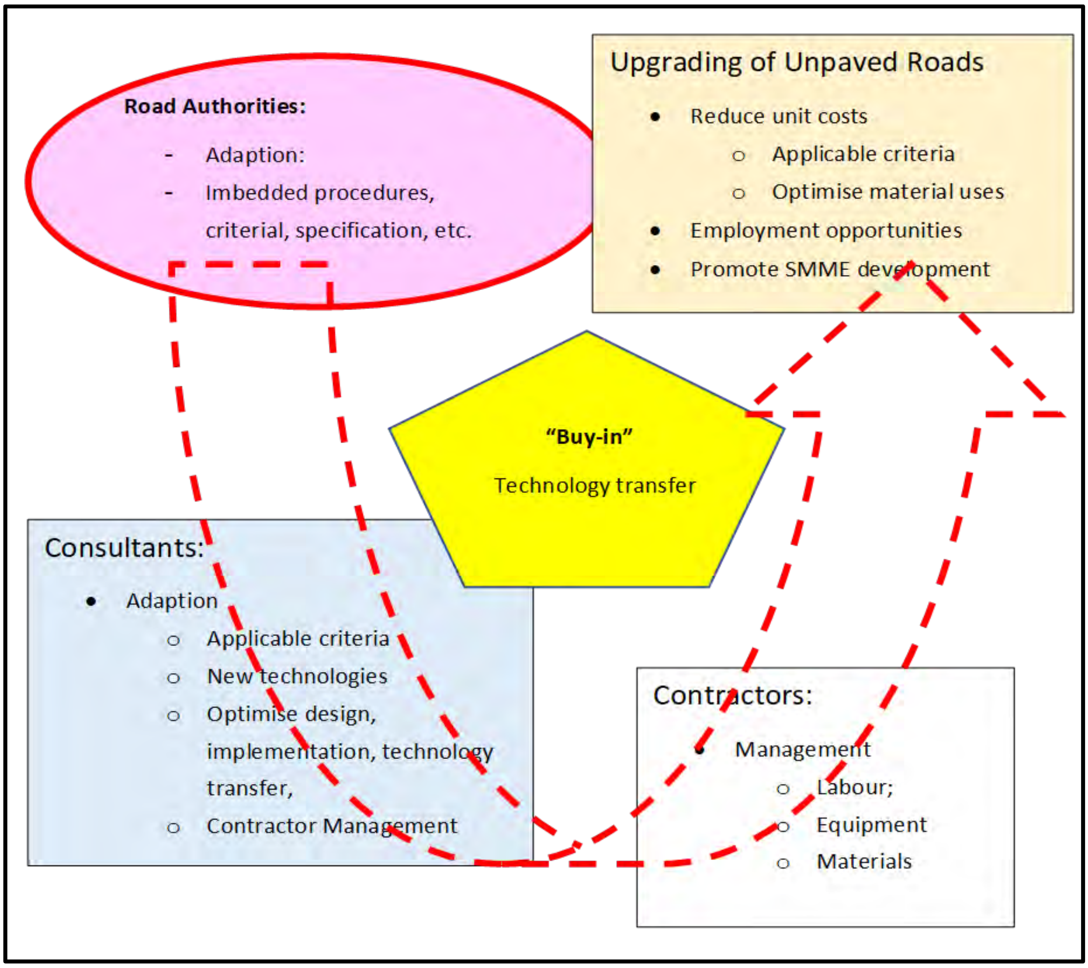


Figure 90 Role-players and their responsibilities in the recommended procurement process

9.2.1 General

The procurement of the Works for road construction and maintenance takes on many forms. Each procurement form is suited to particular circumstances. The various forms of procurement of works are outlined in Table 76.

Conventional wisdom is to allocate risk to the party best placed to manage it. Therefore, it is standard practice to use the contract most suited to the associated risk profile.

There are numerous models developed all over South Africa and the rest of the World aimed at increasing the labour content of road construction projects. Several Provincial and Municipal Road authorities within South Africa have developed their implementation strategies aimed at the development of SMMEs and increasing the labour content of their road infrastructure projects to meet the objectives of their constituencies

In the case of upgrading and maintenance of Low Volume Roads, consideration must be given to:

- Economic situation to secure stable funding;

- Readiness and quality of the industry to take and maintain responsibility;
  - Client: Maturity of Road Asset Management, prioritising needs and development of asset management plans, procuring services timeously, payment for services delivered, and
  - Contractors and small enterprises: Staff skills and quality of equipment to meet specifications, financial standing and stability.

Table 76 General forms of procurement

Procurement type	Description
Conventional Procurement	The contractor is appointed by the client to construct the works as designed by the designer. Normally the designer is a consulting engineer. The consulting engineer also administers the contract and monitors that the contractor constructs the Works as designed and that the works comply with the specified requirements.
Product Performance Guarantee System (PPGS)	The contractor includes a guarantee for one of the final products constructed/used in the works, which is normally a proprietary product or for the result of work utilising a proprietary product. Examples are a specific type of final surfacing, such as a UTFC, a type of bridge joint, or the sealing of joints in concrete pavements utilising a proprietary joint sealant. Therefore, there is a reduced need for monitoring quality during construction on behalf of the client.
Design and Construct	The client specifies the works (facility) required and its intended purpose. The contractor employs a designer and delivers a Turnkey solution that must meet the intended purpose of the facility. Turnkey implies the client literally turns the key and takes over the road.
Design, Build and Operate (DBO)	The client specifies the works (facility) required and its intended purpose, as well as hand-over conditions. The contractor employs a designer and delivers a Turnkey solution that meets the client's requirements. The contractor then operates and maintains the facility for a specified period before handing it over to the client.
Concession	The concessionaire, which is typically a consortium consisting of a contractor, consulting engineer (designer) and financier, provides a complete solution for a section of road for a pre-set period, the concession period. Only the level of service provided to users is audited by the client during the concession period.

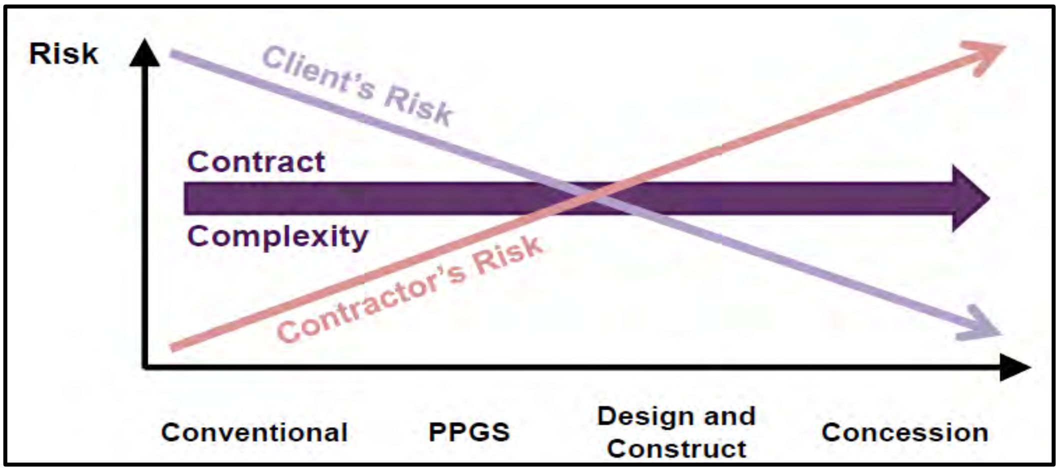


Figure 91 Risk profile in relation to the type of contract adopted

The current situation suggests that the contracting industry is not ready to take high risks. Therefore, most risks should be taken by client bodies.

The conventional/traditional client, consultant and contractor concept can be maintained within a framework where the responsibility and the works are still transferred to a contractor.

a. Conventional contract suitability and procedures

Conventional contracts are suited to projects where the client, or their agent (consulting engineer), knows what is required and can specify this in the tender and contract documentation. The contractor then prices the tender with the knowledge of what is required and how to achieve those requirements. The client has systems and resources, such as consulting engineers, in place to ensure that the contractor achieves these desired requirements during construction, in the knowledge that if these are achieved, the project will be successful.

This form of contract is normally suited to road construction and rehabilitation situations where the clients, consulting engineers and contractors are all knowledgeable and have a good understanding of readily available technologies and materials. It is the most suitable form of contract for roadworks where there is sufficient time for investigation, design and contract documentation. All the possible uses of locally available materials are investigated and all risks can be identified and allowed for in the contract documents. All the items of work are properly quantified and specified in the design, schedule of quantities and related specifications and documentation. The contractor, in turn, prices these items with minimal allowance for extraneous risks. Variation orders are issued during construction to cater for any situations that were not catered for in the bill of quantities. This type of contract, therefore, delivers a fair price for the work involved.

Note: The contractor will still be required to tender for the works, taking limitations into account as to the role required to be performed in the execution of the works. In such a scenario, the Main Contractor will be limited to performing specialised services only, while providing the required skill set for the technology transfer and managerial input to SMMEs to perform non-specialised services. Within such an approach, little change would be affected in many road authorities already implementing similar structures. The appointed contractor will, as usual, provide the entire necessary legal requirement for the execution of the works and deal with the consultant and the Client as per the normal contract.

9.2.2 Recommendations

The main principles of the recommended procurement and execution process to be implemented for the upgrading of unpaved roads are contained in Figure 92.

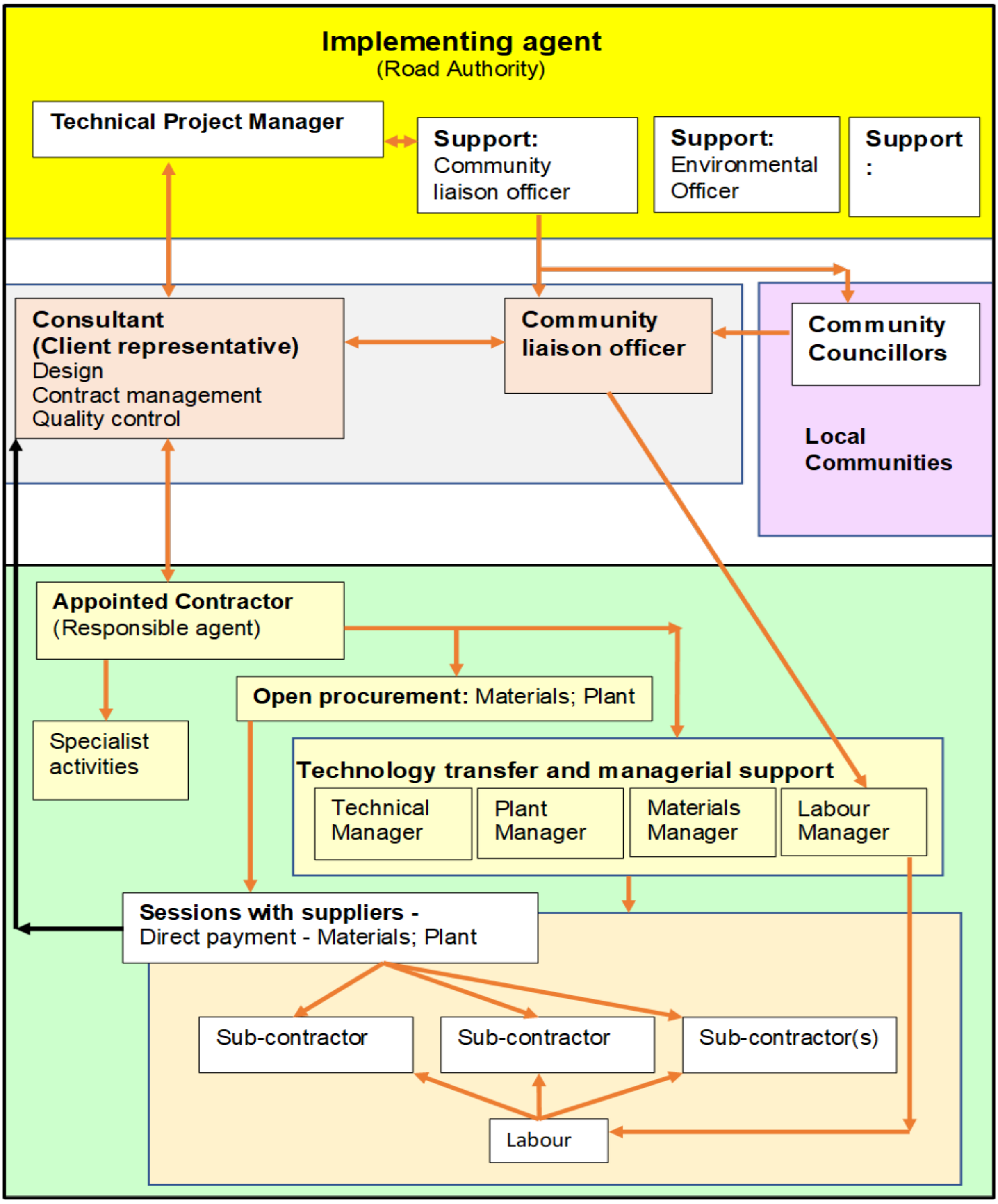


Figure 92 Recommendations towards an applicable method of contract

These recommendations take into consideration that:

- Many road authorities have in place management procedures aimed at the Client, consultant and contractor roles in the provision of road infrastructure;
- Many road authorities already have in place the required structures containing the main elements as shown in Figure 92, with specific reference to in-house labour-relation officers and in-house procedures and requirements for enhanced labour construction projects with all the associated legal requirements;
- Knowledge about construction methods and the practical execution and management of projects is mainly based in the construction sector of the industry and hence, they are the best equipped to give the technical expertise and training to SMMEs, and
- SMMEs will not have the required funds to buy or hire equipment and/or the materials to execute projects and will need assistance, hence it is recommended that Sessions be signed with preferred suppliers and equipment. Direct payment to suppliers of specialised materials such as MC-NME stabilising agents will be done in accordance with the prescribed " End product Specifications" as detailed in Appendix F and, with the risk vested in the Contractor with his supplier to meet the minimum specifications as per the design of the upgrading. During the design stage, the Consultant must do the necessary tests to assure himself that the specifications can be met.

9.3 Procurement of MC-NME solutions for the stabilisation of Naturally Available Granular Materials (NAGMs)

9.3.1 Defining MC-NME stabilising agents

Materials Compatible New (Nano) Modified Emulsion (MC-NME) stabilising agents or similar where an emulsion is defined as any additive in the form of a solution, including any additive added to the construction water, including (but not limited to):

- Bitumen emulsions with/without a modified emulsifying agent (e.g., aggregate adhesive, water-repellent agents (e.g., organo-functional-silanes) and/or with the addition of polymers (micro- and or nano-polymers);
- Material-compatible polymers (micro- and/or nano-polymers) with or without a modifying agent, or
- Any "alternative" rock/aggregate/soil stabilising agent.

In the context of this document, MC-NME may be considered as an abbreviation covering the use of any or all of the above-mentioned stabilising or material improvement additives. However, the engineering requirements in terms of strength criteria, sample preparation and test protocol contained in this document must be met in all cases.

The END PRODUCT SPECIFICATIONS (EPS) require an MC-NME to be verified prior to usage AND GUARANTEED by the contractor through his supplier using a conventional tendering process. It is important to note that the MC-NME stabilising agent (or equivalent) is costed in terms of cubic metre of the material that is being stabilised and NOT by the quantity of the stabilising agent. The cost of a stabilising agent depends on the end result and not on the quantity added to the material.

The principles of a tendering process for the inclusion of a MC-NME stabilising agent could, as an alternative, also be applied during the design phase with the consultant providing materials to interested suppliers to test based on the EPS, in a separate tender for any project. In this case, the quality and performance guarantees of the MC-NME stabilising agent will be vested in the supplier. An implementing agency could also apply the same recommendations in terms of the EPS, to separately procure a MC-NME stabilising agent for a specific project. It follows, that different implementation agencies could apply the EPS in different approaches, all based on the engineering properties contained in the recommended EPS. The general principles contained in the recommended EPS, specifying minimum engineering requirements depending on design requirements, prevents the introduction of inferior technologies into the roads industry on the back of proven scientifically based products.

9.3.2 Principles allowing for open tender

In preparation for the open tender for the provision of an applicable MC-NME stabilising agent for naturally available materials, suppliers need to have access to basic information and materials to submit MC-NME stabilising agents. Potential suppliers are to submit their products for testing and evaluation. The objective is to recommend a contract procurement and project management programme that will enable the objectives of the project to be maximised within the current legal framework, i.e., to:

- Enable the labour content of the works to be performed through the specification of the construction processes aimed at the maximisation of labour-enhanced procedures, and
- Manage projects in such a way as to allow SMMEs to develop and fully participate in all aspects of the road construction works.

The successful implementation of the programme strongly relies on the “Buy-in” of all parties involved, including the clients (road authorities that may require traditionally embedded procedures to be drastically adapted), consultants that will adapt their usual design methods with the emphasis on cost optimisation, especially concerning the traditional use of “Catalogue designs” and contractors that will play a major role in project management.

The appointed Consulting Engineer will be required to do the testing and the structural design of the pavement according to the recommendations contained in this guideline design method. The main aim of the design will be focused on cost reduction, applicable criteria, labour-friendly construction methods and the optimum use of naturally available materials. Only in cases where NAGMs do not meet specifications, more detailed testing will be done. Only the material thicknesses that need to be improved through MC-NME stabilisation will be sampled and tested, determining at least the following material properties:

- Maximum Dry Density (MDD);
- Optimum Moisture Content (OMC);
- Grading of the materials, and
- XRD scans analyses of the NAGMs as per recommended protocol (Jordaan and Steyn, 2019), determining the mineralogy of the **total sample** as well as of the **fraction passing the 0.075 mm sieve size**.

It is important to note that ONLY the material earmarked for improvement must be sampled. Samples should be taken at points that coincide as close as possible with the specific design percentile values applicable to the Category of the road as recommended in Table 77. All identified surface geological or soil structures that are identified for possible use, should be sampled.

Potential suppliers will be given coordinates of materials collection points should they wish (at their own cost) to sample and optimise their MC-NME solutions for submission for independent evaluation if the procurement process requires such an approach.

Table 77 Recommended design reliability and risk profile for the various category of roads

Category of Road	Design Reliability (Percentile level)	Percentage Confidence Interval	Network level	Project level
			Accuracy: (± error)	Accuracy: (± error)
A	95	95	40	10
B	90	95	40	10
C	80	95	40	10
D	65	95	40	20
E	45	95	40	20

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Acknowledgements

- Harry Viljoen, Former Chief Engineer Western Cape Provincial Government for information and photographs provided
- Dawie Malan, Hatch Goba for practical guidance and costs
- Gerrit Basson, ASP Tech for review and recommendations
- Western Cape Provincial Government for review and recommendations
  - H Wolff
  - B Dlamini
  - M Petersen
  - W Lourens

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Appendices

Appendix A. Key Data for Economic Prioritisation

Population data

The population data applied for the current simulation was provided by the CSIR (2021) and reflects the population demand scenarios generated as part of an exercise to estimate infrastructure investment needs for achieving the United Nations Sustainable Development Goals in South Africa. This is likely the most detailed population data publicly available. Alternative population data sources include most recent available Census data at the enumeration area level from Statistics South Africa, or the 2016 mesozone population distribution by the CSIR (available at: http://stepsatest.csir.co.za).

Land use data

Urban roads were identified and subsequently removed from the road network under review using the South African functional town typical developed by the CSIR (2018) (available at: http://stepsatest.csir.co.za). This typology was developed to provide a fine grained, but nationally comparable overview of regional scale settlement patterns and trends. Another useful, albeit less accurate, method to isolate rural roads is to filter urban road categories under the Naming classification (e.g., avenues, lanes, streets).

Basic service facilities data

The Department of Basic Education publishes quarterly key characteristics, including the GPS location, of all publicly registered primary and secondary schools (available at: https://www.education.gov.za/Programmes/EMIS/EMISDownloads.aspx).

The National Department of Health have shared, in response to a special request, the GPS locations for 5 389 healthcare facilities. Unfortunately, this information is not published, in addition to being subject to change as some healthcare facilities are mobile clinics that relocate from time to time. Going forward, road departments must therefore request updated data from their respective provincial Department of Health in order to factor healthcare access, where it differs from basic education access, into the analysis.

Gross Value-Added data

The CSIR (2023) applies the concept of Gross Geographic Value Added (GVA) to estimate regional economic activity (available at: http://stepsatest.csir.co.za). GVA is broadly similar to Gross Geographic Product (GGP): GVA (factor cost) is equal to the Compensation of Employees plus the Gross Operating Surplus. The GVA data for all economic sectors are produced on a local municipal level by Quantec. The CSIR then assigns the municipal level data to mesozones using dasymetric mapping principles, according to which secondary data representing the potential points where production occurs are used to re-assign the economic production data to the mesozones. The result is an indicator of economic production per sector (excluding construction) expressed in Rands per mesozone. Because the data have been transformed through the dasymetric process, they represent normalised rather than real GVA values. The result is a system of ratios that can be used to compare all mesozones across space (‘spatial comparison’), as well as to compare a mesozone with itself over time (‘temporal comparison’).

Basic Access and Multi-functional Road Networks

The procedure to identify the access networks that connect clusters of households with basic service facilities is to geospatially locate all communities in a region of analysis and map which roads link communities to public primary and secondary school and healthcare facilities. Two exclusionary conditions apply to Basic Access Roads and are factored into the simulated potential Basic Access Road Network shown in Figure A 1. First, Basic Access Roads must fall outside the minimum prescribed level of access to constitutionally protected basic education and healthcare facilities. The gazetted access norms and standards prescribe a feeder zone with a radius of 5.0 km for public primary and secondary schools (Government Gazette 33283, 2010). This standard reflects a deemed acceptable walking distance to schools, creating buffers within which road departments are not constitutionally required to provide access roads. Road departments may include specific direct access routes as part of the Basic Access Road Network given the importance of direct and all-weather road access to schools. No such access standard exists for healthcare facilities, which is sensible as it is unreasonable to expect people requiring medical care to walk non-trivial distances. Secondary, urban roads are excluded from consideration as Basic Access Roads due to the availability of alternative routes to service centres in these areas.

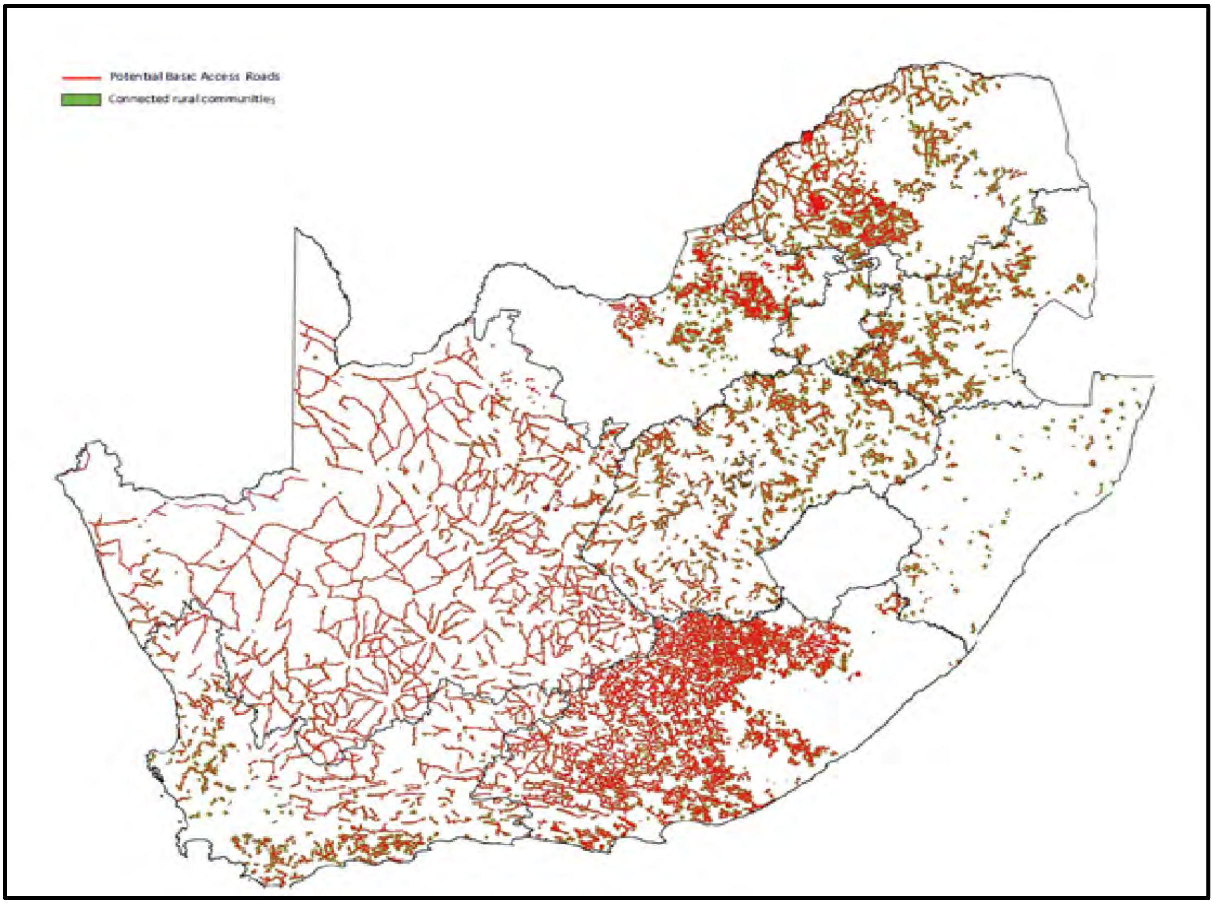


Figure A 1 Potential basic access road network

As noted, some roads that provide a basic access function also contribute to economic growth. These multi-functional roads are efficient as they allow road departments to address access needs at the same time as promoting economic growth, and hence are the highest priority for upgrade to LVSR. While multi-functional roads can be found in any rural or peri-urban setting where there is isolated economic activity, these roads are typically concentrated in areas with relatively higher economic activity. Using the CSIR's GVA data, shows the likely distribution of multi-functional roads disaggregated according to productivity quintiles. Comprehensive traffic data, covering heavy vehicle traffic, were not available for this version of the network level classification. However, road departments should include these data in analyses going forward.

Relocation of basic service centres presents authorities with a means through which to cost-effectively create significant redundancies amongst the Basic Access Roads in the lower GVA quintiles, specifically GVA quintile 1 and some areas in quintile 2. The process entails reclassifying Basic Access Roads as

Surplus Roads by optimally locating schools and healthcare facilities relative to communities they service. In almost all cases, the saved road maintenance costs from this exercise will more than offset the costs to either relocate or build new basic service centres. Townshend (2020) identifies approximately 45,757 km of Basic Access Roads that authorities could convert into Surplus Roads by rationalising network functionality in this way. It is important that authorities address this process of road network optimisation prior to upgrading any Basic Access Roads to LVSR. It therefore makes a virtue of necessity that budget constraints will confine upgrades of unpaved roads to LVSR to multi-functional roads over the medium- to long-term. This provides authorities with time to undertake the complex community consultation processes without which optimisation of the rural road network cannot be achieved.

Strategic Road Network

Strategic Roads include high value transport routes, which are generally within or between key regions and locations such as cities, major towns, international and local trade corridors, and high-volume freight and passenger terminals. While the concept of a Strategic Road Network is often used to refer to national roads, this network should extend to all roads that are core enablers of economic activity. SANRAL’s (2015) Road Network Study identified a 9 200 km Core Strategic Network, a 9 600 km Secondary Strategic Network, and a 14 000 km Primary Road Network. The Secondary Strategic Network provides alternative routes to the Core Strategic Network, which are required in areas where low road density makes the Core Strategic Network difficult to reach. The Primary Road Network feeds the two strategic road networks. The Core Strategic Network and Secondary Strategic Network are designated as national roads, while the Primary Road Network is a combination of provincial and national roads. Importantly, user demand for Strategic Roads must be inelastic with respect to fluctuations in business cycles. Adding this criterion to the designation of Strategic Roads ensures that no investment in them that respects best-practice engineering design principles and specifications can ever be economically irrational. Numerous studies from around the world, over many years, show that roads with inelastic demand from commercial users are the least risky focus for investment among all the elements of standard development infrastructure.

Urban roads, which have similarly inelastic demand to the Core and Secondary Strategic Networks and Primary Road Network, should also be classified as Strategic Roads. Urban roads combine to form integrated networks that support important daily mobility and access functions, including the transportation of goods consumed within urban boundaries and the movement of residents between homes, public facilities, and places of work. Incorporating urban roads into the Strategic Road Network aligns maintenance schedules with population density and trends in urban sprawl.

Given these characteristics of Strategic Roads, none occur as part of the network of unpaved roads being considered for upgrades to LVSR. Road departments can thus move directly from prioritised upgrades to Basic Access Roads on to consideration of Tactical Roads.

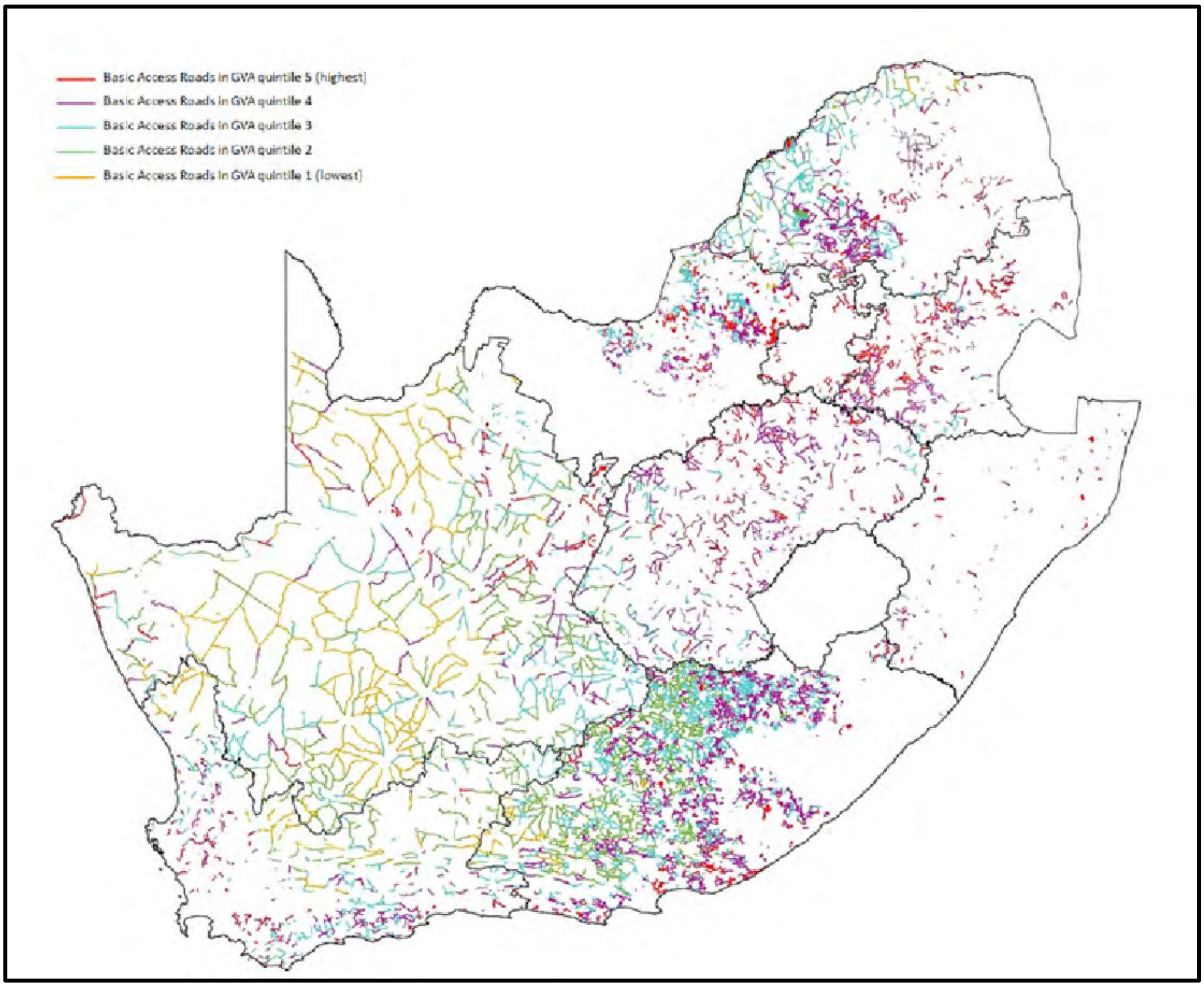


Figure A 2 Potential Basic Access Road Network and GVA, 2020

Tactical Road Network

Tactical Roads are identified as rural and peri-urban roads that support economic growth, at least outside of business cycle recessions, conditional on achievement of macroeconomic policy targets. The NDOT (2006) stress the importance of an effective Tactical Road Network for economic growth as the origin, transport route, and destination for many economic activities are located along secondary and tertiary roads that are not part of the Strategic Road Network.

Having attended to multi-functional roads and then Basic Access Roads, road departments can systematically prioritise the Tactical Roads in descending order of their net expected contribution to GDP. Again, this GDP contribution is approximated through mesozone level GVA. In the event that budgets are insufficient to cover the full network of Tactical roads, which is likely to be a long-term reality given South Africa's current economic outlook, departments are at least assured that unmaintained roads do not leave citizens with neglected basic access rights or support lower levels of economic activity relative to properly maintained roads. The relatively low length of Tactical Roads within GVA quintiles 1 and 2 is due to the fact that most of these roads are classified as Basic Access Roads, with many of these set to fall within the envelope of Basic Access Roads earmarked for rationalisation in the model (Townshend, 2020).

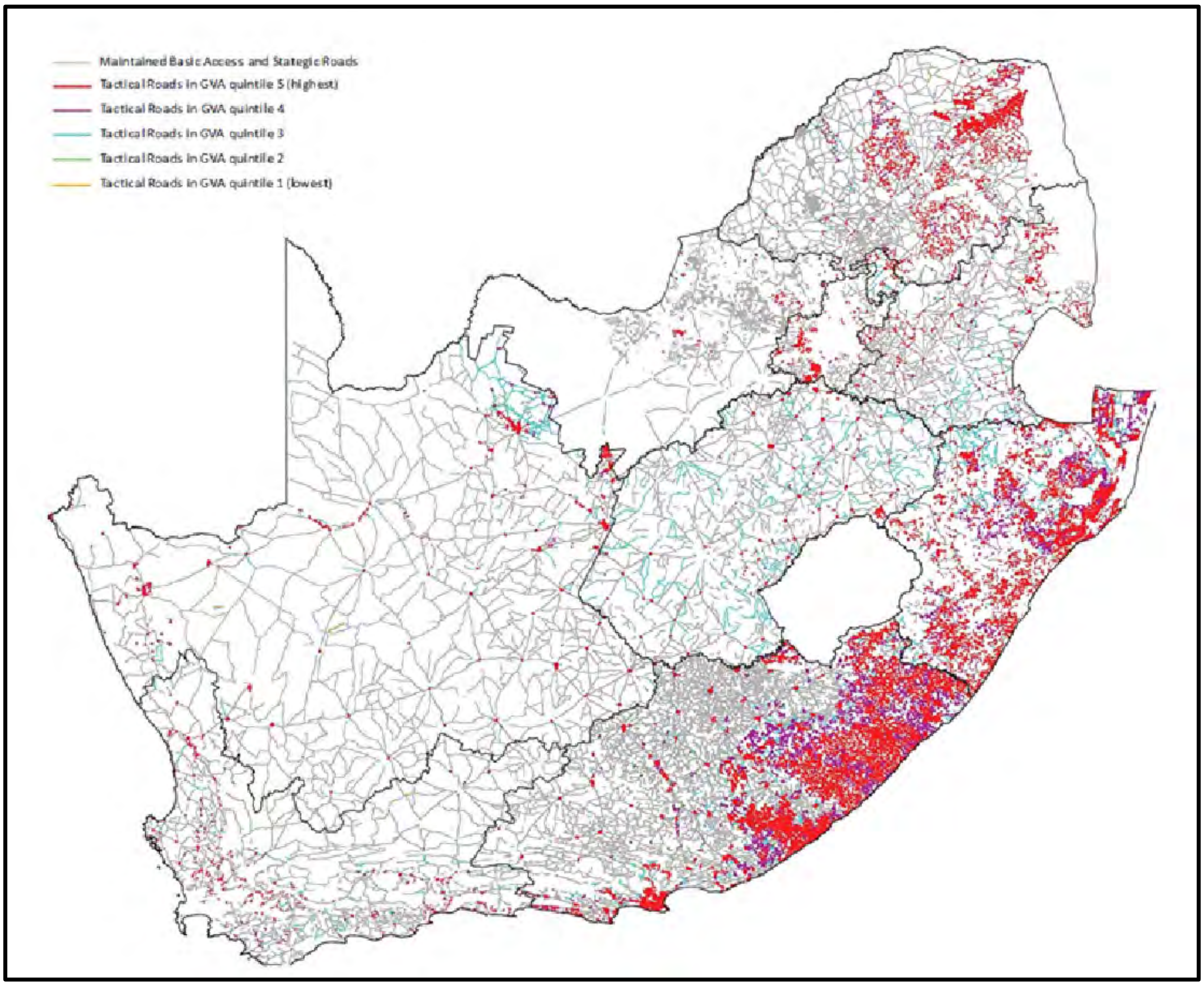


Figure A 3 Potential Tactical Road Network and GVA, 2020

Case study application of the CEA-Based Road Classification System

It is useful to guide road departments about case study applications of the CEA-based road classification. Case study application may be a common requirement given that socio-economic studies are almost always undertaken within but not before a project, and also in light of the somewhat haphazard processes by which LVSR projects are still being identified or passed between departments (e.g. SANRAL taking ownership of certain LVSR projects on provincial roads). The result of these circumstances is that road departments often need to undertake a rapid exercise to confirm that the unpaved road set to be upgraded to a LVSR is in indeed a suitable candidate for such enhancement.

In order to demonstrate a case study application of the CEA-based road classification system we will draw on the pilot projects attached to the development of this manual and rollout of the LVSR programme SANRAL was appointed to manage the upgrade of P133, P143, and D182 in Lidgetton West to a LVSR, shown in Figure A 4. These roads are in the uMngeni Local Municipality in uMgungdunglovo District Municipality in Kwa-Zulu Natal. This project was notably identified by the NDOT as a priority, with no traffic data or socio-economic studies available prior to the award of the contract.

The first classification step is to determine whether the road provides any basic access functions. The road provides access for the communities along its length to Chrystal Springs School. This project satisfies the two necessary criteria (along with not being an urban road) for classification as a Basic Access Road.

Firstly, it is the only transport connection between the communities and the school and secondly, it connects students to the nearest school from a distance beyond 5.0 km. It follows that the road is a required link as per the Access Norms and Standards.

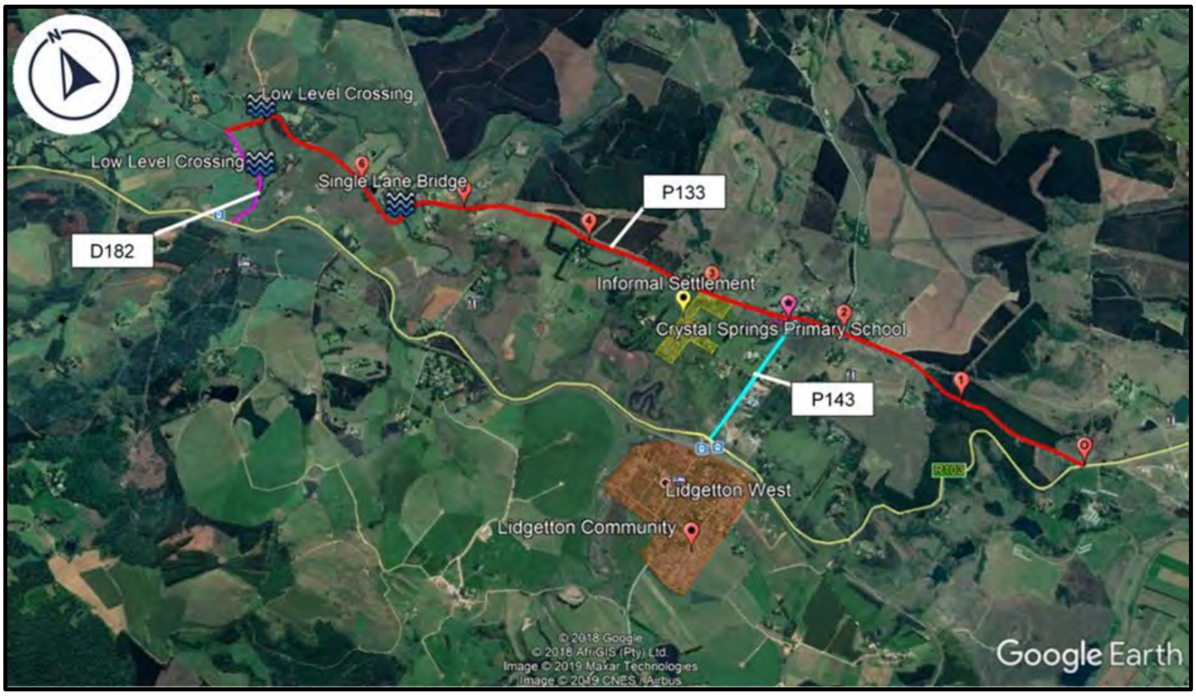


Figure A 4 Project to upgrade P133, P134, and D182 to a LVSR

The next step is to determine whether this road additionally supports economic growth by facilitating the transportation of contributions to exports. This finding will determine whether this road is a Basic Access Road or is in fact a Tactical Road with a multi-functional role. If this road is a Basic Access Road, then it should not form part of the set of immediate upgrade priorities. However, analysis of the GVA confirms that this road falls within an area that lies in the 4th GVA quintile, meaning that the area produces a relatively high level of output. In the absence of traffic data, it is important to analyse the sectoral composition of GVA to ascertain the likely proportion of output that is transportable via road. In this regard, 17.3 per cent of total GVA is contributed by the manufacturing sector and 15.5 per cent by the agriculture, forestry and fishing sector. At least one-third of output (32.8 per cent) must therefore be transported, which is above the national average of one-fifth (19.3 er cent) (including the mining and quarrying sector which additionally contributes to GVA in other areas).

The employment data for Ward 4 in uMngeni Local Municipality from the 2011 Census confirms that there are significant levels of economic activity in the area, with an employment rate of 67.4 per cent - more than double the employment rate of 31.5 per cent in KwaZulu-Natal Province as a whole. There is also anecdotal evidence from the available project documents that the observed road traffic includes farm vehicles, tractors, and heavy vehicles for timber plantations. The area is also a popular tourist attraction, labelled the “Midlands Meander” with many different resorts, restaurants and artist and craft practitioners, particularly over weekends and during school holidays. As such, this road should be classified as a Tactical Road with a multi-functional profile and earmarked for upgrade to a LVSR as part of the first level of upgrade priorities. Moreover, the GVA profile indicates that this road likely has relatively high priority for upgrade to a LVSR within the Tactical Road network.

Appendix B. Guidelines for pre- and post-project assessment

Introduction

The prioritisation of LVSR projects is driven by consideration of improved economic outcomes, in the broad sense, for South Africa. These include shadow-priced welfare improvements and additional employment opportunities in local communities. Consequently, an integral part of a road upgrade project should be to assess expected community benefits *ex ante* and compare these with achieved benefits *ex post*.

This appendix explains the importance of pre-project and post-project assessments for LVSR projects, as well as the processes that administrators and practitioners should follow to implement them successfully. For the purposes of this Manual, we offer guidance on the form and process to conduct appropriate economic assessments of LVSR projects. This guidance is based on good practice with due consideration given to the South African context, highlighting critical existing process and resource deficiencies that were identified when undertaking economic assessments of the pilot projects linked to the development of this Manual.

The importance of project assessments

The programme to upgrade many unpaved roads across South Africa to LVSR will require very large public budget allocations and a long-term investment timeframe. As such, this programme should include comprehensive economic project assessments. Against the backdrop of severely limited resources and a pressing need for economic development, the economic viability and priority of LVSR projects hinges on a nuanced understanding of their potential impact. Pre-project and post-project assessments are indispensable tools in measuring the relative importance and expected impacts of road upgrade initiatives across South Africa, so that priorities can be set for limited budgets.

The importance of comprehensive pre-project assessments lies in aligning infrastructure development with economic development objectives. As South Africa continues to strive for inclusive growth, these assessments are essential for specifying project parameters, estimating costs, and identifying potential economic gains. Principles of economic welfare efficiency emphasise the necessity of deploying resources judiciously, making pre-project assessments a crucial step to try to ensure that LVSR projects yield positive net returns, with opportunity costs fully accounted, in terms of improved accessibility, reduced transport costs, and enhanced economic opportunities for local communities.

The economic situation of South Africa, with its unique socio-economic history and the consequent spatial distribution of its population relative to economic opportunities, demands a customised approach to infrastructure investment optimisation – we cannot simply apply an abstract general model. Where roads are specifically concerned, robust project assessment must incorporate three main special features of the country:

1. South Africa’s rural road network was built to serve a well-developed agricultural sector as well as to connect multiple villages in rural settlements. A consequence is that, unlike most other developing countries, SA has a large network of rural roads adhering to the basic right of access as written in its constitution.
2. Notwithstanding (1) above, some rural communities lack adequate road access, mainly due to several years of neglected maintenance and poor planning and resource allocations.

3. Because of the high rural unemployment rate, which is structural rather than cyclical, the shadow price of unskilled labour outside the major metropoles is close to zero – every unskilled person employed for infrastructure work is a person whose consumption must otherwise be directly or indirectly supported by social grants. Furthermore, human capital development opportunities are extremely large.

Post-project assessments allow us to estimate the actual impact of LVSR projects. Not only can this information serve to ratify investment projects, but it also promises vital feedback for the refinement of strategies and the optimisation of ongoing and future projects. By quantifying economic gains, identifying instances of greatest improvement, and identifying unanticipated challenges, post-project assessments contribute to the overarching goal of maximising the economic impact of available budget envelopes.

These assessments will provide evidence to identify economic benefits that result from expenditures, which can then be added to the LCCA to motivate dynamic prioritisation metrics. Depending on assessment results, especially employment and skills development benefits from surfacing unpaved roads, findings could be used to advocate for additional public funds for this programme as part of ongoing national efforts to boost employment, reduce poverty, and build the country’s capital base. Moreover, the individual project assessments (based on before-after comparisons) should provide road departments with important insights into community responses to surfacing unpaved roads, thereby enabling them to optimise project impacts as the LVSR programme matures. The imperative of comparative pre-project and post-project assessments for LVSR projects thus extend beyond provision of technical knowledge and must be considered a core element of all LVSR projects.

Guidelines for effective economic assessment of LVSR projects

The methods to achieve the project objectives include pre- and post-pilot project economic analysis, to be conducted through a combination of desktop research, community discussions organised following principles of focus group design, and surveys.

Desktop studies

Economic analyses of infrastructure provision in South Africa have often been based on desktop work that manipulates national averages to estimate key variables such as the cost of labour. However, several shortfalls are associated with such desktop assessments. First, averages based on large-scale dashboards discard massive amounts of information that can be obtained by more granular scrutiny. Where the economic impact of rural roads is concerned, this discarded information is typically what is most important. Consider, for example, efforts to estimate the extent of Basic Access Roads. The key determinant of this is household geographical dispersal, since this drives the proportion of people who continue to live outside feeder zones for basic services as roads are progressively upgraded to surfaced standards. Because of historical settlement patterns, this density is far lower in rural KZN Province than in other parts of rural SA. Estimates of the total kilometres of Basic Access Roads based on the national average rural household dispersion would therefore hugely underestimate the extent of that high-priority part of the network in KZN. But this still only scratches the surface of the issue. In relatively flat parts of the country, feeder zone boundaries can be readily adjusted as effective access routes change through network upgrades. In areas characterised by gorges and wetland areas – again, most of KZN Province, and the southern zone of the Eastern Cape – feeder zone boundaries are relatively inflexible, because (for example) children cannot climb cliffs to walk to school. A person’s house might be 2 km from her job, but 8 km by shortest road distance if the road must go around a steep kopje. In addition, it is not enough for the analyst to know the average income in a community where a project is planned; the distribution of household income strata relative to the geography of the target road must also be known.

Calculation of impacts of road upgrades that are insensitive to local variations can lead to community rejection of plans when desktop-derived models meet reality at ground level. Sound economic assessment of projects requires site-level data gathering and parameter adjustment. While desktop research is a useful starting point to gather preliminary data and project insights, it must therefore be supplemented in the project assessments with data gathered through fieldwork.

Pre- and post-project assessments

Pre-project assessments establish pre-project baselines for key variables. These data provide baseline reference points against which a road project's impacts can be measured in the post-project evaluation. Pre-project assessments must therefore be conducted before the implementation of a LVSR project to establish the situation or conditions in the project area. It is critical that pre-project assessment be conducted prior to any roadworks beginning, as this work and its expected impacts might distort road user activity and stakeholders' perceptions regarding some survey questions. The project objectives and variables inform the design of the assessment tool and its implementation, ensuring it is sensitive to issues in the community and addresses all relevant project impacts.

Post-project assessments must establish post-project levels of the same key variables tracked in pre-project assessments, which are then compared to the pre-project baselines to estimate and analyse project impacts. The post-project assessment should be conducted at least 6 months after the project completion to allow road use patterns to adapt to the presence of the upgraded LVSR.

Size and composition of the research team

Assessment fieldwork should be undertaken by a team of 3 researchers, comprising a qualified project leader and two postgraduate research assistants with tertiary-level training in survey administration and interpretation. This recommended size of fieldwork teams is based on direct experience of practical and safety considerations.

In general, rural South Africa lacks corporate infrastructure for professional-quality design and implementation of socio-economic surveys that combine quantitative and qualitative aspects. Consequently, fieldwork personnel need to be recruited from outside project areas, transported to project sites, and maintained there during fieldwork. This generates a further set of costs in managing acceptance of fieldworkers' expertise and good faith: rural populations in South Africa have ample historical basis for wariness of 'outside' experts, rooted in a long-standing tendency in South Africa to promote overly generic strategies that are oblivious to special local conditions and histories. Such wariness can be successfully mitigated, but this requires experienced fieldwork leaders. It is typically not possible to exactly anticipate in advance how many meetings with community representatives an assessment exercise will require.

Some LVSR project sites are in relatively remote areas where prevalent languages require scarce linguistic competence on the part of field researchers. Field researchers must consequently be engaged from a variety of backgrounds that are representative of South Africa's rural population.

Fieldwork protocols

When visiting communities at project sites, fieldworkers should be accompanied by local representatives, such as the Ward Councillor. Teams of fieldworkers should be well briefed and experienced in good-sense personal security management, which includes both avoiding providing temptations to opportunistic theft, but also signalling confidence that most community members are well-intentioned consultants in good faith. Fieldwork must be undertaken with the knowledge and guidance from the road authority and following full notification of relevant local officials.

In order to avoid ad hoc interference with representativeness of data by more relatively influential community members, fieldwork should be conducted in the presence of community officials with objectively legitimated leadership responsibilities. Some of these roles may arise through the LSVR project itself, in connection with Public Liaison Committees (PLCs) (see below for further detail). In addition, there may be labour bodies that need to be consulted prior to, and involved in, fieldwork, as some questions that focus groups must address will relate to job status and employment opportunities.

Variables of interest

The following variables should be covered by the assessment, comparing pre- and post-project differences where relevant:

- 7-day road traffic counts, in line with TMH 14
    - Pedestrian data;
    - Vehicle data (refer **Table B 1**);
- Road accident statistics;
    - Vehicle accident (damage only);
    - Vehicle accident (damage only and injuries);
    - Vehicle accident (damage only and injuries/fatalities);
    - Number of vehicle occupant fatalities;
    - Number of pedestrian fatalities;

Table B 1 Vehicle types

Vehicle class	**Day**							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**Total**
Motor-Bikes								
Cars								
Number of passengers								
Bakkie								
Number of passengers								
Taxi								
Private Kombi								
Kombi Taxi								
C Kombi								
Short Bus								
Long Bus								
Truck-L								
Truck- Med								
Truck-Heavy								
Tractor								
Livestock								
Other								

- Employment opportunities during the road construction phase;
    - Number of full-time equivalent work opportunities for skilled workers;
    - Number of full-time equivalent work opportunities for semi-skilled workers;
    - Number of full-time equivalent work opportunities for low-skilled workers;

- Employment opportunities from routine road maintenance activities following the completion of the road construction phase;
    - Number of full-time equivalent work opportunities for skilled workers per annum;
    - Number of full-time equivalent work opportunities for semi-skilled workers per annum;
    - Number of full-time equivalent work opportunities for low-skilled workers per annum;
- Small contractor training during the road construction phase;
    - Number of SMMEs engaged in the project;
    - Contract value (Rands) directed to SMMEs;
    - Number of staff provided with NQF/SAQA accredited training;
        - Principals;
        - Supervisors;
        - General workers;
    - Number of NQF/SAQA accredited unit standards completed;
        - Principals;
        - Supervisors;
        - General workers;
- Roadside trading and community-service activities;
    - Number of vendors situated alongside the roadway;
    - Extent and size distribution of businesses using the road for access by customers and suppliers, and
    - Schools and health clinics that depend on the road for learner or patient access

Data and information collection process

Pre-project assessments entail wide stakeholder engagement to identify all potential impacts of the road project and to elicit the required data. The policy of most road authorities is to employ a Public Liaison Committee (PLC) as part of its project stakeholder engagement process. The PLC acts as a communication mediator between the road authority and the stakeholders, facilitating dialogue, transparency, and collaboration throughout the project's life-cycle. The PLC aims to create a forum for stakeholders to express their concerns, provide input, and receive updates on the project's progress. It also serves as a platform to address any issues or conflicts that may arise during project implementation. Beyond this, the PLC performs an executive function because it oversees the advertisement for and appointment of a Project Manager. This engagement process is critical in the South African context as community concerns can and often do lead to project delays and even cancellations. As in many other countries, levels of community trust in distant authorities and experts is typically not high in South Africa, and successful engagement with community informants requires appreciation of the reasons for this.

The PLC is established at the beginning of a road project by the road authority. It comprises representatives from the road authority, relevant government departments, local municipalities, community organizations, and other stakeholders impacted by the project. The specific composition of the PLC may vary depending on projects, but for evaluation purposes it is recommended that the following groups of project beneficiaries and interested parties are at least included:

- A representative group of community members;
    - A spokesperson from a local school;
    - A spokesperson from a local healthcare facility;

- A representative group of local business owners and managers;
- A relevant official from the contractor;
- Political officials;
  - Government officials if appropriate (such as a representative from the District Municipality office);
  - Ward Councillor(s), and
  - Trade and labour union representatives if appropriate.

The composition of PLCs will vary depending on the project. Some LVSR projects will have a simpler PLC structure if they are located within very small and evidently quiet and cohesive communities, typically comprising one elected councillor who understands the issues and who enjoys the respect of other members of the PLC. However, LVSR projects that traverse several municipal wards or traditional authorities, as well as diverse interest groups, will require larger PLCs in order to be representative. It is important to stress, based on experience, that the composition of a PLC must include representatives from the main economic interests in the area. Principal economic sectors are usually organised, and representatives can usually be included in PLC subcommittees (see below) through direct engagement with the research team.

The PLC holds regular meetings, typically monthly or quarterly, to discuss project-related matters. These meetings provide a structured platform for stakeholders to voice their opinions, seek clarifications, and receive information from the road authority. The information typically shared by the road authority includes updates on project milestones and plans, socio-economic and environmental assessments, and potential impacts on the affected communities. This wide spectrum of already engaged stakeholders with pre-established and regular meeting times makes the PLC the preferred forum through which to conduct the pre-project and post-project assessments.

Experience strongly indicates, however, that at the scale of the whole PLC (in a complex project area) it is difficult to focus in real time on issues at the level of granularity to which assessments must attend. In order for project assessments to best use the PLC structure to recruit required ranges of informants, the PLC should be asked to create 3 sub-committees based on distinct domains of project impacts:

- Sub-committee 1: Community access;
- Sub-committee 2: Commercial activity, and
- Sub-committee 3: Procurement and training of labour, sub-contractors and service providers.

These sub-committees should each contain some PLC members but should also co-opt other community members based on knowledge and interest. Each sub-committee should meet about 3 times per assessment to investigate their particular areas using the guideline discussion questions as per Section 3.7. The outcomes of these investigation meetings should be reported back to the full PLC and community through ‘Town Hall’ style meetings.

In order to feed into assessments, and particularly to support systematic comparisons between pre- and post- project assessment phases, sub-committee and town hall discussions should be facilitated by a fieldworker trained at tertiary level in qualitative social research. This involves two key elements. First, discussions should be managed following focus group principles. These principles mainly concern ways of ensuring that some classes of participants (e.g. women, or younger people) are not silenced, and techniques for following up remarks to ensure that ambiguous comments are clarified. The latter is directly related to the second element of focus group facilitation expertise. Qualitative information must ultimately feed into quantitative welfare analysis by economists. This requires that it be coded according to a pre-designed metric. Focus groups thus resemble surveys with multiple simultaneous respondents. Agendas are important, and free-form discussions must be led to settle on clear enough alternative conclusions – on which, of course, there may be differences within the group – for these to be coded against the metric. This is a set of skills that requires professional training. Such training is available in all South African university programmes in marketing and organisational psychology. Thus, although the assessment exercises should be led by economists trained in quantitative welfare analysis, fieldwork teams should include post-graduate assistant researchers from disciplines that incorporate training in focus group design and facilitation.

Standard focus group discussion questions

The following set of standard focus group discussion questions has been prepared as guidance for the respective PLC sub-committees. The discussions and data should take place as part of both pre- and post-project assessments in order to effectively evaluate project impacts.

Specific questions for Sub-committee 1: Community access

1. As a community, what do you use the road for?
2. Other than (facilitator to list the uses/purposes/reasons mentioned in question 1) what else does the community use the road for?
3. Does this road currently serve the needs of this community very well? If not, why are you as community members not satisfied with the road?
4. Do all community members have easy access to the road? If some community members struggle to access the road, what are the challenges that limit easy access to this road?
5. Does this road help you as community members to access social services? If so, which social services do you access using this road?
6. Do children in this community depend on this road to go to school? How far must most children in this community walk on this road to get to school?

Specific questions for Sub-committee 2: Commercial activity

1. How important is this road to farmers in this community?
2. How important is this road to other business operators in this community?
3. How does this road help the different commercial operators in this community?
4. What challenges do commercial operators in this community face when using this road?
5. How can an upgrade or improvement of the road benefit commercial operators in this community?
6. Are there any people that sell or trade along the road? If so, what do they sell or trade in?

Specific questions for Sub-committee 3: Community engagement in the project

1. Who maintains this road? When it’s time to do maintenance work on the road, do community members get employed to do some of the maintenance work?
2. Does the maintenance of this road skills and tools that are locally available? Or does the maintenance of the road require specialised skills and expensive tools and are not locally available?
3. How should available work best be shared among those in the community who are capable of and interested in doing it?

General questions for PLC and Town Hall discussions:

1. What challenges is the community facing when using the road?

2. How are you as community members affected by the current status of the road?
3. What can you say about the condition of the road?
4. What situations have made it difficult for the community to use the road?
5. How long does it take for (facilitator to name the situations given by participants) to be resolved so that the community can easily use the road again?
6. Let's talk about the rainy season (a bit more), what changes happen to the road during the rainy season?
7. How do the changes in the road during the rainy season affect you as members of the community?
8. Are you as community members satisfied with how this road is maintained? If you are not, why are you not satisfied?
9. How has the road affected the quality of life of the people in the community?
    a. How has the road positively affected your quality of life as community members?
    b. How has the road negatively affected your quality of life as community members of?
10. How important is this road to the livelihoods of community members?
11. Who are the people in the community that depend on this road to support their livelihood, and how do these people/groups use the road to support/sustain their livelihoods?
12. Does this road connect this community to other communities, towns, or cities? If so which communities, towns or cities does this road connect this community with?
13. Does this road connect with other transport routes? If so, which other routes are connected to this road?
14. Does this road help with transportation of people in and outside this community? If so, which transport routes depend on this road to move people in and out of this community?
15. As community members and road users, can you comment about travel time and costs related to using this road?
16. What mode of transport do people mainly use on the road?
17. How would you describe the motorised traffic volume and type in this road?
18. Are motorists using this road happy with the quality of the road? If not, what are some of the problems that they face when using this road
19. Can you describe the non-motorised traffic volume and type in this road?
20. Can having bicycles help this community use the road more efficiently and effectively? If yes, elaborate further.
21. Do you as a community consider the road as a good and safe road or bad and dangerous road?
22. Are there areas along this road that are perceived as concerning areas with regards to dangerous turns, blind spots or accident areas? If yes, elaborate on these areas.
23. Which accidents occur more frequently in this road?
24. Are there high rates of accidents that involve pedestrians or domestic animals on this road?

25. What do you think can be done to improve the road?

Details regarding sub-committee meetings and surveys

Project-adjacent business conditions and opportunities should be probed through surveys administered to local businesses. All relevant businesses along the road should be identified by driving the length of the road and mapping business sites. All businesses must then be contacted and presented with a standard description of the project. Those businesses successfully contacted should be given a version of the general survey questions below to complete and be assured that responses will be anonymised prior to analysis. The same companies should be surveyed in the pre- and post- project assessments.

1. What is the nature of your business?
2. In what year was your business established?
3. Is your business regarded as formal or informal business? Is it registered as such with the relevant authority?
4. What is the size of your business in terms of number of employees, floor space of physical premises, number of transactions per month?
5. Where are your main supplies sourced from?
6. What condition are these input supplies when they arrive?
7. Where are your main products delivered to?
8. What condition are these main products when they are delivered?
9. Do you have any comments about the current condition of the road being upgraded?
10. In what way, if any, does the current condition of the road being upgraded have an impact on your business' monthly profits?
11. How does the current road condition affect (positive or negative) trade and investment in the area?
12. How will the proposed road upgrade, when it is finalised and operational, influence trade in this area? What are prospective sectors and areas for trade activities, and trade routes? Why?
13. How will the construction of the proposed road upgrade boost investment in this area? What are the prospective sectors and areas for investment, trade activities? Why?
14. What are the principal barriers to trade and investment in the area?
15. When this road is upgraded, how do you expect it will influence your businesses during the construction/post-construction periods?
16. During road construction, the intention is to hire labour near the site to provide temporary employment.
    a. What types of skilled and unskilled labour are available in this area for temporary employment during construction?
    b. What impacts will the hiring of local labour have on your business, positive or negative?
17. What kind of services can potentially be provided by local businesses during construction?
18. What kind of business, if any, could be initiated in this area after construction, when the road is operational?

19. Sometimes the presence of infrastructural development leads to people setting up temporary businesses nearby the construction site. Would your business be thinking of doing something like this?

20. If other businesses set up trading nearby the construction site, do you think that this will result in increased competition against your business? How and what would be the impact on your business?

Procuring assessment expertise

In many countries (including some developing countries) there are companies that employ professionally trained social and economic researchers to conduct surveys and facilitate focus groups in rural areas. This capacity is not present in South Africa, largely due to the extreme nature of the gap between urban and rural service infrastructure. Most private-sector research companies based in cities lack expertise in work based in poor rural communities (because their business clients do not commission such work). The experience of the pilot studies that inform TRH24 demonstrated that satisfactory pre- and post- project assessments of the kind described here can only be carried out by researchers based in universities.

There is an additional reason for this beyond availability of relevant expertise. Road authorities rightly operate very stringent procurement rules for sub-contracted work. Fieldwork research teams cannot be expected to have the capacity to operate the required procurement protocols for sourcing their logistical provisions (e.g., transport, accommodations, catering, banking arrangements for compensating informants). These require numerous small providers that vary from assessment to assessment. Universities have such capacities. Their procurement rules, though stringent and effective at screening out conflicts of interest and fraud, differ from road authorities in that these rules are tailored to the practical circumstances of fieldwork researchers.

We therefore recommend that road authorities commission project assessments by issuing tender advertisements addressed to South African universities. Bids should be assessed according to the road authority's mandated criteria. Sub-contracting should be devolved to the university administering the project. Since the core of assessment is comparison of pre- and post- project exercises, the university that is awarded a tender should always be required to commit to performing both phases, however separated in time these may turn out to be as a result of unforeseen contingencies in project implementations.

Universities will only be able to bid for assessment contacts if suitably expert researchers in their employ are motivated to do the work. Academics are motivated primarily by opportunities to publish their research. Contracts for project assessments should therefore designate aspects of anticipated data that will be regarded as usable for publication of analyses through recognised peer-reviewed processes. Ethics committee oversight at all South African universities is sufficiently strong and reliable to ensure that all information furnished by community informants would be properly anonymised, and that informants rights to informed consent would be respected. Contracts should exclude use of proprietary data from construction and maintenance contractors in publications.

Publication and peer-review of findings from road project assessment research would enhance the credibility, rigour, and quality of analyses, and would enhance the accumulation over time, and public availability of, knowledge about the social returns on road infrastructure investment programmes.

Assessment cost estimates

Table B 2 and Table B 3 give an indication of general budget estimates for undertaking pre-project and post-project assessments. These estimates currently exclude flight and road transport costs, which will vary with project locations but must be appropriately factored into specific budgets. Moreover, budgets may differ depending on the number of jurisdictions covered by the road project, the number of affected communities and businesses, and the complexity of community dynamics.

Table B 2 Budget estimate (2024) for the pre-project assessment

Task	Team member	Unit	# of units per project	Unit cost	Total cost per project
Regional situation analysis	Project leader	Hours	32	R950.00	R30 400.00
	Research assistant 1	Hours	4	R800.00	R3 200.00
	Research assistant 2	Hours	4	R245.00	R980.00
Pe-project scoping meeting	Project leader	Hours	24	R950.00	R22 800.00
	Research assistant 1	Hours	24	R800.00	R19 200.00
	Research assistant 2	Hours	24	R245.00	R5 880.00
PLC engagement meeting	Project leader	Hours	16	R950.00	R15 200.00
	Research assistant 1	Hours	16	R800.00	R12 800.00
	Research assistant 2	Hours	16	R245.00	R3 920.00
	Accomodation	Person nights	3	R1 500.00	R4 500.00
	Road travel	Kms		R4.00	R0.00
	Flights	Return		R4 500.00	R0.00
	Catering	Per head	15	R100.00	R1 500.00
	Translation	Hours	2	R750.00	R1 500.00
PLC sub-committee meetings & meetings with businesses	Project leader	Hours	40	R950.00	R38 000.00
	Research assistant 1	Hours	40	R800.00	R32 000.00
	Research assistant 2	Hours	40	R245.00	R9 800.00
	Accomodation	Person nights	10	R1 500.00	R15 000.00
	Road travel	Kms		R4.00	R0.00
	Flights	Return		R4 500.00	R0.00
	Catering	Per head	56	R100.00	R5 600.00
	Translation	Hours	8	R750.00	R6 000.00
	Participant remuneration	Hours	192	R35.00	R6 720.00
Survey analysis and report development	Project leader	Hours	80	R950.00	R76 000.00
	Research assistant 1	Hours	8	R800.00	R6 400.00
	Research assistant 2	Hours	40	R245.00	R9 800.00
Sub-committee research	Snowball by sub-committee members	Hours	384	R35.00	R13 440.00
PLC finalisation meeting	Project leader	Hours	8	R950.00	R7 600.00
	Research assistant 1	Hours	8	R800.00	R6 400.00
	Research assistant 2	Hours	8	R245.00	R1 960.00
	Accomodation	Person nights	3	R1 500.00	R4 500.00
	Road travel	Kms		R4.00	R0.00
	Flights	Return		R4 500.00	R0.00
	Catering	Per head	15	R100.00	R1 500.00
	Translation	Hours	4	R750.00	R3 000.00
	Participant remuneration	Hours	60	R35.00	R2 100.00
Town Hall meetings	Project leader	Hours	8	R950.00	R7 600.00
	Research assistant 1	Hours	8	R800.00	R6 400.00
	Research assistant 2	Hours	8	R245.00	R1 960.00
	Participant remuneration	Hours	200	R35.00	R7 000.00
	Catering	Per head	52	R100.00	R5 200.00
	Translation	Hours	4	R750.00	R3 000.00
Total cost (Excluding VAT)					**R398 860.00**

Table B 3 Budget estimate (2024) for the post-project assessment

Task	Team member	Unit	# of units per project	Unit cost	Total cost per project
Update and review of regional situation analysis	Project leader	Hours	32	R950.00	R30 400.00
	Research assistant 1	Hours	0	R800.00	R0.00
	Research assistant 2	Hours	0	R245.00	R0.00
PLC sub-committee meetings & meetings with businesses	Project leader	Hours	40	R950.00	R38 000.00
	Research assistant 1	Hours	40	R800.00	R32 000.00
	Research assistant 2	Hours	40	R245.00	R9 800.00
	Accomodation	Person nights	15	R1 500.00	R22 500.00
	Road travel	Kms		R4.00	R0.00
	Flights	Return		R4 500.00	R0.00
	Catering	Per head	56	R100.00	R5 600.00
	Translation	Hours	8	R750.00	R6 000.00
	Participant remuneration	Hours	192	R35.00	R6 720.00
Survey analysis and report development	Project leader	Hours	80	R950.00	R76 000.00
	Research assistant 1	Hours	8	R800.00	R6 400.00
	Research assistant 2	Hours	40	R245.00	R9 800.00
Sub-committee research	Snowball by sub-committee members	Hours	384	R35.00	R13 440.00
PLC finalisation meeting	Project leader	Hours	8	R950.00	R7 600.00
	Don Ross	Hours	0	R1 450.00	R0.00
	Research assistant 1	Hours	8	R800.00	R6 400.00
	Research assistant 2	Hours	8	R245.00	R1 960.00
	Accomodation	Person nights	3	R1 500.00	R4 500.00
	Road travel	Kms		R4.00	R0.00
	Flights	Return		R4 500.00	R0.00
	Catering	Per head	15	R100.00	R1 500.00
	Translation	Hours	4	R750.00	R3 000.00
	Participant remuneration	Hours	60	R35.00	R2 100.00
Town Hall meetings	Project leader	Hours	8	R950.00	R7 600.00
	Research assistant 1	Hours	8	R800.00	R6 400.00
	Research assistant 2	Hours	8	R245.00	R1 960.00
	Participant remuneration	Hours	200	R35.00	R7 000.00
	Catering	Per head	52	R100.00	R5 200.00
	Translation	Hours	4	R750.00	R3 000.00
Total cost (Excluding VAT)					**R314 880.00**

Appendix C. Physical Environment

General

The physical environment of the project site exerts a great influence on the design and performance expected from the upgrading of unpaved roads. It is thus essential to have a comprehensive understanding of the various factors that make up the physical environment of the road in the identification of uniform sections along the length of the road. The composition and nature of the subgrade soils along the alignment of a road, for example, are primary determinants of the requirements of the pavement structure. In addition, drainage design (Chapter 4) is dependent on climatic factors such as rainfall intensity and duration, while binder selection for bituminous surfacings (Chapter 7) is influenced by the prevailing ambient temperatures.

The purpose of this section is to highlight the various features of the physical environment that could affect the structural design of the road. Both the physical features and climate classifications are discussed and their potential impact on the design process is highlighted.

The following physical features are considered in this section:

- Topography;
- Geology;
- Soils, and
- Climatic zones and classification.

Maps applicable to the identification of the physical nature of a project and examples as to the use thereof are given in this appendix.

Topography

South Africa covers a large surface area and thus has a highly variable topography as a result of its long geomorphologic history. Most of South Africa’s inland landscape is made up of high, flat plateau areas. These areas are covered with rolling grasslands and tree-dotted plains. To the east, south, and west of the plateau lands is a mountainous region (the Great Escarpment) as shown in simplified form in Figure C 1. The topography plays a major part in the route location and geometric design of the roads, with generally more costly works in the areas with more rugged topography. In addition, construction materials availability is strongly related to topography.

Detailed topographic mapping is available for South Africa at a scale of 1:50 000, which is more useful during design, although Digital Elevation Models (DEMs) allow easier use during design. Google Earth can also be used to identify major topographic features.

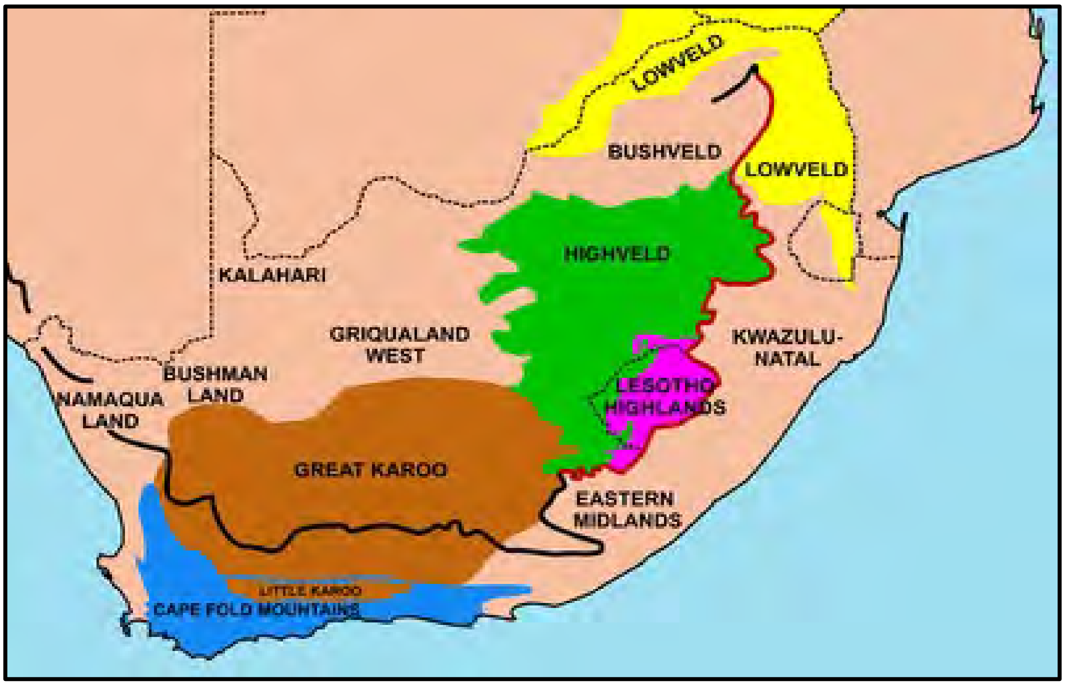


Figure C 1 Topographic regions of South Africa

Note: The thick black line traces the Great Escarpment which is marked by the red line in the area known as the Drakensberg

Source: (https://upload.wikimedia.org/wikipedia/commons/humb/c/cf/Regions_of_South_Africa_1.png/400px-Regions_of_South_Africa_1.png)

Geology

South Africa has some of the oldest rocks in the world resulting in a varied and complex geology with large areas of sedimentary, metamorphic and igneous rocks as well as extensive tracts of relatively young sands and pedocretes.

Surface geology maps showing petrology and lithology are generally available on the internet, containing information about the general in-situ materials and their variation that can be expected along a road. This information will indicate weathering patterns (together with applicable maps showing climatic factors such as temperature and rainfall patterns) and indicates the main rock types, the changes to their properties that have occurred over time and the expected mineralogy that is present within any specific area. Similar to all other data sources, the available information varies from the superficial (but useful) generalised geological features, which may indicate the original primary rock formations, to more detailed (general country features) to very detailed surface geology maps.

The geology along the route alignment will affect the available construction materials, subgrade conditions, potential subgrade problem materials, etc. and this must be studied early in the project. Figure C 2 shows a simplified geological map of South Africa at a small scale. It is recommended, however, that all road design offices have a copy of the more detained 1:1 000 000 geological maps of South Africa available from the Council for Geosciences in Pretoria. Various digital files for this map are also available at:

https://www.geoscience.org.za/index.php/publication/downloadable-material.

Geological maps at various scales (down to 1: 50 000) are available from the Council for Geosciences in Pretoria.

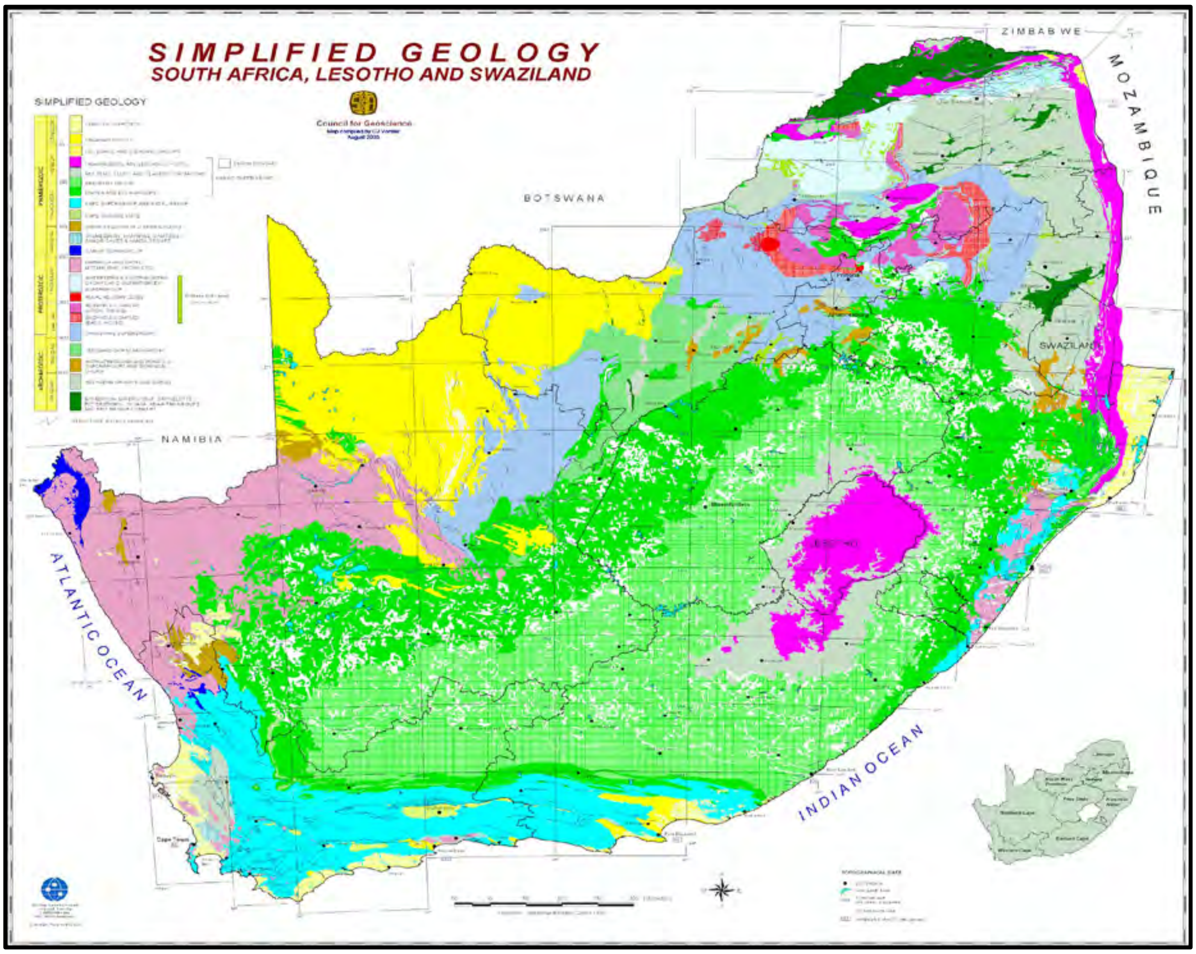


Figure C 2 Simplified geological map of South Africa

Source: (https://www.geoscience.org.za/images/Maps/rsageology.gif)

Detailed geological maps covering the whole of South Africa are available. These maps allow for a specific road under investigation to be scaled to the same level of detail as can be identified using Google Earth. This will enable the main geological features and their variations (if any) over the length of the route to be identified (example shown in Figure C 3).

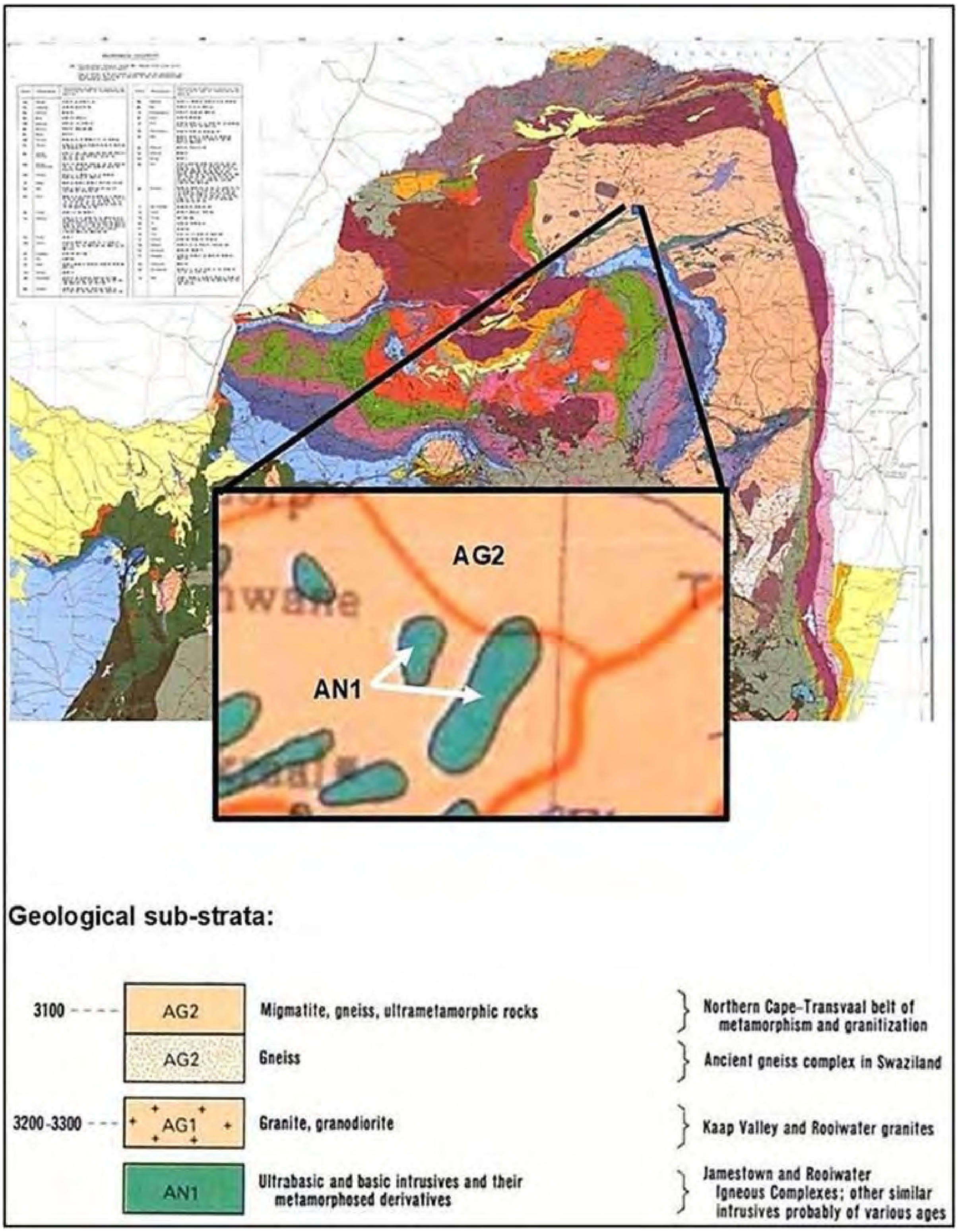


Figure C 3 Detailed geological map of the North of South Africa

Note: The location of the route scaled to the same scale

The rock types (lithologies) beneath the surficial soil cover can be used to get a preliminary indication of the type of residual material and soils that would form from weathering and alteration of the underlying rock.

Large areas of South Africa, however, are covered by transported soils, and the underlying geology thus plays only a minor part in the overlying materials. The materials in areas covered by residual soils (derived from weathering of the in-situ material beneath them, are a direct function of the original material type as well as the type of weathering (decomposition or chemical weathering under wet environments and disintegration or physical weathering, where the materials break down with little change in their mineral composition).

The geology along the route alignment will affect the available construction materials, subgrade conditions, potential subgrade problem materials, etc. and this must be studied early in the project.

Knowledge of geology will provide the basic information necessary regarding the expected material types and properties in the area.

Soils

Soils comprise at least the upper metre of the land surface in most parts of South Africa and will affect the support and founding conditions of most roads. Like the geological maps, the soil maps of South Africa can provide important information regarding the underlying conditions along proposed road alignments. Figure C 4 shows the wide distribution and variety of broad soil patterns occurring in South Africa including coastal sands, swelling clays, plinthic soils, duplex soils, rocky soils, wetlands and many others (No legend is shown on the map in Figure C 4 due to a large number of soils present). This map has been developed from the 1: 250 000 soil maps covering the whole of South Africa that, together with their accompanying Memoirs are available from the Agricultural Research Council.

(https://www.arc.agric.za/arc-iscw/Product%20Catalogue%20Library/Land%20Type%20Maps%20and%20Memoirs.pdf).

Many different types of soil occur in South Africa, each the result of weathering through a combination of the climate and the source rock material as affected by the local drainage and geomorphology of the area during the formation of the soils over long periods (hundreds of thousands to millions of years). These parameters may be very different to those prevailing at present. However, it is important to understand the nature and type of minerals in these soils, especially when considering material improvement using chemicals.

Similar to surface geology maps, soil maps can easily be accessed to obtain knowledge about the expected materials and the variation thereof in the area through which the road is earmarked for upgrading traverses. Details on soils may vary from superficial to very detailed. The available detail will depend on the extent of detailed investigations that have previously been done in the area of interest.

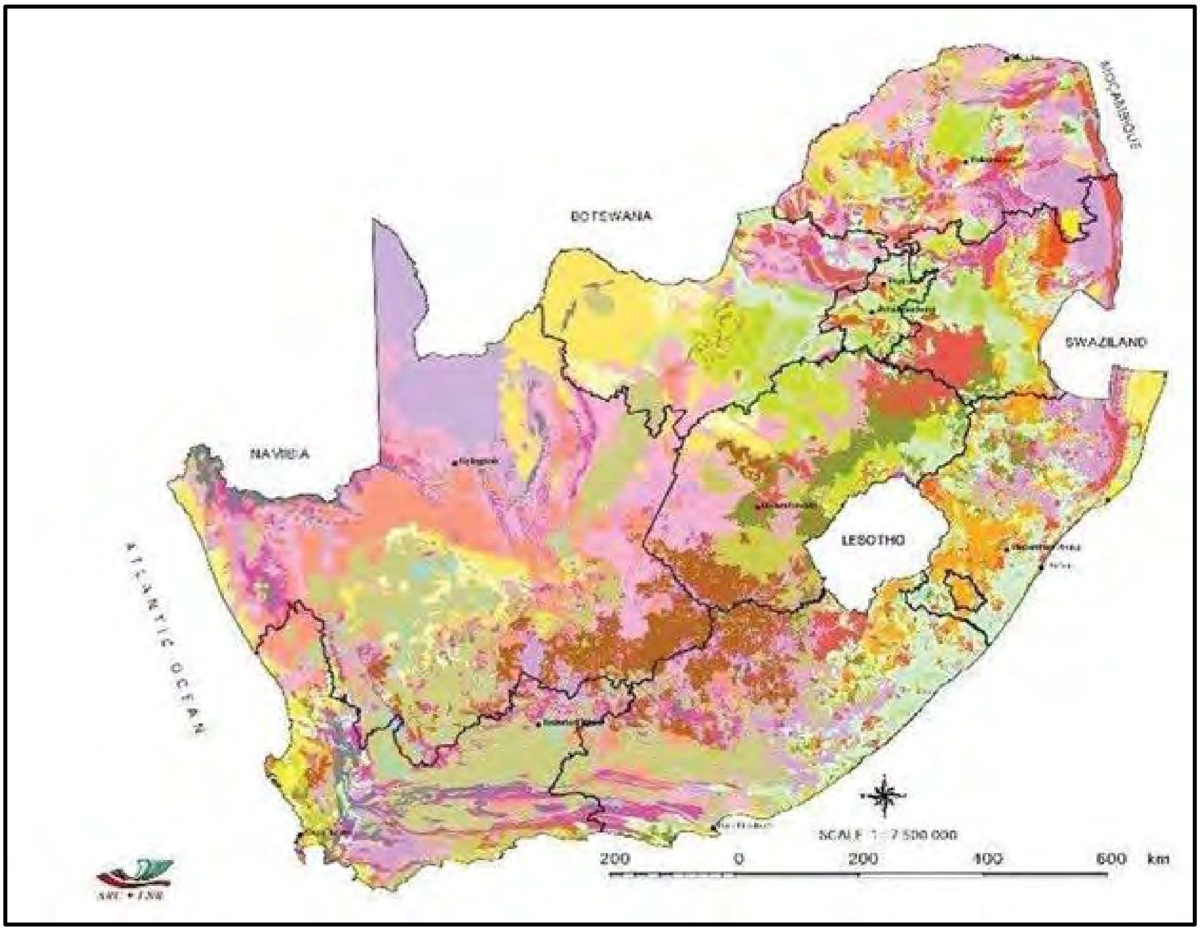


Figure C 4 Broad soil pattern map of South Africa

Source: (https://www.grainsa.co.za/natural-resource-assessments-for-agricultural-planning-and-development)

Similar to the other identified available data maps, considerable information may also be available on the soils covering the area of interest in which the identified route to be upgraded is situated. A detailed soil map covering the area of interest (as an example) of the unpaved route to be upgraded is shown in Figure C 5.

Referring to the major soil Classification systems, the following valuable information is readily available.

Three major soil regions can be identified within the borders of South Africa. East of approximately longitude 25°E, recent soils have formed under wet summer and dry winter conditions. The most important soil types in this region are Laterite (also called Ferricretes) (brown-red, leached, iron-bearing soils), un-leached sub-tropical soils and greyish (i.e., blue-grey, sticky, and compact) Podzolic soils (highly leached soils that are low in iron and lime). The example route used in the previous maps of reference is situated within this region.

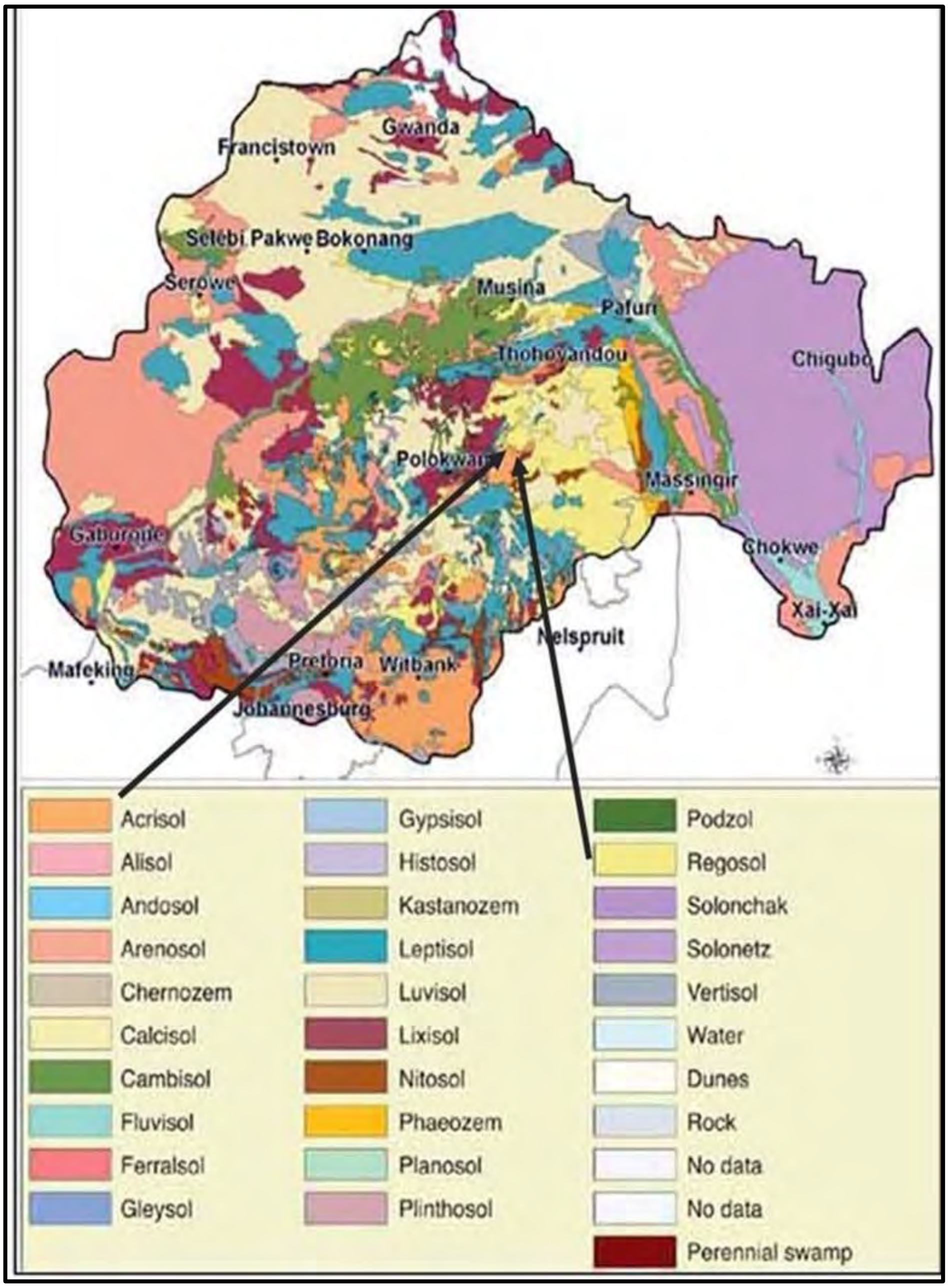


Figure C 5 Detailed soil-map of the area of the Gravel Road to be upgraded

The winter-rainfall coastal regions of the Western Cape and Eastern Cape can be identified as a second major soil-region. Soil types within this region generally contain grey-sandy and sandy-loam soils. The rest of the country can mainly be classified as dry to very dry (semi-desert). This area is associated with soils consisting of a sandy top layer (often sandy-loam) underlain by a layer of lime or accretion of silica. South African soils are, with few exceptions, classified as low fertility with higher fertility soils associated with high chemical weathering characteristics.

The area of the route used as an example is related to the soil groups shown by the arrow markers Figure C 5. As shown, these soils associated within the general area can be associated with Acrisols and/or Regosols. Regosols only form about 8 per cent of the sub-region and are usually associated with dry or semi-desert regions with some exceptions. These soils are characterised by shallow, medium- to fine-textured, unconsolidated parent material that may be of alluvial origin and by the lack of a significant soil-horizon (layer) formation, due to dry climatic conditions. Regosols can show accumulations of calcium carbonate or gypsum in hot, dry climatic zones. The normal description of Regosols does not currently fit the general description of the area in which the example route is situated, indicating that they probably formed under past climates.

Acrisols typically form on an old landscape, such as that associated with an original Craton that developed into a continent over millennia. They are normally associated with an undulating topography and a humid tropical climate. The soil is associated with woodlands that gradually give way to tree-savannahs associated with seasonal burning. The age, mineralogy, and extensive leaching of these soils result in low levels of plant nutrition, excess aluminium and high erodibility with resultant problematic agriculture potential. However, acid-tolerant crops or plants, normally adapt well to conditions associated with Acrisols. The example route is associated with a relatively wet area for South Africa, associated with a hot, humid seasonal climatic region with high weathering characteristics that could more easily be associated with Acrisols.

Climatic zones and classification

It must be noted that all the available climate maps and zones included are based on long-term climate records. As the climate changes, any classification or boundaries between climatic zones based on temperature, rainfall or evaporation/ evapotranspiration (e.g., Köppen, Thornthwaite, Weinert, etc.) will be constantly changing until full climate-change mitigation efforts limit such changes. It is, however, a relatively simple calculation to determine the Weinert (Weinert 1980) or Thornthwaite index (Thornthwaite, 1848) at any point using weather data from a local weather station.

The climate is a major factor affecting roads both in terms of the weathered materials resulting from climatic effects on the local geology as well as the hydrology and drainage in the area. Due to its large area, South Africa has a wide range of rainfall and temperature conditions, with large variations from year to year. The Köppen Geiger weather zones are shown in Figure C 6, with most of the country being arid and temperate and a small area of Tropical savannah.

In terms of material weathering characteristics, the Weinert N-value (Weinert, 1980) (Figure C 7) and Thornthwaite Moisture Index (Thornthwaite, 1848) (Figure C 8) are widely used in pavement design as an indication of granular material weathering due to chemical decomposition. It can be seen that the two maps have similar trends, both being based on various combinations of temperature, rainfall and evaporation. The important boundaries on these maps are the N-values of 2, 5 and 10 which relate to wet, moderate and dry areas and the difference between the decomposition and disintegration of rocks. The equivalent Thornthwaite values are +20 (wet), 20 - -20 (moderate) and < -20 (dry).

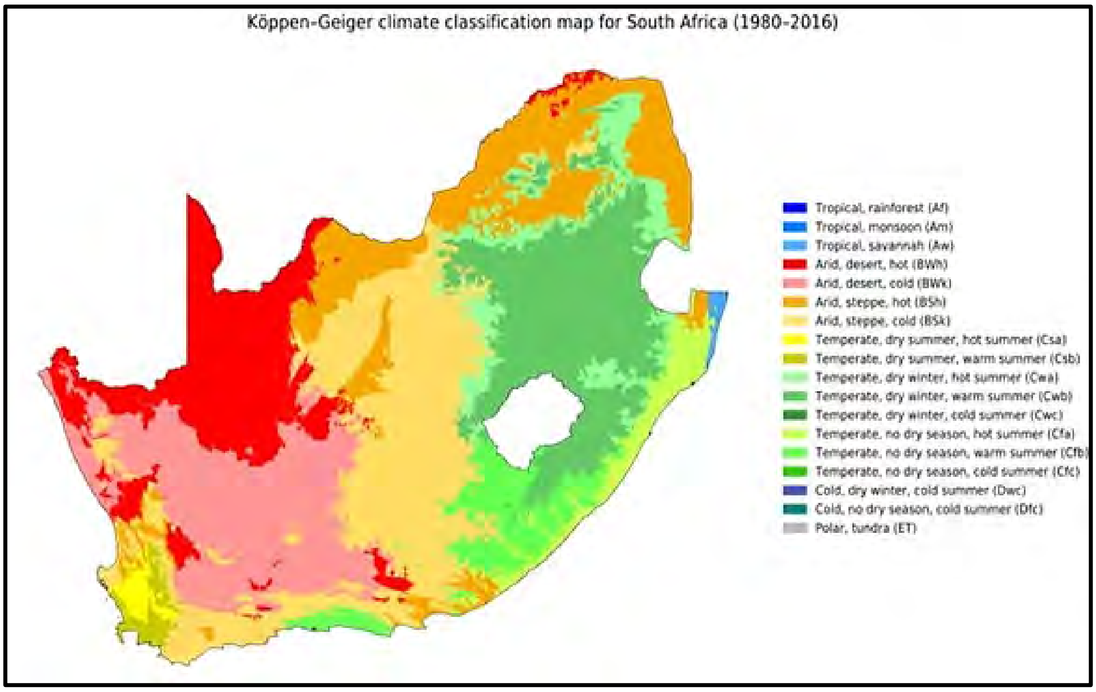


Figure C 6 Köppen Geiger climatic zones of South Africa

Source: (https://en.wikipedia.org/wiki/Climate_of_South_Africa#/media/File:Koppen-Geiger_Map_ZAF_present.svg)

Figure C 7 Simplified Weinert N-value map for South Africa

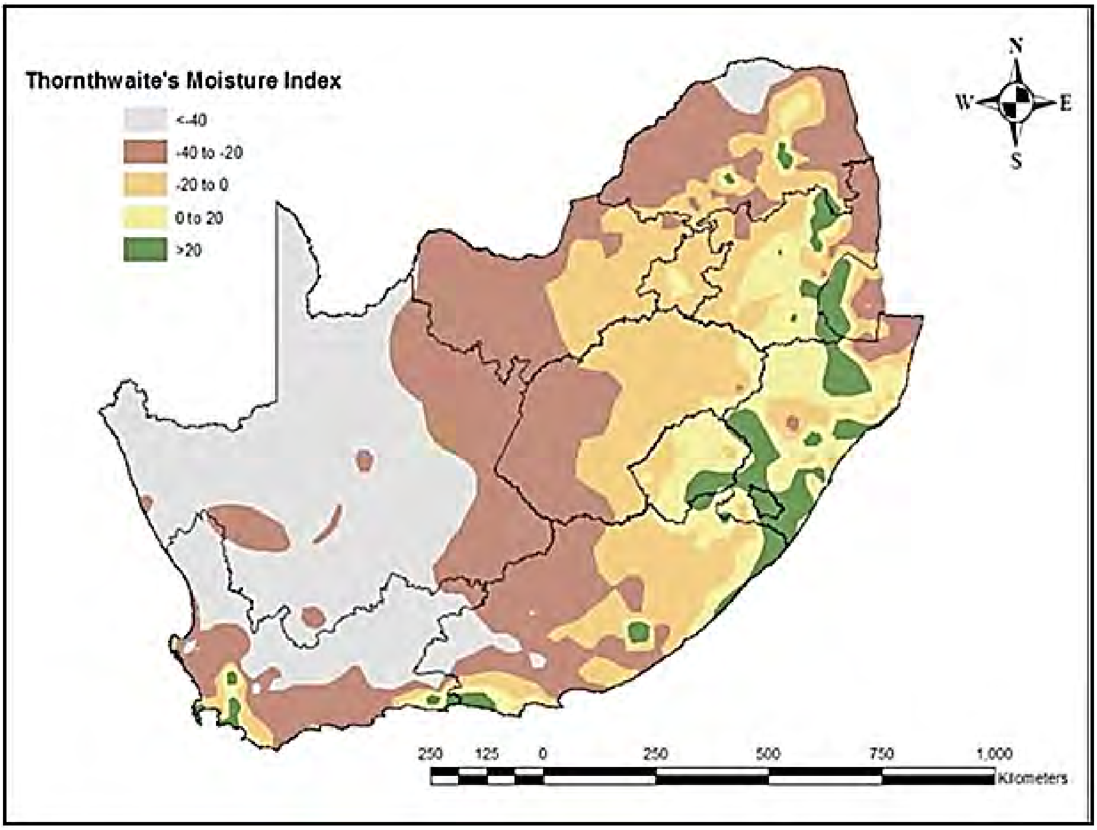


Figure C 8 Thornthwaite Moisture Index map for South Africa

Appendix D. Laboratory DN Testing and Selection of a Moisture Regime

Introduction

This appendix provides guidance for testing the adequacy of materials in a laboratory to perform well in the upper layers of a pavement in a selected climatic environment at specific densities.

Climatic environment – Refer Appendix C (Figures C6, C7 & C8)

The Climatic Zones (Figure C6) the Thornthwaite Moisture Index (Figure C7) and the Weinert N-value have been correlated against each other (taking into consideration that this is not an exact correlation of as these climatic indicators are based on different input values), as shown in Table D 1.

Taking into consideration the various climatic classification systems described in Appendix C, a climatic adjustment factor (C_f) has been correlated as shown in Table D 1. Table D 1 is then used to determine the Climatic Adjustment Factor (C_f), which is used as the expected equilibrium moisture content under which the upper layers of the pavement will perform.

Table D 1 Climatic areas

Adjusted Moisture Regimes	Climatic Adjustment Factor (C_f)	Climatic Zones of the World (Köppen, 1923)*	Thornthwaite Moisture Index	Weinert N-value
M1A: (Dry) - Arid	0.75	Bwh; Bwk	< - 40	> 10
M1B: Semi-Arid	0.90	Bsh; Bsk	-20 to -40	5 - 10
M2A: (Optimum) - Temperate	1.00	Csa; Csb; Cwa; Cwb	-20 to 0	2 - 5
M2B: Temperate-Wet	1.10	Csc; Cwc	0 to 20	< 2
M3A: (Wet) - Wet-humid	1.25	Cfa; Cfb; Cfc	20 to 60	
M3B: Sub-Tropical	1.35	Aw; As	60 - 100	
M4: (Soaked) - Tropical /Monsoon	1.50	Af; Am	> 100	

Preparation of test samples

The samples must be prepared following SANS 3001–GR30, as described below:

Procedure 1 – Scalping Method that applies to materials that have 30 per cent or more (by mass) retained on the 20 mm sieve, may be summarised as follows:

- Remove material passing the 37.5 mm sieve and retained on the 20 mm sieve and lightly crush by means of a steel tamper so that all the material passes the 20 mm sieve, and
- Recombine a portion of the crushed material, representing 30 per cent by mass of the original sample, with the rest of the original sample and mix thoroughly before testing.

Procedure 2 - Crushing Method that applies to materials that have 30 per cent or less (by mass) retained on the 20 mm sieve, may be summarised as follows:

- Screen field sample on 20 mm sieve;

- Remove material retained on the 20 mm sieve and lightly crush by means of a steel tamper so that all material passes the 20 mm sieve, and
- Recombine the crushed material with the rest of the original sample and mix thoroughly before testing.

Note: *Care should be taken that the aggregate is not crushed unnecessarily small. If the material contains soil aggregations, these should be disintegrated as finely as possible with a mortar and pestle without reducing the natural size of the individual particles.*

Some natural, particularly pedogenic gravels (e.g., ferricrete, calcrete) can exhibit a self-cementing property in service, i.e., they gain strength with time after compaction. This effect must be evaluated as part of the test procedure by allowing the samples to cure/equilibrate before testing in the manner prescribed below:

Thoroughly mix and split each borrow pit sample into nine sub-samples for DN testing in a CBR mould at three moisture contents and three compaction efforts, as shown in **Table D 2.**

Table D 3 Sample requirements per Compaction effort and Moisture regime

Compaction effort	Moisture regime		
	Soaked	OMC	0.75 OMC
Light (4.5 kg rammer, 5 layers, 11 blows/layer)	3 samples	3 samples	3 samples
Intermediate (4.5 kg rammer, 5 layers, 22 blows/layer)	3 samples	3 samples	3 samples
Heavy (4.5 kg rammer, 5 layers, 55 blows/layer)	3 samples	3 samples	3 samples

The compacted samples should be allowed to equilibrate for the periods shown below before DN testing is carried out to dissipate pore-water pressures and compaction stresses and to allow the moisture content to equilibrate within the sample.

- 4-days soaked: After compaction, soak for 4 days, allow to drain for at least 15 minutes, then undertake a DCP test as described below in the CBR mould to determine the soaked DN value;
- At OMC: After compaction, seal in a plastic bag and allow to “equilibrate” for 7 days (relatively plastic, especially pedogenic, materials (PI > 6)), or for 4 days (relatively non-plastic materials (PI < 6)), then undertake a DCP test in the CBR mould to determine the DN value at OMC, and
- At 0.75 OMC: Air dry the compacted samples in the sun (pedogenic materials) or place the sample in the oven at a maximum of 50°C (non-pedogenic materials) to remove moisture. Check from time to time to determine when sufficient moisture has been dried out to produce a sample moisture content of about 0.75 OMC (it does not have to be exactly 0.75 OMC, but as close as possible). Once this moisture content is reached, seal the sample in a plastic bag and allow it to cure for 7 days (pedogenic materials) or for 4 days (non-pedogenic materials) to allow moisture equilibration before undertaking the DCP test at approximately 0.75 OMC. Weigh again before DCP testing to determine the exact moisture content at which the DN value was determined.

Test procedure

The procedure to be followed for determining the DN value of a material is similar to that for the more traditional CBR test except that a DCP is used to penetrate the CBR mould instead of the CBR plunger. Each of the specimens should be subjected to DCP testing in the CBR mould as summarised below.

A. Secure the CBR mould to the base plate, place the mould on a level (preferably concrete) floor, and place the annular weight on top of the mould;

B. Measure the height of the compacted specimen inside the mould. This is to enable the operator to stop the test just before the tip of the cone hits the base plate;

C. Place an empty CBR mould upside down or another device (e.g., bricks or cement blocks) next to the full mould, as shown in 1 to support the base of the DCP ruler level with or slightly higher than the top of the full mould;

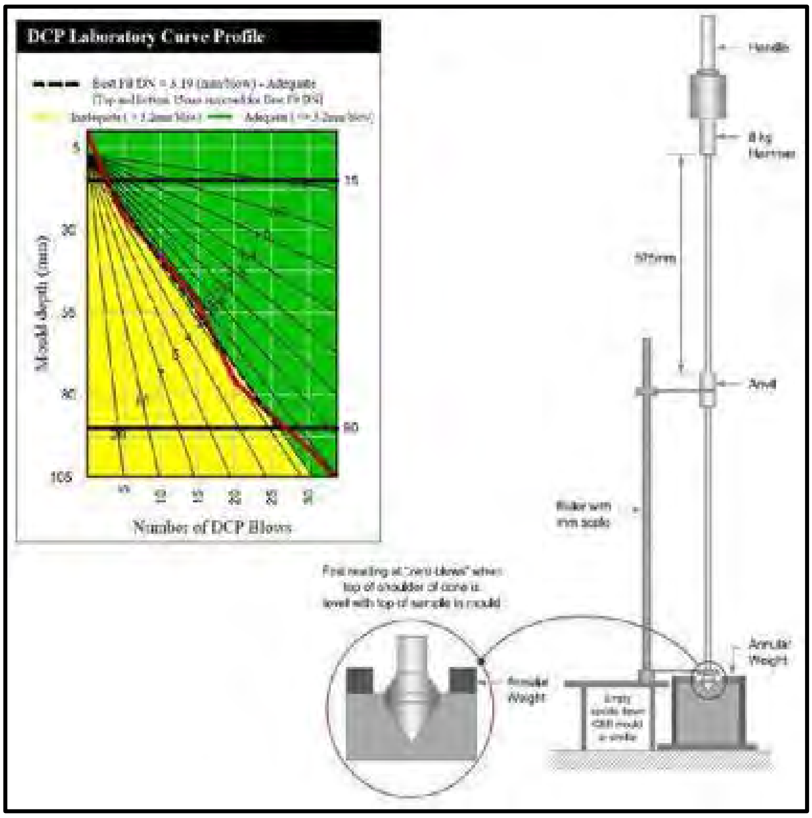


Figure D 1 Set-up and typical output from the laboratory DN test

D. Position the tip of the DCP cone in the middle of the CBR mould, hold the DCP in a vertical position, knock it down carefully until the top of the 3 mm shoulder of the cone is level with the top of the sample and record the zero reading;

E. Knock the cone into the sample with “n” number of blows and record the reading on the ruler after every “n” blows. At OMC and 0.75, OMC “n” may be any number between 1 and 10 depending on the hardness of the sample. At 4-days soak “n” may be 1 or 2. “n” does not have to be the same number for all readings;

F. Stop just before the tip of the cone touches the base plate in order not to blunt the cone (the last reading minus the “zero blows” reading must be less than the height of the sample inside the mould);

G. Enter the test data (sample description, number of blows and corresponding readings, etc.) into a spreadsheet or the Laboratory Module of the AfCAP LVR DCP Software. With a laptop at hand, the data can be entered directly as the test is carried out, and

H. Take a representative sample from the middle of the specimen for determination of the actual moisture content at which the DN value was determined.

Analysis of the test data

A typical output from the Laboratory Module of the AfCAP DCP DN software from the test of one sample is shown in Table D 3. The representative DN value for the specimen is taken as the slope of the "best fit" line from the middle of the mould. The DN value in the top and bottom 15 mm of the specimen often diverges from this "best fit" DN due to a lack of vertical confinement at the top and possibly a higher density at the bottom.

Note that the densities of each specimen for the same compaction effort and moisture content will never be exactly the same, as illustrated in Table D 3. It is therefore imperative that the volume of each mould is pre-determined, and that the laboratory equipment (particularly the scales) is properly calibrated to ensure that the actual densities of each specimen can be calculated with the required level of accuracy.

Table D 4 Summary of typical laboratory DN test results

Compactive effort	DN mm/blow		
	Soaked	OMC	0.75 OMC
Light	11.20	6.40	3.60
Intermediate	6.90	4.50	2.90
Heavy	5.30	3.90	2.40

Compactive effort	Density kg/m^3		
	Soaked	OMC	0.75 OMC
Light	2165	2192	2179
Intermediate	2234	2242	2246
Heavy	2315	2329	2321

MDD 2340.000 g/cm^3				
Soaked	Relative compaction	92.5 %	95.5 %	98.9 %
	DN mm/blow	11.20	6.90	5.30
OMC	Relative compaction	93.7 %	95.8 %	99.5 %
	DN mm/blow	6.40	4.50	3.90
0.75 OMC	Relative compaction	93.1 %	96.0 %	99.2 %
	DN mm/blow	3.60	2.90	2.40

Table D 3 shows a summary of a typical laboratory DN test, as described above. Plot the "best fit" DN values against the actual densities (average values of three specimens) in a diagram, as shown in Figure D 2..

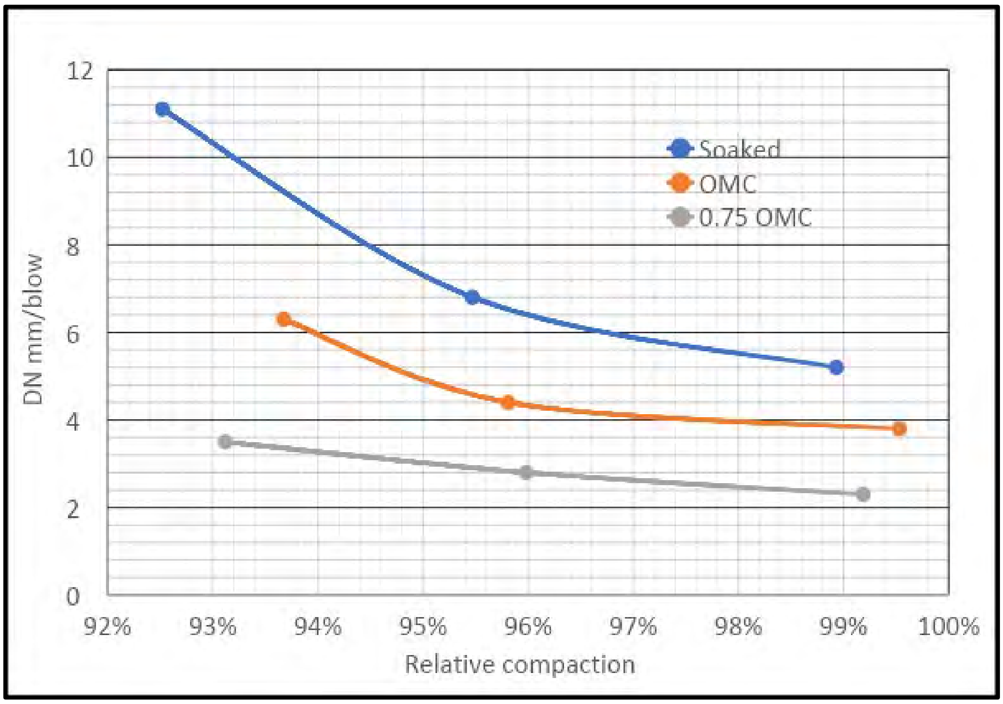


Figure D 2 DN/density/moisture relationship

Figure D 2 illustrates the relationships between DN, density and moisture content for a naturally occurring material. This will enable the designer to determine whether the material is suitable for use in the pavement, and where in the pavement it can be used based on the anticipated long-term moisture condition and the minimum field density of the layer(s) after compaction, by comparison with the requirements specified in the DCP-DN design catalogue for each pavement layer.

Figure D 2 also illustrates two critical factors that crucially affect the long-term performance of the road:

- The need to specify the highest level of density practicable (so-called “compaction to refusal”) by employing the heaviest rollers available. This will result in a stronger material with lower voids and reduced permeability, enhancing the overall properties of the material. Compaction to refusal (without degrading the material) is indicated by the number of roller passes, established through compaction trials, at which no additional density is achieved for any specific compaction effort. Additional compaction thereafter is a waste of time and money and may result in the breakdown of individual particles of the material. Compaction meters can help with identifying the optimum compaction effort.
- The need to ensure that the moisture content in the outer wheel track of the road does not rise above OMC. This will require careful attention to drainage, as discussed previously

Appendix E. Projects Specifications

Introduction

An "End product specification" will apply for the selection of a MC-NME stabilising agent using the test procedure as specified under C1003 – no alternative test procedure will be allowed. Should more than one stabilising agent meet the engineering specifications, the stabilising agent with the least cost for the stabilisation and improvement per cubic metre of the naturally available material, will be selected. The stabilising agent also needs to meet the minimum required specifications of stability on site without an increase in viscosity of more than ± 10 per cent and any visible separation.

The recommended project specifications apply to all categories of roads and are not restricted to the upgrading of unpaved roads. The criteria contained in Table C1002/1, applies to the upgrading of unpaved roads, the design of new roads and rehabilitation of roads, applicable both to lower-order and higher-order roads.

In rems of clarification, an NME stabilising agent is defined as:

Materials Compatible New Modified Emulsion (MC-NME) stabilising agents or similar where an emulsion is defined as any additive in the form of a solution, including any additive added to the construction water, including (but not limited to):

- Bitumen emulsions with/without a modified emulsifying agent (e.g., aggregate adhesive, water-repellent agents (e.g., organo-functional-silanes) and/or with the addition of polymers (micro- and or nano-polymers);
- Material-compatible polymers (micro- and/or nano-polymers, e.g. Nano Polymers Nano Silanes (NPNS)), or
- Any "alternative" rock/aggregate/soil stabilising agent.

Reference to a NME stabilising agent will be interpreted as to have the same definition as that of a MC-NME.

In the context of this document, MC-NME may be considered as an abbreviation covering the use of any or all of the above-mentioned stabilising or material improvement additives. However, the engineering requirements in terms of strength criteria, sample preparation and test protocol contained in this document must be met in all cases.

The **END PRODUCT SPECIFICATIONS** require an MC-NME to be verified prior to usage **AND GUARANTEED** by the contractor and/or supplier. It is important to note that the NME stabilising agent (or equivalent) is **costed in terms of cubic metre of the material that is being stabilised and not by the quantity of the stabilising agent.** The cost of a stabilising agent depends on the end result and not on the quantity added to the material.

Project Specifications

Add the New Section 5.6 to COTO (2020);

A5.6 CONSTRUCTION OF PAVEMENT LAYERS USING COLD IN-SITU STABILISATION WITH A MATERIAL COMPABIBLE NANO MODIFIED EMULSION (MC-NME) STABILISING AGENT

CONTENTS

In all cases, reference should be made to applicable sections within COTO, 2020. However, MC-NME stabilisation is not specifically addressed within COTO, 2020. Hence, these “Product Specifications“ have been compiled as complementary to COTO, 2020.

PART A: SPECIFICATIONS

A5.6.1 SCOPE

This section covers work required for the construction of new roads (including upgrading of existing unpaved roads) or the rehabilitation of the upper pavement layers (base and sub-base) using the cold in-situ recycling process with (a) labour-intensive construction methods with a mixture of conventional equipment (b) conventional equipment, i.e., water-cart, grader(s) and compaction equipment (b) recycler and (c) central mixing plant. The construction of new pavement layers, using a MC-NME stabilising agent (or alternative stabilising additive) in an emulsified state (to be applied together with the construction water), is aimed at the use of naturally available materials (often in-situ) from the area of the road that can cost-effectively be utilised in the upper pavement layers.

The use of a MC-NME stabilising agent for the rehabilitation of existing roads is aimed at the optimum use of damaged or weathered in-situ materials in a cold in-situ recycling process. This may include a pre-stabilisation process of the milling and breaking-up of existing pavement layers (e.g., existing surfacing) and the mixing of the milled materials, with or without the addition of new materials to achieve a uniformly mixed material to be stabilised with the MC-NME. In such cases, the size diameter of the pre-milled materials should not exceed a third of the total thickness of the layer that is to be stabilised in-situ. After a homogeneous mix has been achieved, the material is stabilised in place with the MC-NME stabilising agent to produce a homogenous mix, which is spread, cut to level and compacted to the required specification. This section also covers the use of an applicable prime as a temporary surface for early trafficking. It is important to note that the prime must also be Material Compatible (MC) with the NME stabilising agent to ensure adequate adhesion.

A5.6.2 DEFINITIONS

The relevant definitions in the standard specification are applicable. Additional definitions for this Section are included here.

Conventional equipment – this is equipment that is normally used for the construction of the Works, including graders, water-bowsers and compaction equipment. This equipment excludes equipment specifically designed and used for in-situ reconstruction works and/or for the recycling of materials.

Pavement rehabilitation – involve measures used to improve, strengthen or salvage existing deficient road pavement structures so that these can continue (with adequate maintenance) to carry traffic at adequate speed, safety and comfort in a cost-effective way (refer draft TRH12 – Road pavement rehabilitation investigations and design). Road pavement rehabilitation may involve various options, including:

- Complete pavement reconstruction;
- Partial reconstruction or in-situ recycling involving the strengthening of existing pavement layers, with or without an applicable stabilising agent before re-surfacing;
- Asphalt and/or granular layers with a suitable wearing course (surfacing);
- Concrete inlays and overlays;
- Levelling courses;
- Resealing with or without rut-filling;
- Improvement or provision of drainage (surface and/or sub-surface, and
- Any combination of the identified options as specified in the Contract Documentation.

MC-NME – Material Compatible New Modified Emulsion (MC-NME) - where an emulsion is defined as any additive in the form of a solution, including any additive added to the construction water, including (but not limited to):

- Bitumen emulsions with/without a Material Compatible modified emulsifying agent (e.g., aggregate adhesive, water-repellent agents (e.g., organo-functional-silanes) and/or with the addition of polymers (micro- and or nano-polymers);
- Polymers (micro- and/or nano-polymers) with/without a Material Compatible modified emulsifying agent (e.g., aggregate adhesive, water-repellent agents (e.g., organo-functional-silanes), or
- Any "alternative" rock/aggregate/soil Material Compatible stabilising agent.

Reference to a NME stabilising agent will be interpreted as to have the same definition as that of a MC-NME.

Slushing - the process of wetting the surface of a compacted layer accompanied by rolling with a smooth-drum roller and/or a pneumatic tyre roller to generate saturated fine material, a slush, on the upper surface of the compacted layer.

Uniform pavement section - an uniform pavement section has pavement layers with similar layer materials characteristics, similar layer bearing capacity properties and similar layer thicknesses throughout the section. A pavement section is considered as uniform when the Coefficient of Variation (CoV) of the measured properties is less than ± 25 per cent. Uniform pavement sections shall be clearly identified in the Contract Documentation.

In-situ materials – materials within the existing pavement structure. In the case of an unpaved road in-situ materials would refer to the existing granular materials comprising the unsurfaced road.

A5.6.3 GENERAL

A5.6.3.1 Traffic accommodation

The traffic accommodation arrangements required during construction of roadworks in urban and rural areas are specified in Chapter 1 of the specifications.

A5.6.3.2 Material selection

The material specifications in this section refer to:

- Reclaimed material from existing pavements shall be utilised as specified in the Contract Documentation. All reclaimed material from existing pavements, shall be broken down and oversize material removed, to comply with the maximum size and grading requirements for the particular use of the reclaimed material as specified in the Contract Documentation;
- Material Compatible Nano Modified Emulsion (MC-NME) shall be material sourced by the Contractor whereby the Contractor will take full responsibility and liability for using a stabilising agent not meeting the END-PRODUCT specification, and
- Material classifications must be in line with design specifications and material classification as contained in the Contract documents.

A5.6.3.3 Construction limitations

The Contractor shall arrange the processing and stabilisation of pavement layer operations in such a manner as to minimise the disruption of public traffic. Every effort shall be made to ensure that the safety of the travelling public on existing roads is prioritised throughout the site of the works at all times. In-situ processing and stabilisation operations shall be carefully planned and executed following the following limitations:

(a). Individual work areas shall be clearly demarcated with traffic signs, delineators and traffic control facilities as specified.

(b). Individual work areas shall be planned in such a manner that all processing and stabilisation of pavement layers and the compaction thereof as specified in Clause A5.6.7.13 be completed within the same day or period specified.

(c). No priming shall be done unless the processed and stabilised pavement layers have been tested, inspected and accepted by the Engineer. In cases where access needs to be given to the public, priming will be done on the instruction of the Engineer. With the enrichment of the processed and stabilised layers, light traffic (urban) can be allowed to use an un-primed layer with confidence, depending on the characteristics of the materials and the NME stabilising agent used, without any serious damage being inflicted on the stabilised layers. In such cases, the same procedures should be followed before priming and/or surfacing as discussed with light traffic being allowed to use a primed surfacing.

(d). Within each working area, the contractor shall make adequate provision for drainage of milled, excavated and/or asphalt overlay areas where water can pond or be contained within or on a road layer surface. No separate payment item will be made for the provision and use of standby pumps and de-watering equipment for cutting drainage slots and/or channels to effectively drain the roadway surface as instructed by the Engineer in the interests of safety for the travelling public. The Contractor shall make allowance for this drainage in this tendered rates.

(e). Delineators shall be placed along each longitudinal step exceeding 30 mm between adjacent lanes of the roadway. The maximum allowable step within a lane opened to traffic shall be restricted to 40 mm. If, due to plant breakdown or other unforeseen circumstances, a longitudinal or transverse step higher than 20 mm occurs within a lane, the strip shall be feathered off using quick-drying NME slurry or compacted asphalt over a distance of 500 mm to the satisfaction of the Engineer.

(f). In the event of rain occurring during the stabilisation process, the work must be stopped and the area must be sealed using a single roller pass. The continuation and stabilisation using the MC-NME stabilising agent shall only commence when the moisture content of the area has reduced to the level it was before it started raining or to an acceptable level with the necessary adjustments in the construction water and the NME stabilising agent as a percentage of the construction water.

A5.6.3.4 Weather Limitations

No in-situ processing and stabilisation of materials shall commence if the threat of rain is present. The in-situ moisture condition should allow for the dilution of the NME in the construction water as described. Materials earmarked for stabilisation should be allowed to reach a moisture condition that allows for the mixing of the stabilising agent at the required moisture content. The ripping of the materials and exposure thereof to sunny conditions could assist with the natural drying of materials before the processing and stabilisation are to proceed.

A5.6.3.5 Protection and Maintenance

The Contractor shall protect the completed base layer from all damage until the surfacing is complete, or if opened to traffic, ensure that the surfacing complies with the required condition to the satisfaction of the Engineer. Any damage occurring to the completed base or any defects that may develop due to faulty workmanship shall be made good by the Contractor at his own cost and to the satisfaction of the Engineer.

Repairs shall be made in a manner approved by the Engineer to ensure an even and uniform surface.

During the working and construction of the base layer, precautionary measures shall be taken to prevent kerbs and channelling and concrete works from being damaged or shifted. Care shall be taken to protect all pre-cast units from chipping and breakage. Concrete kerbing and channelling, as well as other structures adjacent to the road, shall be protected against staining, by the NME product and the subsequent surfacing of the road. Any work stained by the NME and/or surfacing shall be broken down and replaced unless all such NME or surfacing material is completely removed so as not to show any stains. Painting over stained work will not be allowed.

Where the cold in-situ processing and stabilisation are to be carried out at existing structures, care shall be exercised to avoid damage to concrete elements, expansion joints, manholes, catch-pits, etc. Damage caused to any element forming part of the permanent works shall be repaired by the Contractor at his own cost.

Damaged caused by the Contractor through careless operations shall be repaired at his own costs. New construction shall be done following the drawings and the Specifications. The Contractor will be held responsible for the timely adjustment of all covers and frames in advance of surrounding construction, whether they are indicated on the drawings or by the Engineer or not. No claims for delays arising from the failure of the Contractor to affect the necessary adjustments in good time will be allowed.

The type of surfacing and selection of the binder or modified binder should allow for evaporation of moisture to continue (similar to any other type of pavement layer (e.g. granular, cement stabilised, etc.) that will continue to dry and reach an equilibrium moisture content due to evaporation over a period of at least two seasons). It should be noted that some modified binders inhibit the ability of the evaporation of moisture to occur, leading to the trapping of and concentration of moisture underneath the surfacing and formation of water below the surfacing which could result in early problems in terms of stripping of the surfacing and/or, in the case of chip-seals, punching of the stone (chips) into the base, resulting in severe bleeding of the surfacing and early failure (refer SABITA Manuel TG1 – The use of Modified Bituminous Binders in Road Construction - Table 12 : Advantages and disadvantages of modified binders compared with conventional binders).

A5.6.3.6 Construction Tolerances and Finish Requirements

Care shall be exercised to avoid damage to any concrete elements, expansion joints, joint nosing, manholes, kerbing, catch pits and any other roadside furniture during reconstruction of the layers. Damage caused to any element forming part of the permanent works **shall be repaired by the contractor at his own cost.**

A5.6.3.7 Programme of reconstruction work

All reconstruction work shall only take place in accordance with the accepted reconstruction programme which the Contractor shall compile and submit to the Engineer prior to commencing the reconstruction of each uniform road pavement section. The programme shall be updated and the updated programme shall be submitted to the Engineer at the end of each week.

Prior to the start of each single-operation of work, the Contractor shall prepare a M&U plan detailing proposals for the work. This plan shall at least include the following:

- Overall layout of the length and width of road intended to be reconstructed during the single-operation. The width shall be divided into the number of parallel cuts required to achieve the specified width of treatment;
- Location of and overlap width (minimum overlap of 200 mm) at each longitudinal joint between adjacent cuts;
- Location of the inner and outer wheel paths of each construction lane affected by the reconstruction;
- Sequence and length of each cut to be reconstructed before starting on the adjacent or following cut, and

- Estimate of the time required for the reconstruction along each cut and for finishing off the work.

A5.6.3.8 Contractor plans for the reconstruction of existing roadworks

The Contractor shall prepare and submit an M&U plan for the RR of existing roadworks to ensure that it is worked in a sustainable and sensitive manner, to ensure that the environmental impact is minimised, that material use and haulage are optimised and that the work is carried out in a cost- effective manner.

The M&U plan shall at least take cognizance of the following and provide detail of the following as appropriate:

The pavement layer construction/rehabilitation programme;

- A method statement and programme for the construction of each of the pavement layers including the reclaiming of existing road materials, the breaking down and processing in-place of an existing pavement layer and the completion of each layer;
- Details of the programme for the movement of materials to ensure that the material is not handled unnecessarily;
- The survey methods to be used to set out and control the levels and width of the pavement layers for each processed layer;
- A method statement for the construction of a trial section using a recycler;
- A method statement of how oversize material will be dealt with;
- Measures to comply with the general and specific conditions of the road environmental management plan;
- Measures to comply with the latest applicable Construction Regulations;
- Measures to comply with safety regulations and obligations in terms of the latest Occupational Health and Safety Act;
- The full quality and process control testing detail for the applicable materials tests along with the frequency and quantity of such testing for each constructed section of each layer to ensure full compliance of the constructed layer in terms of compaction density, material quality and stabilisation testing (visual and laboratory), and
- Procedure for the regular monitoring, auditing and reporting.

The RR of an existing pavement layer shall only commence once the Contractor's M&U plan for that layer has been reviewed and accepted by the Engineer.

A5.6.4 DESIGN BY THE CONTRACTOR / PERFORMANCE BASED SYSTEMS

The Contractor will take full responsibility and liability for using a stabilising agent not meeting the END PRODUCT SPECIFICATION (EPS).

During the design phase, the Design Engineer must test and ensure that products are available that will meet the specifications with the given NAGM or mixture of materials (e.g., milled surfacing with NAGM base layer with/without additional NAGM).

A5.6.5 MATERIALS

The use of a MC-NME stabilising agent (or alternative stabilising additive/product) aims to optimally use naturally available material (new or in-situ) in the upper pavement layers of a road meeting the minimum design requirements as specified in Table **A5.6.5/1** (applicable during construction for quality control and use during the detailed material design in the laboratory as detailed).

TABLE A5.6.5/1: Standard specifications for MC-NME stabilised materials

Test or Indicator	Material[1]	Material classification			
		NME1	NME2	NME3	NME4
Minimum material requirements before stabilisation and/or treatment (Natural materials)					
Material spec. (minimum) Unstabilised material: Soaked CBR[2] (%) (CBR as % of MDD)	NG /(CS)	> 45[2] (95%) ACV < 30%	> 25[2] (95%)	> 10[2] (93%)	> 7[2] (93%)
Grading Modulus (GM)	NG	> 1.5	> 1.0	-	-
	GS	NA	> 1.0	-	-
Sieve analysis: % < 0.075 mm ($P_{0.075}$)	ALL	< 25 %	<25 %	< 35 %	< 50 %
XRD scans: - Total sample - 0.075 mm fraction ($P_{0.075}$)	ALL ALL	Required Required	Required Required	Required Required	Required Required
% Material passing 2 µm ($P_{0.002}$) (e.g. Clay & Mica & Talc) as a % of Material (with Talc <10%) (XRD-scans of the material passing the 0.075 mm sieve are used to determine the % clay, mica and talc in the material – In this case $P_{0.002}$ = $P_{0.075}$ x ($P_{clay, etc.}$ in $P_{0.075}$)	MC-NME stabilisation with micro-meter (µm) emulsion particle sizes				
	ALL	< 15 %	< 15 %	< 15 %	< 15 %
	MC-NME stabilisation with emulsion containing micro-scale as well as nano-scale particles (adjusted according to material grading)				
	ALL	NA	< 35 %	< 35 %	< 35 %
	MC-NME stabilisation with emulsion containing nano-scale and pico-scale particles (grading adjustments) together with technologies addressing workability of materials on site				
	ALL	NA	NA	> 35 %	> 35%
Material specifications after stabilisation and/or treatment					
In-situ density to be required after stabilisation and compaction (% of MDD)	Base	> 100 %	> 100 %	> 98 %	> 97 %
	Sub-base	NA	> 98 %	> 97 %	> 95 %
DCP(DN mm/blow)(Quality control in field testing - base only) (stabilised and compacted = wet; 7 days cured = dry)	DCP-DN	NA	NA	< 2.6(wet) < 2.0(dry)	< 3.5(wet) < 2.3(dry)
Density (% of MDD) (for laboratory testing)		> 100 %	> 100 %	> 100 %	> 100 %
*UCS_{wet} (kPa) (150 mm Φ Sample)	**Design[3]**	**> 2 500**	**> 1 500**	**> 1 000**	**> 750**
	Construction[4]	**> 2 200**	**> 1 200[5]**	**> 700[5]**	**> 450[5]**
Retained Compressive Strength (RCS): (UCS_{wet}/UCS_{dry}) (%)	RCS	> 85	> 75	> 70	> 65
RCS in relation to minimum $UCS_{wet(criteria)}$ = $RCS_{effective}$ = (RCS x (UCS_{wet}/$UCS_{wet(criteria)}$)) (%)	RCS-E	>100	> 90	>85	> 80
*ITS_{wet} (kPa) (150 mm Φ Sample)	**Design[3]**	**> 240**	**> 200**	**> 160**	**> 120**
	Construction[4]	**> 220**	**> 180[5]**	**> 140[5]**	**> 100[5]**
Retained Tensile strength (RTS): ITS_{wet}/ITS_{dry} (%)	RTS	> 85	> 75	> 70	> 65
RTS in relation to minimum $ITS_{wet(criteria)}$ = $RTS_{effective}$ = ((RTS x (ITS_{wet}/$ITS_{wet(criteria)}$)) (%)	RTS-R	>100	> 90	> 85	> 80

[1]CS – crushed stone; NG – natural gravel; GS – gravel soil, and SSSC – sand, silty sand, silt, clay.\
[2]CBR only used as reference to traditionally used test procedures as a broad first indicator
*Definitions: UCS = Unconfined Compressive Strength; ITS = Indirect Tensile Strength);
UCS_{dry}; ITS_{dry} = testing after rapid curing; UCS_{wet}; ITS_{wet} = testing after rapid curing and 4 hours in water (as per test procedure specified for the testing of cementitious stabilising agents (SANS 3001-GR32:2010, 2010));
Design[3] = Minimum criteria to be met in the laboratory during the design phase
Construction[4] = Minimum criteria to be met during construction as part of quality control
[5]Criateria based on reference TG2 (Asphalt Academy, 2009)
$RCS_{effective}$ and $ITS_{effective}$ are used to obtain and effective Material Classification, i.e., NME1 to NME4

The aim is to cost-effectively utilise NAGM as an alternative to new crushed-stone materials in both the upgrading of existing unpaved roads, design and construction of new roads as well as the rehabilitation of existing pavements, through the improvement of appropriate available materials normally considered to be “non-standard”, “marginal”, “low-cost”, or even “sub-standard” in terms of the standard material indicator tests.

A MC-NME stabilising agent will be able to neutralise the effect and possible negative impact of secondary minerals formed during weathering as a result of chemical decomposition and nullify any possible risk associated with the use of the potentially water sensitive natural materials by meeting the material classification criteria specified in Table **A5.6.5/1** for the design material class (NME1 to NME4).

Materials from existing pavement layers shall be classified as follows for excavation and processing purposes:

A5.6.5.1 Existing bituminous materials

Bituminous material shall be an asphalt surfacing or a bituminous seal from an existing layer. Where the asphalt surfacing and bituminous seal are recycled together with the underlying layers, the mixture will not be classified as bituminous material.

A5.6.5.2 Granular Materials

The base and sub-base pavement layers in the existing pavement shall be classified as granular materials. Granular material shall include crushed stone, gravel soil and natural gravel and can consist of cemented or non-cemented material. Crushed stone obtained from existing pavements and processed as gravel material will be paid for as gravel material and not as crushed stone.

The mixture of bituminous material (RA) and base and sub-base material shall be classified as granular material.

A5.6.5.3 Extra material

Extra material as specified consists of:

(a). Naturally Available Granular Materials (NAGM) (and (if cost-effective) crushed stone materials). The pavement layers will be designed based on the requirements of the design traffic loadings and the material specifications required for the various pavement layers as designed, complying with Table **A5.6.5/1.**

(b). Crusher dust.
No crusher dust is to be used with a NME stabilising agent unless specified for that specific alternative stabilising agent.

(c). Gravel.
The gravel material shall be of a minimum quality as per Table **A5.6.5/1.** (Higher quality materials will normally require less of the MC-NME stabilising agent and/or the modifier contained withing the stabilising agent, depending on the inherent mineralogy.)

A5.6.5.4 Material stabilisation/improvement products/additives

(a) Stabilising Agent: MC-NME as defined in the preamble to the Project Specifications.

During the Detailed Design Phase of the project, the Design Engineer must identify the potential use of an NME for the improvement of materials not adhering to the design characteristics and the volume of material for such stabilisation calculated for inclusion in the Bill of Quantities (BOQ). Contractors and their suppliers must show proof of concept and provide guarantees to the following:

The MC-NME stabilising agent must be environmentally stable and produce/release NO adverse negative substances during the process of hydrolysis (i.e., when mixed with the construction water) and condensation (i.e., when attachment to the material/soil occurs). A Safety Sheet to this effect must be produced by the supplier. The specified cold-mix NME must be stable in containers (i.e., flow-bins or tankers) on site (with or without minimum maintenance (e.g. weekly circulation of the stabilising agent - **the cost of which will be included in the cost of the stabilising agent**)) for a minimum period of at least 4 months. At all times during site storage, the MC-NME stabilising agent will be able to be used with the tested material to meet the applicable design criteria as contained in Tables **A5.6.5/1. The supplier/contractor shall take full responsibility (and cost implications) for using an NME stabilising agent resulting in inferior test results and/or stability as per Clause A5.6.4.**

The NME stabilising agent as provided by the contractor with his supplier as guaranteed by the contractor, must at all times meet the specified criteria for the specific pavement as contained in Tables **A5.6.5/1.** It should be **noted that different specifications are applicable for the design in the laboratory and quality control during construction** to allow for laboratory versus site variations and conditions. The prescribed test procedures are detailed in Clause **A5.6.9.2**.

The MC-NME stabilising agent must have a guaranteed minimum on-site storage stability exceeding **4 (four)** months and a workable Viscosity during all seasons of the year without pre-heating, allowing for the in-situ cold recycling of the available materials, taking into account storage at higher ambient temperatures during the summer months and possible cold temperatures during winter months. The contractor **will take full responsibility for maintaining the stabilising agent on-site to ensure that it will remain stable during storage with no visible separation and without an increase in viscosity during storage. The NME must meet the following minimum specifications proven by the supplier/contractor:**

- A guaranteed shelf life on-site (e.g., in flow bins if applicable) **exceeding (at least) 4 (four) months or as specified by the engineer**. (The shelf life can normally be increased to at least 6 to 12 months through the circulation of a quality MC-NME mix once a week using a normal circulation pump.)
- Laboratory test results using the prescribed rapid curing test procedure on available materials from site testing the UCS (dry and wet) and ITS (dry and wet) and meeting the required Retained Compression Strengths (RCS) (UCS_{wet}/UCS_{dry} in percentage) and Retained Tensile Strengths (RTS) (ITS_{wet}/ITS_{dry} in percentage), as well as the required Effective, Retained Compressive Strength ($RCS_{effective}$ = RCS x ($UCS_{wet}/UCS_{wet(criteria)}$)) and Effective Retained Tensile Strengths ($RTS_{effective}$=RTS x ($ITS_{wet}/ITS_{wet(criteria)}$)). **The $RCS_{effective}$ and $ITS_{effective}$ will be used for the material NME classification**. The average values of at least 3 tests shall be used to obtain the laboratory results. The laboratory results should meet the criteria for the design phase as contained in **Table A5.6.5/1** (the higher design criteria take into account variations between laboratory and on-site conditions). The $RCS_{effective}$ and $ITS_{effective}$ are used to get the Material class most closely associated with the NME stabilisation.
- Additional test samples shall be prepared and cured at 22-25°C for 28 days and retested. The test results should either show similar or higher results as tested after the initial rapid curing process as prescribed in Table **A5.6.5/1** to ensure that no negative mineral and or stabilising agent interaction or degeneration of polymers (where applicable) occurs.

The prepared MC-NME on site must be ready for immediate dispersion within the construction water (using a standard circulation pump) and ready for stabilisation. It is important to note that all containers and water tankers must be thoroughly cleaned before the MC-NME is added. Unclean (contaminated) equipment could result in activating any residual bituminous mix left in the container or water tanker when the MC-NME is added, resulting in an unusable sticky substance, such as balls or strings of bitumen. **Any losses occurred during construction due to the use of contaminated equipment will be at the cost of the contractor.**

(b) Additives for granular material stabilisation/treatment alternatives other than those defined in Item

The material stabilisation/treatment additive must have a guaranteed on-site stability exceeding 4 (four) months taking into account storage at high ambient temperatures during summer months and possible cold temperatures during winter months**. The supplier/contractor will take full responsibility for maintaining the stabilising additive/product on site to ensure that during storage, before application, the additive /product will remain stable with no visible separation of particles and without any change in measurable properties during storage (e.g., an increase in viscosity). The stabilised mix must meet the following minimum specifications proven to be the supplier/contractor:**

- A guaranteed shelf-life on-site (e.g., in flow bins if applicable) exceeding 4 (four) months. (The shelf-life can normally be increased to at least 6 to 12 months by maintaining the additive/product regularly as required by the supplier.);
- Laboratory test results using the prescribed rapid curing test procedure on available materials from site testing the UCS (dry and wet) and ITS (dry and wet) and meeting the required Retained Compression Strengths (RCS) (UCS_{wet}/UCS_{dry} in percentage) and Retained Tensile Strengths (RTS) (ITS_{wet}/ITS_{dry} in percentage), as well as the required Effective, Retained Compressive Strength ($RCS_{effective} = RCS \times (UCS_{wet}/UCS_{wet(criteria)})$) and Effective Retained Tensile Strengths ($RTS_{effective}=RTS \times (ITS_{wet}/ITS_{wet(criteria)})$). **The $RCS_{effective}$ and $ITS_{effective}$ will be used for the material NME classification** The average values of at least 3 tests shall be used to obtain the laboratory results. The laboratory results should meet the criteria for the design phase as contained in Table A5.6.5/1 (the higher design criteria takes into account variations between laboratory and on-site conditions), and
- Additional test samples shall be prepared and cured at 22-25°C for 28 days and retested. The test results should either show similar or higher results as tested after the initial rapid curing process as contained in Table **A5.6.5/1** to ensure that no negative mineral and or stabilising additive/product interaction or degeneration of the additive/product (where applicable) occurs as an indication of durability.

  The prepared stabilising additive/product on-site must be ready for immediate dispersion within the construction water (using a standard circulation pump) ready for stabilisation or the supplier must clearly specify the process of application during the construction process to ensure that a uniform mix with uniform qualities is achieved. **The differences in methods of application will be to the cost of the contractor.**

It is important to note that all containers and water tankers must be thoroughly cleaned before any stabilising additive/product is added. Unclean (contaminated) equipment could result in the activating of any residual mix left in the container or water tanker when the stabilising additive/product is added, resulting in an unusable substance. **Any losses occurred during construction due to the use of contaminated equipment will be at the cost of the contractor.**

c) Water.

Water used for diluting the stabilising additive/product shall be potable water (clean and free from salts and contamination) that will cause the stabilising additive/product to be adversely affected by these chemical impurities. The stabilising additive/product will be tested for compatibility with the compaction water. Water must be potable and the pH shall not exceed 7 (or as required for the use of the specific stabilising additive/product). Should local sources be considered, prior laboratory testing to ensure acceptability will be required. The quality of the water must adhere to the requirements given in Table **A5.6.6.4/1**. **Any additional requirement for the construction water as required by the supplier of the stabilising additive/product will be the cost of the contractor.**

d) Chemical modification of material

No additional chemical modification of the stabilised material will be allowed if not contained in the original specification. **In all cases, the requirements as given in Table A5.6.5/1 must be met.**

e) Stabilisation of sub-base

In the case of the rehabilitation of an existing road or the construction of a new road, the sub-base shall conform to the requirements of the layer as per design. In all cases, the possible consequences and compatibility of the layer characteristics, in terms of the expected behaviour of the pavement structure as a whole, needs to be assessed by the Engineer.

A5.6.5.4 Composition of Recycled Mixes

During the rehabilitation of existing pavement layers, the recycled material shall consist of the existing surfacing (where present), granular material from existing pavement layers, additional material where required and an applicable NME stabilising agent/product. The actual composition of the mix shall be determined by design requirements. The NME stabilising agent with proof of concept will be provided by the contractor and approved by the Engineer to comply with the testing requirements as specified in Table A5.6.5/1 as obtained using the test methods as detailed under Item A5.6.9.2. Any NME stabilising agent not meeting the requirements of a specific layer during construction will be to the cost of the contractor

Adjustments to the actual mix constituents are not normally required as it is already accounted for in the differences in specifications for the design versus in-field conditions during construction (some slight adjustments may be authorised by the Engineer, based on the results of the trial section taking into account additional factors such as equipment used, e.g. conventional equipment vs recycler vs central mixing plant and climatic conditions) – in all cases such adjustments must be authorised by the Engineer. The Engineer reserves the right to adjust the composition of the mix at any time should he deem it necessary. The Contractor and Supplier shall provide the Engineer with the proposed final mix proportions based on the required test results and the Engineer must approve the results before any materials are ordered. **The risk of alternative designs using any alternative additive/product not specified remains with the Contractor as per normal contract specifications.**

The average values for in-situ moisture contents shall be tested by the Contractor and confirmed by the Engineer prior to any work commencing on any specific day for adjustments in the amount of construction water together with the stabilising agent to be made if necessary.

Table A5.6.6.4/1: Water classification for Construction Testing

		Water Quality Classification Code						
		H0	**H1**	**H2**	**H3**	**H4**	**H5**	
Property	Unit	Pure water (AR)	Clean water (Rain)	Treated water (Municipal)	Silty (muddy) water with low salt content	Highly mineralised chloride sulphate water (brackish)	Waste brick, sewage, marsh, sea, etc. water	Method
PH*	-	7.0	5.7 – 7.9	4.5 – 6.5	4.5 – 8.5	9.0	-	SABS M113 SM 11 - 1990
Dissolved solids*	ppm	0	1000	1500	3000	-	-	SABS 213 SM213 - 1990
Total hardness*	-	None	None	Temporary	Temporary	Permanent	-	SABS 215 SM 215 - 1971
Suspended matter	ppm	0	2000	2000	5000	-	-	SABS 1049 SM 1049 - 1990
Electrical conductivity	mS/m	0	200	200	500	-	-	SABS 1057 SM 1057 – 1982
Sulphates (SO_4)	ppm	0	200	300	500	1000	-	SABS 212 SM 212 - 1971
Chlorides (Cl)	ppm	0	500	1000	3000	5000	-	SABS 202 SM 202 - 1983
Alkali Carbonates (CO_3) & Bicarbonates (HCO_3)	ppm	0	500	1000	1000	2000	-	SABS 241 - 999
Sugar	-	Negative	Negative	Negative	Negative	Negative	-	SABS 833
Quality of water required		Untreated layer works	a	a	a	a	Investigate effect on the quality	
		Chemically treated layer works	a	a	Investigate the effect on the quality of the stabilised material	Investigate the effect on the quality of the stabilised material		
		Concrete mass	a	a	a	Investigate the effect on the quality		
		Concrete prestressed	a	a				
		Slurry & emulsion	a	a				
		Soil/gravel tests	a	a				
		Chemical or control tests	a	a				

References:
1. Concrete Technology – Dr S Fulton (1989)
2. Materials Manual (PAWC)

A5.6.6 CONSTRUCTION EQUIPMENT

A NME stabilising agent is usually highly reactive. Hence, it is imperative that all storage tanks, water tanks, etc., must be thoroughly cleaned (normal good housekeeping site operations), with no residue from previous mixes present in these tanks. The contractor shall allow the engineer to inspect the equipment before use, to ensure that the equipment is suitable for use with the NME stabilising agent or any other alternative as submitted for use by the contractor and his supplier. In all cases the supplier shall ensure that the stabilising agent application is clearly specified and the contractor shall take full responsibility to meet the specifications of the supplier. The NME stabilising agent in use must be freely available to the Engineer to test for quality control purposes at any time.

A5.6.6.1 Conventional Plant

A heavy-duty motor-grader is an essential item of plant for NME stabilisation, irrespective of the combination of any of the other plant items used. This grader is required to pre-shape the material prior to being treated, for processing the material and thereafter, to cut the layer to final levels. Processing by grader includes mixing the material prior to treatment and mixing in of the NME diluted within the construction water or alternative additive/product as specified and guaranteed by the contractor and his supplier.

In the case of in-situ recycling of existing surfaced pavement layers, a milling machine will be required to adequately mill asphalt or multiple seals and/or high-strength cemented material to produce a material of a size suitable for the stabilisation or treatment with the stabilising agent. When in-situ material is to be supplemented with imported material, a milling machine can also be used effectively to blend the two materials after the correct quantity of additional material has been levelled out on top of the in-situ material and pre-shaped with a grader.

Alternatively, layers that have developed high in-situ strength can be broken down using a “woodpecker-type” attachment fitted to an excavator. The resulting chunks of pavement material can then be transported to a single-stage crusher to be crushed and transported back to the road for further processing**.**

A5.6.6.2 Recycling Equipment

The plant shall be so equipped that it will be able to recycle pavement layers to depths up to at least 300 mm in one operation. The plant shall be equipped so that the stabilising agent mixed in with the construction water as per calculations, can be added uniformly in a calibrated and controlled manner directly to the material being recycled or processed. Width reduction must be possible on the application nozzles when overlap recycling is done. The recycling depth shall be controlled electronically.

Pre-mixing of the layer(s) to be stabilised with the surfacing (when specified) will be done to ensure that a uniformly mixed layer is present before stabilisation with the recycler is to be done. In the case of the upgrading of an existing unpaved road, ripping the material to the specified depth should be done. Oversized material can be removed by labour-intensive hand picking before the layer is stabilised, although the recycler often breaks down this material if not too hard.

The direction and speed of the recycling machine and the speed of rotation of the scarifying drum shall be adjusted to obtain the required grading and sufficient mixing of all the components of the recycled material. The machine shall be capable of making a neat vertical cut at the outer edges when recycling the layer.

The recycler should, as a minimum, be equipped with:

- Self-cleaning nozzles, and

- Be equipped with a micro-computer, able to adjust the application of the water and stabilising agent according to the speed of the recycler – the proper working of this equipment is essential to ensure that the stabiliser is applied to specification. The Contractor shall ensure that equipment operators receive the necessary training to operate the equipment to enable the required specifications to be met.

The recycler will be pre-tested using clean water to ensure that all systems, as per specification, are in proper working order, that operators are fully trained and that the stabilising agent will be added as adjusted by the speed of the recycler.

A5.6.6.3 Water Tanker

Self-propelled water tankers, with a 15 000 L capacity, are essential plant items for the successful construction of a stabilised layer. In addition to supplying the stabilising agent/additive/product for mixing, water tankers are required to ensure proper finishing of the treated layer of material after the initial mixing and processing stage has been completed (AT NO STAGE SHOULD WATER WITHOUT THE STABILISING AGENT BE ADDED TO THE LAYER).

Sufficient construction water mixed with the stabilising agent must be added to the mix to account for a loss of moisture during processing, taking into account the equipment to be used and climatic conditions to ensure that compaction starts with the layer preferably at approximately OMC. (Results from detailed testing under actual as well as research conditions indicate that the OMC of the material is reduced by approximately 10 % when using a water-repellent modifier and that the moisture/density relationship may not be as critical compared with that of stabilisation without the NME stabilising agents not containing a water-repellent modification. Experience has shown that the best results are usually obtained when final compaction is achieved at a moisture level of 0.5 per cent to 1.0 per cent below OMC (taking into account the total fluid content and not only the water content of the stabilising agent). Unusual high percentages of problematic minerals within the in-situ materials to be stabilised using a NME may require compaction to be done at lower moisture contents. In such cases trail sections are essential to determine optimum moisture contents for the stabilisation and compaction of the pavement layer(s). Sufficient water tankers must be provided to ensure that the processing of the material is a continuous procedure with no stopping to wait for a water tanker.

Where applicable, water tankers involved with the treatment and distribution of a stabilising agent should be earmarked only for the transportation of the stabilising agent in various stages of dilution as dictated by the in-situ moisture content of the material to be stabilised. In the case of NME stabilisation, it is recommended that a small percentage of the NME mixture be retained in the tanker in the cases of the use of conventional equipment to treat a “dry” surface before or during compaction when the moisture loss is deemed to be excessive for one or another reason that may occur in practice due to numerous unforeseen (e.g., weather) conditions. A surface is visually considered to be too dry when fine cracks appear directly behind the rollers. Supervision personnel must be on site during stabilisation operations to visually note any changes that may occur during the stabilisation process.

Due to material variations, some sections along a road may also contain excessive moisture. In these cases, a small “wave” will form in front of the compaction equipment. When this phenomenon is observed, the section should be ripped and allowed to expel some moisture (evaporation) before being recompacted. This operation should not exceed a period to the end of compaction of 6 hours. In all cases, reworked layers need to meet the material specifications as contained in Table **A5.6.5/1** for the material class specified. The contractor will take full responsibility for any reworking of the layer not meeting the required specifications.

All water tankers used for NME treatment must be equipped with a circulating pump system to circulate the diluted NME after standing for an extended period and for circulating during the dilution process – in all cases contractors will take full responsibility for the end product specifications to be met with maintenance being carried out as required. Water tankers must not be fitted with a conventional spray bar but with valves (such as a clam-lock valve) which will not easily clog. The application of the diluted NME is a cold process and a modified stabilising agent containing a water-repellent agent considerably reduces the possibility of blockages of the nozzles. However, it is the responsibility of the Contractor to ensure that no blockages occur during the stabilisation process, resulting in the uneven distribution of the stabilising agent. In cases where such blockages do occur, the Engineer will require the layer to be remixed using conventional equipment or that the layer be reworked in total. Tankers must be properly flushed should they need to stand empty for extended periods (e.g., overnight).

A5.6.6.4 Rollers

The equipment to be used for the conventional breaking-up and excavation of existing pavement layers will be determined by the size and depth of the pavement section to be processed or excavated, taking into consideration the fact that work may have to be carried out in restricted areas.

One heavy-duty grid roller and an adequately powered pneumatic tyre tractor that will pull the grid roller when fully loaded, or an equivalent self-propelled sheep foot roller, may be required in the case of very coarse material to break down the material suitable for the construction of the layer. The breaking down of the material should be done prior to the addition of the NME. During the NME stabilisation and compaction of the layer compaction equipment should be used with a minimum risk of further breaking down of the NAGM as new surface areas created after addition of the NME will not be covered by the water-proofing agent, resulting in a reduction of the test results. The use of a sheep-foot roller is not recommended for use for the final compaction of the layer stabilised with a NME stabilising agent.

The compaction of a stabilised base layer is normally adequately achieved with a vibratory smooth drum roller in combination with a pneumatic wheel roller to achieve a surfacing finish, meeting the required specifications of the layer in terms of density as well as a finish suitable for a surfacing consisting of a chip seal only or even a NME slurry seal as per the design. It is the responsibility of the Contractor to ensure that operators of the compaction equipment are fully trained in the importance and effect of amplitude and frequency adjustments when compaction is done using vibratory rollers.

A5.6.6.5 General

Static tanks shall be provided to store sufficient quantities of the stabilising agent for the needs of the project. Normally such tanks will have a capacity of between 30 000 litres and 120 000 litres. Static tanks must be fitted with a circulating pump system that will enable the stored stabilising agent to be properly circulated from time to time in the static tank, as per the requirements of the supplier. These tanks must be fitted with a flowmeter to ensure that the required volume of the stabilising agent is carefully measured and added to the construction water.

A5.6.7 EXECUTION OF THE WORKS

A5.6.7.1 Removal of grass and weeds

Before commencing in-situ recycling, all grass, weeds, etc., encroaching into or onto the road surface or growing between the edge of the existing surfacing and kerbs, channels, etc., shall be removed.

A5.6.7.2 Preparing the pavement surface

Before any cold in-situ processing by any equipment may commence, the pavement surface shall be clean and free from any material that could be harmful to the execution of the works and affect the quality thereof.

For rehabilitation works, any asphaltic surface with granular sub-layers and/or cemented layers will be pre-milled before the preparation of the layer. Where specified/required, additional material shall be spread to the thickness and width as specified and milled together with the part of the existing pavement. The area to be processed shall be properly demarcated. No payment will be made for cold, in-situ reworking/processing of materials beyond the required width.

Before cold in-situ processing may commence, the moisture content of the in-situ materials to be reworked must be determined in an approved manner to determine the amount of water required to reach optimum moisture content. In the case of the measured moisture content exceeding the optimum by more than 0.5 per cent with the addition of the diluted stabilising agent, the layer shall be ripped and left to dry until the moisture content has reached an acceptable level before applying the stabilising agent and reaching the required moisture conditions.

A5.6.7.3 Construction in confined areas

In such an event where any material stabilisation as specified has to be executed in an area the width of which is less than 1.0 m or the length of which is less than 50 m and the area is less than 50 m^2, it shall be classified as work in restricted areas.

A5.6.7.4 Recovery of bituminous material

When specified, existing bituminous material shall be milled out as indicated by the design. Excavated pavement material intended for reprocessing but which cannot be reprocessed in place or, in the opinion of the Engineer, cannot be windrowed next to the excavation, nor placed in position directly at any other place, and material intended for recycling or reprocessing in a plant, shall be transported to approved stockpiles with the written permission of the engineer.

Stockpile sites for material intended for recycling or reprocessing in a plant shall be set out at the corresponding mixing or crushing plant or at such other locations as approved by the engineer. The stockpile site shall be cleaned and all loose stones. Vegetation and other materials which may cause contamination shall be removed. The site shall be graded smooth with an adequate slope to ensure proper drainage of water.

The limits of milling shall be demarcated clearly and these limits shall not be exceeded by more than 100

mm. Areas milled outside the specified limits shall be repaired by the Contractor at his own cost and to the satisfaction of the Engineer.

A5.6.7.5 Spreading of extra material on a layer before reprocessing

Where the existing road layer or surfacing level is too low, or existing material has to be spoiled due to unsuitability and/or where specified or instructed by the Engineer, suitable pavement material shall be added to the layer to make up the shortfall before the processing and stabilisation of the layer. Suitable pavement material for addition to make up a layer shortfall shall consist of NAGM as specified (and tested) as directed by the Engineer.

The extra pavement material shall be spread uniformly over the full area of the underlying shortfall layer by means of an approved type of mechanical spreader to such thickness as to comply with the requirements specified in Clause A5.6.3.6 after the final compaction. Segregation of the materials shall be avoided and the additional material shall be placed free from pockets of course and fine materials. Extra material shall only be spread on the section to be processed and stabilised and only immediately before the processing operation.

A5.6.7.6 Application of stabilising agent diluted with water

At no time whatsoever should an undiluted stabilising agent (such as an NME) be applied to the layer of material that is being processed. The NME must be added to the construction water (taking into account the total fluid content of the NME (a water-repellent modified emulsion effectively reduces the OMC of the material). Hence, not only the water percentage within the emulsion needs to be taken into account but the total fluid content, to ensure that the mix is properly distributed throughout the layer and that the compaction can be done to meet the specified density criteria. The supplied NME needs to be diluted by a factor of between 1:4 (1-part NME and three parts water) and 1:1 (50-50) to ensure proper distribution of the stabilising agent. A high percentage of fine material (in the order of more than 20 to 25 per cent passing the 0.075 mm sieve size), will normally require higher rates of dilution (depending on the particle sizes of the NME and the specifications of the supplier) to ensure that a thorough distribution of the stabilising agent is achieved.

Coating of all the granular particles within the layer will not take place when the NME is added separately to the construction water (as is possible with modern recycling equipment). Any “wetting” of material before stabilisation will be detrimental to the material adhesion between the aggregate and the stabilising agent to be achieved. As a consequence, the in-situ moisture content of the untreated layer must never be so high that it cannot accommodate the NME stabilising agent that has been distributed within the construction water. The construction water is effectively used as a carrier of the NME stabilising agent, ensuring that all granular particles within a layer will be covered.

A5.6.7.7 Pre-treating an unsurfaced base layer

A material-compatible designed NME stabilising agent will not require the pre-treatment of materials to account for “problem” minerals such as smectites, muscovite (Mica), etc. The NME must be tested to automatically address the presence of such minerals during the detailed design phase and must be specifically designed to neutralise the effect of these minerals. In cases with high contents of specifically identified minerals, a pre-treatment may be prescribed using an appropriate co-product prior to the stabilisation process. The identification of the need for pre-treatment shall be done as part of the detailed design process through the detailed testing of the mineral composition of available materials (using XRD-scans), to be used in the upgrading, construction or rehabilitation of a road pavement.

Testing during the design development stage was undertaken as given in the project information. However, the contractor is required to undertake testing to ensure material compatibility and performance with the NME product that is preferred by the Contractor.

A5.6.7.8 Breaking down of material using conventional methods

During rehabilitation works, the existing pavement material shall be broken down to the specified depth and processed in place either through pre-milling or ripping as previously discussed.

The ripped material shall then be broken down in situ with a fully loaded grid roller hauled by an adequately powered tractor. During the process of grid rolling and breaking the material, the material shall be windrowed constantly and any oversize material shall be removed.

Unsuitable material for sub-base and base shall, as directed by the Engineer, be removed and spoiled and will be paid under pay Item C5.6.9.

Where sub-base layers need to be constructed, the base material shall be windrowed to the side and the sub-base layer should be inspected first. After inspection by the Engineer, the demarcated sub-base area should be reworked and re-stabilised as per design or required by the Engineer.

A5.6.7.9 Adding diluted NME

The emulsion tanker supplying the diluted NME (containing the mix of the NME and the required construction water as measured and calculated) shall be equipped with an approved measuring device (e.g., dipstick) to enable the site staff to take control calibrated depth measurements at intervals specified by the Engineer. The material processing and stabilisation operation will be cancelled/interrupted by the Engineer until this required specification is met.

The method of introducing the various materials comprising the final mix shall be done as per design and subject to the Engineer's approval. Care shall be taken to prevent excessive loss of moisture between the time when the materials are mixed and when they are compacted on the road (taking into account climatic conditions as mentioned).

A5.6.7.10 Spreading

The recycled mix shall be spread and levelled with a motor grader to the required width and to such thickness as to comply with the requirements specified in Clause A5.6.9.1 before final compaction. Segregation of the materials shall be avoided and the layers shall be free of pockets of course or fine materials.

A5.6.7.11 Stabilisation

(i) Mixing Recycler

The recycled base/sub-base material, extra material, and NME stabilising agent diluted in the construction water shall be thoroughly mixed by the recycling mixing process with plant as specified in Clause A5.6.6.

The NME diluted in the construction water, shall be measured by mass and quantities, calculated in accordance with the formulas given in Clause A5.6.5.4. It shall be introduced continuously in a controlled manner into the material that is being stabilised, proportionally to the speed of the recycler, to ensure that the correct quantity of the stabilising agent is added to the full width of the section being recycled. Care should be taken that all nozzles are fully operational during the recycling process. In cases where an uneven distribution of the stabilising agent is noticed, the layer will be re-mixed using conventional blade mixing with graders, at no extra costs or reworked in total as per instruction of the Engineer at no additional costs.

(ii) Conventional Method

Blade mixing by grader is undertaken by using the blade to move the material from side to side. This mixing process is often supplemented with the use of ploughs and/or rotavators. Where the width of the treatment restricts the horizontal movement of the material, extra use should also be made of the grader rippers with specially designed "shoes" welded onto the rippers. Such shoes are in the shape of a horizontal "V", with the sharp end of the V pointing in the direction of travel of the grader. The rippers with their V-shaped shoes are lowered to the treated depth and the "fast forward" gear of the grader is used to plough through the layer. In this manner, the material is pushed aside, ensuring that proper mixing is achieved, even when working in confined widths.

The NME must first be diluted with the compaction water to a residual NME content of between a 1:1 to 1:4 dilution and applied in several applications onto the material over the width and length previously determined. Water tankers are used to apply the NME and the grader(s) must travel directly behind the water tanker, immediately covering the freshly sprayed NME with material, thereby preventing excessive loss of moisture and the NME from immediate breaking (where applicable). The volume of diluted NME applied is determined by the designed percentage of the NME, expressed as a percentage of the mass of the layer that is being treated.

Should weather conditions be particularly hot or dry, adjustments to the construction water must be made to ensure that the compaction moisture content (containing the NME stabilising agent) is achieved. This process is exactly the same as for the compaction of any granular layer, requiring the same care during construction to achieve the required densities.

Care should be taken to ensure that the diluted NME is applied in such a way that no rivulets are formed, that the NME does not run off the layer before it has been mixed into the layer and that the exact application rate is achieved.

During mixing, attention must be paid to the fluid content of the mix. The fluid content is the total quantity of fluid in the mix, including hygroscopic moisture, the diluted NME still in suspension and the water in the NME.

The addition of the post-mixed construction water (mixed with the NME stabilising agent) should not be so high as to result in deformation of the surface under final compaction. (Observed as a “wave” forming in front of the compaction equipment.) The required total mixed construction water as determined in the laboratory before the start of the stabilisation process may be amended based on on-site observations, allowing for the type of compaction equipment used.

Additional adjustments in the pre-mixed construction water may be required when working with porous materials. Such materials will absorb some water leading to a need for a higher percentage of pre-mixed water to achieve the required results. The design process, as recommended, should identify the presence of materials that will require higher than normal percentages of pre-mixed construction water. However, due to the limits to which pre-testing can be done, the Engineer on site should be aware of this possibility and require adjustments as recognised on site.

Where the existing asphalt surfacing or cemented base layer is being recycled with the underlying gravel layer using conventional construction equipment, the asphalt layer must first be milled off and left in a windrow on top of the granular base that is to be recycled. Once the asphalt layer has been milled off in this manner then the base layer can be milled or ripped and broken down. The stabilisation of the layer using a material-compatible NME should only commence once the milled asphalt layer and the existing gravel base material have been thoroughly blended to form a uniform material.

A5.6.7.12 Preparation before the stabilisation/treatment of the material

The following will need to be determined in advance for input into the Moisture Calculation Sheet:

- Length, width and depth of section to be stabilised; MOD, OMC and in-situ moisture content; Content of water tanker in litres; Water tanker volume will also need to be calibrated and marked out on a volume measuring gauge.

Preparation before stabilisation:

- Prior to applying the stabilising agent, the NME shall be mixed with water in the water tanker to form a diluted NME which, when applied to the material, will act as a carrier of the diluted NME to the soil fines.
- The Contractor shall determine the rate of dilution of the additive using the Moisture Calculation Sheet, which may range from 1 litre of NME to between (5 litres and 40 litres) of water depending on the type of material/soil, in-situ moisture content and percentage of the NME stabilisation required. This calculation sheet shall be submitted to the Engineer daily for approval, both before and after the completion of each section to be stabilised. Experience has shown that NME stabilised material/soil will reach optimum strength when final compaction is done at a moisture content of

just below OMC taking into account the total fluid content (taking into consideration that a water-repellent modification will normally reduce the OMC by about 10 per cent - the contractor and his supplier will confirm the implications of any specific stabilising agent with the Engineer before the start of any operations to enable quality control to be effectively executed). To reach this target OMC, it may be necessary to apply 1.0 per cent to 2.0 per cent moisture above OMC (depending on climatic conditions which could result in the drying and loss of moisture due to evaporation during very hot conditions and the mixing equipment used – e.g., conventional grader mixing will take longer and will allow more moisture to escape (evaporate) than mixing with a recycler). Compaction at moisture conditions which are too low will lead to the formation of fine cracks (immediately visible after the roller) which will compromise the integrity of the top of the layer, resulting in the formation of a weak inter-layer at the top which may result in the failure of the seal by separation from the rest of the base layer (the appearance of fine "cracking" when compaction commences can be addressed through a further application of some diluted NME (kept in reserve in the water-tanker) which will increase the surface moisture to achieve the desired compaction densities and a uniform layer. Too high moisture conditions will be seen when the layer is moving in front of the roller (kneeing) – in these cases, the drying out of the layer may be required by ripping, drying and re-compaction (as per previous discussions and guidelines). Such operations should not exceed more than 6 hours. The following processes may be followed:

1. The diluted NME may be sprayed onto the road surface using a spray bar fitted to the water tanker or by hand spraying in places with difficult access.
2. Initial thorough and complete mixing of the NME with the construction water is essential. The NME products using a double emulsification process usually result in small particles that distribute easily through the construction water without much additional effort. However, it is the Contractor's responsibility to ensure that the NME is evenly distributed within the construction water. In the cases where constant mixing of the stabilising agent with the construction water is required to prevent separation (usually a function of the particle size of the stabilising agent), an electrical or petrol-driven stirrer must be used. In such cases, the contractor must ensure that:
   - (i) The pump has sufficient capacity to circulate the entire contents of the tank in 15 minutes;
   - (ii) There are no internal baffles in the tank restricting circulation, and
   - (iii) Before the commencement of spraying, the contents are circulated for at least 20 minutes.

A5.6.7.13 Compaction

The completed compacted layer shall have a minimum in-situ dry density as specified for the specific layer (as per the requirement of the designed layer as in Table A5.6.5.3/1 and Table A5.6.10). It shall be the responsibility of the Contractor to determine the maximum dry density and Optimum Moisture Content (OMC) of the material to be stabilised for purposes of quality control (compaction control). The Contractor may select any suitable compaction technique to achieve the required compaction, subject to the following conditions:

1. The initial compaction shall be carried out with plant, which achieves stability suitable for subsequent compaction, without causing undue displacement of the material or deformation of the layers. The rolling pattern shall be designed to retain the shape of the layers as far as possible;
2. The types and number of compaction equipment to be used and the amount of rolling to be done shall be such as to ensure that specified densities are obtained without damage being done to

lower layers or structures. During compaction, the layer shall be maintained to the required shape and cross-section, and all holes, ruts and laminations shall be removed;

3. Compaction equipment shall be adequate for obtaining the specified density within the specified time limits;
4. The compaction equipment and techniques shall be capable of producing the specified surface finish and density without any interruption, and
5. Not more than four (4) hours shall elapse between the time of starting the mixing process and that of starting to compact the material.

From the time when the diluted NME is added, not more than six (6) hours shall elapse until the compaction has been finally completed.

It is important to note that when adding water to material only diluted NME should be used.

The only time when the clean water can be used on its own is **during the pre-wetting of the completed layer before priming if required as per specification, depending on the type of product and supplier specification. This information must be shared with the Engineer before the start of any works and tested as per a test section to ensure that materials are compatible and approved by the Engineer**.

At no time is it allowed to "cut back" materials, to achieve levels without remixing the layer – materials added by "cutting back" material will result in "biscuit" layers and the disintegration (breaking up) of the top of the layer. Under such circumstances, high penetration of the stone with associated bleeding within the wheel tracks will occur when a surfacing consisting of a seal is used. A ring and ball test performed on top of the base course before sealing should normally expose this weakness and potential risks. The normal criteria used to evaluate ring and ball tests are applicable.

A5.6.7.14 Rejected work

The Contractor shall note that should he fail to meet the specified requirements for the NME stabilised layer placed at ambient temperatures, he shall remove the unacceptable layer and **will rework or replace it with approved material as instructed by the Engineer, at his own costs.**

Reworking of an existing layer may be allowed by the Engineer by ripping of the stabilised layer, adding 50 per cent of the original NME stabilising agent (this may be a function of the characteristics of the stabilising agent used) and compaction at the required OMC as per the original process to achieve the required results. It should be noted that the OMC of the material may have changed due to the first NME application. The reduction of the OMC is a function of the mineralogy of the granular material used, but normally in the order of 10 per cent. **Such reworking of the layer will be at the risk of the Contractor who will not be paid extra for the reworking of rejected works.**

A5.6.7.15 Providing a temporary wearing course

Immediately after completion of the compaction described in subsection (l), a material-compatible prime shall be applied to the finished surface using a water truck, binder distributor or hand sprayer at a spray rate of 1 litre/m2 (or as specified for a specific supply). The spray rate may be adjusted by the Engineer following a trial section of not less than 100 m in length. Costing is to be done per constructed m2 and not per litre, accounting for differences in product requirements.

As an alternative, a 50:50 diluted NME may be sprayed onto the layer and compacted using a steel-wheeled roller with a mass of not less than 12 tons, and/or with pneumatic rollers.

The following process is to be followed:

- Immediately after compaction, slushing of the surface will commence: Spray 1 litre/m^2 of the diluted NME onto the surface followed immediately by further compaction utilizing a 13-ton vibratory roller that must follow directly behind the water cart. A 22-ton Pneumatic Tyre Roller (PTR) must then follow directly behind the vibratory roller;

- Turn around and on the same strip have the water cart first drench the surface with a further 1 litre/m² diluted NME. This time the pneumatic tyre roller follows directly behind the water cart and the vibratory roller follows closely behind the PTR. It is important that the water cart and roller must work in close tandem at all times; to prevent any pick-up of the material by the drum of the vibratory roller (this is usually not a problem with the use of a material-compatible, water-repellent NME stabilising agent);
- Continue with the above points until the total area to be worked is completed, and
- The area treated with a prime (recommended a diluted (50:50) NME similar to that used in the stabilisation of the base layer) is to be kept closed to traffic for the prime to properly set and dry (until the top 50 mm of the layer has dried out) with a moisture content of < 50% of OMC. The time of required closure is dependent on the prevailing weather and may be as short as 1 hour in the case of a material-compatible, water-repellent NME. Due to the addition of the water-repellent modification of a stabilising agent, a hydrophobic material surface is created and water is effectively repelled from the layer. Hence, stabilised layers constructed using a water-repellent modifier in the NME stabilising agent normally dry much quicker than pavement layers treated using traditional emulsion stabilisation processes that depend only on evaporation as a method of drying. In dry and hot conditions, a pavement layer will dry sufficiently within less than 24 hours to reach 50 per cent of OMC. The final surface should be smooth, tightly knit and free of undulations, corrugations, holes, bumps or loose material.

The application of a compatible prime (i.e., a recommended compatible NME-based prime) at a time when the base has reached a moisture content of 50 per cent of OMC should prevent most damage under conditions of light trafficking in urban areas. Heavy brushing with soft bristles is recommended before the application of the prime to remove any dust or loose materials on the surface, not disturbing the surface itself. The instructions of the supplier should apply - the risk remains with the contractor to achieve an acceptable base condition after the application of the prime. Experience has shown that a material compatible with NME prime will dry within an hour. In cases where the surfacing is applied immediately, the prime may be substituted by an appropriately specified tack coat. However, this is only applicable to cases where the contractor can ensure that the surfacing material and equipment are available for immediate application of the surfacing.

A5.6.7.16 Reconstruction of pavement layers using conventional equipment

Uniform pavement sections shall be clearly identified and detailed in the Contract Documentation. In accord with these uniform pavement sections an in-place gravel base layer or crushed stone base layer may be specified in the Contract Documentation to be reconstructed using conventional construction equipment.

The Contractor shall first remove any asphalt surfacing to spoil or to stockpile as specified in the Contract Documentation before reconstructing the base layer. A bituminous seal surfacing is normally not removed before reconstructing the base layer unless specified otherwise in the Contract Documentation.

The exposed in-place gravel base layer or crushed stone base layer shall then be scarified to the full depth of the existing layer or to the depth as specified in the Contract Documentation. In order to comply with the grading specification in the Contract Documentation the scarified material shall then be broken down and all oversize material removed. Compliant material may also be added and thoroughly mixed in as specified in this Chapter if required to improve the grading and/or other properties of the in-place material or to increase the layer thickness as specified in the Contract Documentation.

The Contractor shall then reprocess the layer as specified for new pavement layers in this Chapter. All required stabilisation of material shall be done as specified in this Chapter.

A5.6.7.17 Reconstruction of pavement layers using a recycler

Uniform pavement sections shall be clearly identified and detailed in the Contract Documentation. In accord with these uniform sections an existing gravel or crushed stone layer may be specified in the Contract Documentation to be reconstructed in-place, using a recycler.

a) Establishing construction levels – minor level changes

Before commencing any in-place reconstruction, the Contractor shall establish reference and level beacons for the setting-out and control of the works.

When only minor level changes (less than 15 mm up or down) will be made to the existing vertical alignment and/or to the road cross-fall or camber in order to restore the riding quality of the road, then new road design levels will not usually be provided in the Contract Documentation.

At each level control location, the Contractor shall record the existing road surface levels at the centre- line and at the outer limits of each lane including any surfaced shoulders. The Contractor shall use the existing road levels to determine the new construction levels along the centreline and the outer limits of each traffic lane and any surfaced shoulders. A line of best fit shall be used to determine the final levels for the reconstructed layer taking into account the following:

- The required camber or super elevation.
- The minimum requirements governing changes in the vertical alignment.
- The thickness of the existing layer to be reconstructed.
- Minimising the amount of preparatory work required ahead of reconstruction, such as minimising the importation of material.

At least two calendar weeks before reconstruction work is programmed to commence on any specific uniform pavement section, the Contractor shall submit the level proposals to the Engineer in sufficient detail to enable the proposed reconstruction levels to be reviewed. The detail shall incorporate a schedule as well as a drawing, of all the design levels and the grade lines respectively. Once agreement has been reached regarding the proposed levels, reconstruction work may commence.

The Contractor shall establish a series of level control poles placed at a constant offset on both sides of the road prior to commencing any construction work at a maximum interval as indicated in Table A5.3.8-2. The Engineer shall take control measurements to determine the accuracy and adequacy of the level control poles and shall instruct the Contractor to make any adjustments as required.

b) Establishing construction levels significant level changes

When significant level changes (more than 15 mm up or down) will be made to the vertical alignment and/or to the road cross-fall or camber, the reconstructed layers shall be reconstructed to new design levels provided in the Contract Documentation.

Before commencing any in-situ reconstruction, the Contractor shall establish reference and level beacons for the setting-out and control of the works.

The Contractor shall survey the existing road levels and compare these with the new design levels and prepare a schedule of the areas where there will be surplus material and of where there will be insufficient material. This schedule will be used to prepare a layer material transfer diagram which will enable the transfer of surplus reconstructed material to areas where there is a shortage of material. The material transfer diagram shall be submitted to the Engineer for review at least two calendar weeks before reconstruction work is programmed to commence on any specific uniform pavement section.

The Engineer shall subsequently instruct the Contractor regarding the proposed reuse or spoil of surplus material, or the need to import any additional new material prior to the commencement of the reconstruction work.

The Contractor shall establish a series of level control poles placed at a constant offset on both sides of the road prior to commencing any construction work at a maximum interval as indicated in Table A5.3.8-2. The Engineer shall take control measurements to determine the accuracy and adequacy of the level control poles and shall instruct the Contractor to make any adjustments as required.

c) Preparation of the road surface

Before any reconstruction work may commence, the surface of the existing road shall be prepared as follows:

- Remove all vegetation, dirt and other foreign matter including from any adjacent lanes or shoulders that are not to be reconstructed.
- Remove road studs from the full road width.
- Remove standing water.
- Establish an off-set reference line, for each cut, for the recycler to follow and ensure accurate steering.
- Record the location of all road marking features that will be obliterated by reconstruction.
- Mill off the asphalt or bituminous seal surfacing to spoil or stockpile where specified in the Contract Documentation.

A5.6.7.17 Disposal of surplus material

Recovered pavement material remains the property of the Employer. Surplus materials, including waste or oversized material, bladed or skimmed off the road, shall be stockpiled at designated areas within a free-haul radius of 5 km as directed by the Engineer with approval from the Client, considering environmental implications. Should the Employer decide not to use the surplus material, the Contractor shall then dispose of the material to the satisfaction of the Client within a free-haul distance of 5 km.

A5.6.7.18 Checking moisture content and surface condition before priming and/or surfacing

The mixing and placing of asphalt or seal will not be allowed if:

(i) Free water is present on the working surface or when rain is imminent – no surfacing will be allowed during adverse weather conditions as this could result in the detachment of the surfacing from the base layer;

(ii) The moisture content of the upper 50 mm of the recycled base exceeds 50 per cent of the Optimum Moisture Content (OMC);

(iii) Loose material is present on the surfacing - in cases where the base has been primed and exposed to trafficking, the surface needs to be cleaned of all loose material and any localised problem area repaired using an NME slurry mix (the same NME used for the stabilisation of the base layer) It is usually a good idea to prepare small quantities of slurry to ensure excellent bonding with the existing base layer).

A5.6.8 SETTING OUT OF THE WORKS

A5.6.8.1 Setting-Out and Control of The Work

The Contractor shall establish his own reference and level beacons for the setting out and control of the works. The Contractor shall indicate his own reference and control beacons to the Engineer at least one week before the work is programmed to commence. The Engineer will take control measurements to determine the accuracy and adequacy of the reference/control beacons and may instruct the Contractor to correct any faulty work and to take and provide such additional measurements and details as may be deemed necessary. This survey work will not be measured and paid for directly and compensation for any work involved in staking or setting out will be deemed to be covered by the rates tendered and paid for the various items of work included in any contract. No payment will be made for any inconvenience or delay caused by compliance with these requirements.

A5.6.8.2 Trial Sections (Refer COTO, 2020)

Where ordered by the Engineer, the Contractor shall construct trial sections with the preferred material-compatible NME stabilising agent (first proven through laboratory testing as per the test protocol contained in A5.6.9.2), to evaluate in practice the construction process, the compatibility of materials and the ability of the modified stabilising agent to be able to meet the specified criteria as per Table A5.6.5/1. During the trial sections, any adjustments in terms of the addition of water and applicable OMC should be finalised. The latter is of importance, especially if layers above 150 mm thick are to be stabilised in one operation (not advised). The water released and repelled by the NME will be pushed upwards towards the top part of the layer, requiring an adjustment in the pre-mixed construction water.

Trial sections shall be carried out at locations approved by the Engineer.

A5.6.8.3 Work Outside Normal Working Hours (Refer COTO, 2020)

Any work carried out outside of normal working hours must be approved by the Engineer. The Contractor shall give the Engineer at least 48 hours' notice of his intention to do work outside the normal working hours. The closure of traffic lanes will only be permitted during these times. The provision and layout of lighting for the works and warning lights for the accommodation of traffic shall be approved by the Engineer. No additional payment will be made for the provision of additional warning lights for work done outside of normal working hours. The Contractor shall allow for the provision, erection and maintenance of additional items required in his tendered rates.

A5.6.9 WORKMANSHIP

A5.6.9.1 Construction Tolerances and finish Requirements

(**a) Construction tolerances (Refer COTO, 2020)**

The applicable construction tolerances are the relevant tolerances indicated in the project specifications as related to the Category of Road. Where the existing granular base abuts kerbs or channels or New- Jersey barriers, the new work shall extend to the edge of these facilities.

Unless otherwise specified, the processed and stabilised base shall be constructed to the existing levels, cross-section profile and cross-fall to allow for a surfacing layer as specified.

(b) NME stabilising agents

The average rate of application of the diluted NME as measured at operating temperatures in the water cart shall be within 5 per cent of the specified rate of application.

(c) Uniformity of mix (chemical stabilisation)

Unless specified by a specific supplier and results proven as per specification, no additional chemical stabilisation agent (e.g., cement) is required with the use of a material-compatible NME stabilising agent.

(d) Statistical judgement schemes (Refer COTO, 2020)

Routine inspections and tests will be carried out by the Engineer to determine the quality of the materials and workmanship for compliance with the requirements of this section.

The statistical judgement schemes to be used to determine whether the requirements specified are being complied with shall be those set out in the prescribed contract documents and/or design and quality control methods.

A5.6.9.2 Testing

(a) Testing

The Contractor shall give the Engineer at least 24 hours' notice of his intention to process/stabilise/recycle/rework any materials so that the actual process can be monitored and tested (quality control) by the Engineer. Unless otherwise agreed in advance, the Contractor shall only process/stabilise/recycle/rework any materials when the Engineer or his representative is present.

(b) Test Methods for determining UCS and ITS values – applicable during the design as well as quality control process. The number of tests done during construction as part of quality control will be done in accordance with the instructions of the engineer.

The following material test methods shall be used for the testing of NME stabilising agents or equivalent (engineering properties in terms of UCS and ITS values):

- As an input into the testing of the UCS and ITS of the material, the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) are to be determined using normal prescribed test procedures (SANS 3001-GR51), and
- The testing of the Unconfined Compression Strength (UCS), and the Indirect Tensile Strength (ITS) of the stabilised materials shall be done according to the protocols prescribed in the following paragraphs.

In all the above test methods, the +37.5 mm material must be screened off and discarded. The aggregate passing the 37.5 mm sieve and retained on the 19.0 mm sieve must not be crushed and must be used in the testing process. A pH test must be performed to determine the acidity/alkalinity levels of the material.

The curing and testing process of the 152 mm diameter samples (127 mm high) shall be as follows:

The MC-NME stabilising agent is mixed in with the construction water and the sample is prepared at Optimum Moisture Content (OMC). For example, if the OMC of the material is 8 per cent and 1 per cent of the MC-NME stabilising agent is added and the in-situ moisture content is 3 per cent, the addition of (8 - 3) 5 per cent moisture should be added to the material to achieve OMC. The 5 per cent to be added will consist of a mixture of 4 per cent construction water and 1 per cent MC-NME as per the total requirement. (Accordingly, the total fluid content (i.e., the total percentage of the MC-NME) is added as part of the compaction water – not only the water percentage of the MC-NME).

No cement or lime is added to a material-compatible NME stabilised material (unless specified by the supplier). Hence, the samples are not placed in plastic bags to assist with the hydration of the cement (as per usual, Bituminous Stabilised Materials (BSM) designs, contain cement as an additive and hence, the samples need to be placed in plastic bags in the oven during the rapid curing process to assist in the hydration of the cement in the mix):

1. The prepared 152 mm diameter by 127 mm height samples are to be prepared as per SANS 3001 – GR 50: 2013 and SANS 3001 – GR51 with the following changes:
2. **When no cement is used as part of the stabilising agent the samples are not to be enclosed in a plastic bag. (Plastic covering is required when cement is included in the mix to assist in the hydration of the cement).**
3. Samples are cured for 24 hours in an oven at 22-25°C before being subjected to a “rapid curing” process in an oven for 48 hours at 40-45°C (temperatures in the oven should NOT exceed 50°C).

4. After 48 hours the samples must be allowed to "cool off" for twenty-four (24) hours. This is preferably to be done in the oven at 22-25°C for 24 hours (SANS 3001 – GR 50: 2013; SANS 3001 – GR51) .
5. Directly after the "cooling off" period, three (3) samples each must be crushed to determine the ITS and UCS values. The values obtained are called the DRY ITS and the DRY UCS values (as per the test procedure specified for the testing of cementitious stabilising agents (SANS 3001-GR53:2010, 2010 and SANS 3001-GR54:2014)).
6. Six (6) samples must be placed in a bath of water with a temperature of 22-25°C for four (4) hours (as per the test procedure specified for the testing of cementitious stabilising agents (SANS 3001-GR53:2010, 2010 and SANS 3001-GR54:2014)) and thereafter removed from the bath and allowed to drain off excess water before determining the wet ITS and wet UCS values. The values obtained are called the WET ITS and the WET UCS values.
7. If approved by the Engineer, the "wet" tests (UCS and ITS) may suffice during the quality control during construction. For the lower-order roads (Category D and E), DCP tests done (as specified in Tables C1002/1 and C1014/1 for the specific material class) at randomly selected spots, may be approved for quality control as approved by the Engineer.
8. During the design stage 3 samples, each (twelve (12) in total) must be preserved outside the moulds for 28 days at temperatures of 22-25º C. After 28 days the UCS (wet and dry), as well as the ITS (wet and dry), should be tested as per the procedure described above. The results of the 28-day tests should not show a decrease in the tested values of the respective UCS and ITS tests (dry and wet) compared with results obtained after the rapid curing process (an increase in tested UCS and ITS values is normally expected with the use of a material-compatible MC-NME stabilising agent).
9. **It is important to note that sample preparation must be done in strict compliance with the prescribed procedures and NO deviation shall be allowed**, including:
   - 9.1 The moulds in which the samples are prepared are not to be **treated with grease or any other lubricant** to facilitate the easy removal of the sample as this could influence the loss of moisture or seal the sample and hence, the measurements of UCS and ITS;
   - 9.2 **No additional soaking of samples** in any "covering" liquid or any other material will be allowed as this will make any comparison and application of test requirements invalid and not comparable to what is practically achievable during construction,
   - 9.3 **Compaction of the samples** for testing will be done in strict compliance with the specified procedure in SANS 3001 – GR 50: 2013.

A5.6.10 TREATMENT OF RELATIVELY POOR-QUALITY IN-SITU MATERIALS AS A SUPPORTING FOUNDATION FOR THE CONSTRUCTION OF A MC-NME STABILISING LAYER OR PROTECTION OF GRAVEL SHOULDERS AGAINST EROSION OR GRAVEL PRESERVATION ON GRAVEL UNSURFACED ROADS

All preparations of the NME materials and construction processes and testing as per normal construction and rehabilitation of roads as discussed under items Table A5.6.9.2 also apply to the treatment of relatively poor in-situ materials to for a supporting foundation for the construction of a NME stabilised layer using NAGM. In such cases, Table A5.6.5/1 is supplemented by Table A5.6.10/1. This is also applicable for the treatment and protection of gravel shoulders against erosion and for gravel preservation on unsurfaced gravel roads.

In cases where the in-situ material consists of very fine materials (percentage passing the 0.075 mm sieve in excess of 50 per cent) the in-situ material may be treated with a NME consisting of a Nano- Polymer Nano-Silane (NME-NPNS) which is transparent in nature or slightly milky coloured, retaining the natural colour of the material treated. After compaction an application of a Micro Polymer Nano-Silane (NME-MPNS) should be applied to bind the surfacing together.

Table A5.6.10/1: Recommended material specifications for the treatment of relatively poor in-situ materials, gravel protection and gravel perseverance (Jordaan and Steyn, 2020))

Test or Indicator	**Material[1]**	**Material classification**
		MC-NME(NPNS)- EG5
Minimum material requirements before stabilisation and/or treatment (Natural materials)		
Material spec. (minimum) Unstabilised material: Soaked CBR (%)(CBR as % of MDD)	NG/GS/SSSG (CS)	-
Sieve analysis % passing the 0.075 mm sieve ($P_{0.075}$)		Required
XRD scans: - Total sample - 0.075 mm fraction		 Required Required
% Material passing 2 µm ($P_{0.002}$) (e.g. Clay & Mica & Talc), with Talc <10%) (XRD-scans of the material passing the 0.075 mm sieve is recommended for use to determine the % clay, mica and talc in the material).	MC-NME stabilisation with emulsion particle size > 2 µm	
	ALL	< 15 %
	MC-NME stabilisation with emulsion containing micro-scale as well as nano-scale particles (adjusted according to material grading)	
	ALL	< 35%
	MC-NME stabilisation using Nano Polymer with Nano Silane (NPNS) (special design and treatment)	
	ALL	> 35%
Material specifications after stabilisation and/or treatment		
In-situ density to be required after stabilisation and compaction (CBR as % of MDD) (minimum)	Base-layer	>97%
	Support	>95%
DCP(DN mm/blow)(Quality control in field testing - base only) (stabilised and compacted = wet; 7 days cured = dry)	Base-layer	< 3.5 (wet) < 2.3 (dry)
	Support	< 5.5 (wet) < 3.5 (dry)
Density (% of MDD) (for laboratory testing)		> 100%
*UCS_{wet} (kPa) (150 mm Φ Sample)	**Design[3]**	**> 750**
	Construction[4]	**> 450**
Retained Compressive Strength (RCS) = (UCS_{wet}/UCS_{dry}) (%)	RTS	> 65
RCS in relation to minimum $UCS_{wet\ (criteria)}$ = $RCS_{effective}$ = (RCS x ($UCS_{wet}/UCS_{wet\ (criteria)}$)) (%)	RTS-E	> 75
*ITS_{wet} (kPa) (150 mm Φ Sample)	**Design[3]**	**> 70**
	Construction[4]	**> 50**
Retained Tensile strength (RTS) =: ITS_{wet}/ITS_{dry} (%)	RTS	> 65
RTS in relation to minimum $ITS_{wet\ (criteria)}$ = $RTS_{effective}$) = ((RTS x ($ITS_{wet}/ITS_{wet\ (criteria)}$)) (%)	RTS-E	> 75

[1]NG – Natural Gravel; GS – Gravel Soil, and SSSC – Sand, Silty sand, Silt, Clay.
Design[3] = Minimum criteria to be met in the laboratory during the design phase
Construction[4] = Minimum criteria to be met during construction as part of quality control

A NME consisting of a NPNS treatment can be done as a surface enrichment and strengthening action or used for the protection of gravel shoulders against water erosion or as a gravel preservation product for the protection of the gravel wearing courses on unsurfaced gravel roads. Treatment of the surfacing only can result in a relatively deep penetration (> 60 mm), to bind the surfacing together (especially where the in-situ material consists of a very fine material containing a high percentage of problematic material, presenting problems in terms of workability and compatibility. Such treatment will enable the formation of a supporting layer on which a NME layer can be constructed in a conventional way. The supporting layer should be bladed to the required geometric requirements before the NME-NPNS is applied and then compacted using a smooth drum roller.

The dilution of the NME-NPNS should be pre-determined through testing in a laboratory using a standard Marshall mould to ensure that a depth of penetration of 60 mm is achieved, binding the material together. Typically, dilution rates of 1 to 5; 1 to 10, 1 to15 and 1 to 20 (1 being the NME-NPNS diluted in various ratios in water) applied at a rate of about 2 litres/m2 (applicable application rates should preferably be established on a trail section). After application the layer should be compacted using a smooth drum roller.

For deeper penetrations and and/or treatment of a typical 150mm base/surfacing layer as part of a supporting layer, the in-situ material can be ripped, sprayed, grader mixed and bladed before compaction. The testing requirements shown in light yellow in Table A5.6.10/1 is not applicable to material testing in the field for the treatment of in-situ material or gravel surfacings. Quality control of the treatment efficiency is to be done using the DCP penetration rate (mm/blow) of the treated layer. The curing of this layer should conform to the DCP-DN values as given in Table A5.6.10.

Quality control of a NME-NPNS can be done in the field on each container delivered on site by spraying the required dosage on a building sand placed in a Marshall mould (60 mm in depth). After 48 h in an oven at 40 – 45°C, the total depth of the building sand in the Marshall mould should be bound together. Water placed on the bottom of the building sand in the Marshall mould should form droplets not penetrating the bound building sand as an indication of the waterproofing achieved with the supplied NPNS.

In the case of a 150mm deep treatment, enrichment surface sprays with NME-MPNS may be needed as a maintenance action.

The surface of the wearing course shall receive additional treatment as described under Item A5.6.7.15.

Additional protection of the surface can be provided by the application of an applicable seal, including an NME-MPNS sand seal, slurry or “clear seal” to maintain a natural look as may be required by any specific road agency. A clear seal consists of a combination of a water-repellent-modified graded polymer. The clear seal is applied as per product specifications using a diluted (as little as 5 per cent dilution dependent on the type and quality of the polymer) compatible water-repellent modified graded polymer (applied at 0.6 litre/m^2 to 1.5 litre/m^2) which is transparent when applied, similar to a traditional prime or enrichment layer, but with extended expected service life, especially on fine graded materials.

B5.6 RE-CONSTRUCTION OF PAVEMENT USING LAYERS COLD IN-SITU STABILISATION WITH A NANO MODIFIED EMULSION (NME) STABILISING AGENT

PART B: LABOUR ENHANCEMENT

CONTENTS:

B5.6.1 SCOPE

This Section covers the work requirements for the Reconstruction of existing road pavement layers. This section covers work required for the construction of new roads (including upgrading of existing unpaved roads) or the rehabilitation of the upper pavement layers (base and sub-base) using the cold in-situ recycling process with (a) labour-intensive construction methods with a mixture of conventional equipment (b) conventional equipment, i.e., water-cart, grader(s) and compaction equipment (b) recycler and (c) central mixing plant. A relatively large proportion of activities as defined in Part A under the various sections are therefore suitable for labour enhanced methods of construction**.**

B5.6.2 DEFINITIONS

Definitions as provided in Clause A5.6.2 apply. B5.6.3 GENERAL

Any activity specified in Part A, where hand work is given as an alternative, shall be executed in such a way as to maximise labour**.**

B5.6.4 DESIGN BY CONTRACTOR/PERFORMANCE BASED SYSTEMS

The provisions of Part A shall apply. B5.6.5 MATERIALS

The provisions of Part A shall apply. B5.6.6 CONSTRUCTION EQUIPMENT

Where reference is made in Part A to appropriate equipment, the use of light equipment shall be evaluated during trial sections.

B5.6.7 EXECUTION OF THE WORKS

For the reconstruction of pavement layers, oversized material can be removed by labour-intensive hand picking before the layer is stabilised are suitable components for labour enhancement.

B5.6.8 WORKMANSHIP

The provisions of Part A shall apply.

C5.6 CONSTRUCTION OF PAVEMENT LAYERS USING COLD IN-SITU STABILISATION WITH A NANO MODIFIED EMULSION (NME) STABILISING AGENT

PART C: MEASUREMENT AND PAYMENT

(i) Preamble

The tendered rate for each pay item shall include full compensation for providing, maintaining and decommissioning upon completion, of all the equipment, labour, tools, incidentals and supervision to carry out the activity or construct the works in the pay item, unless otherwise stated.

Any prime cost or provisional sums shall be paid in accordance with the provisions of the conditions of contract. The charge or mark-up tendered or allowed for is a percentage of the amount actually paid under the prime cost or provisional sum. This percentage shall cover all the Contractor’s handling, supervision, profit and liability costs to provide the services in the prime cost or provisional sum pay item.

(ii) Items not measured in this Section

The following required activities will not be measured or paid for separately and the Contractor shall include the cost thereof in other items as deemed appropriate:

- Drainage and protection of the pavement layers from all damage that may occur for any reason until the Employer has taken over the works;
- Protection of all existing or new kerbs, channels, sidewalks, lined drains, catch pits, kerb inlets, gratings, culverts, bridges, structures, buildings, road signs, guard rails, street lights, fencing, service pipes or cables and any other items adjacent to, over or under the road that could be damaged by the Contractor‘s vehicles, construction equipment, or by public traffic being accommodated on or alongside the pavement layers, during the construction of the pavement layers, until the Employer has taken over the works;
- Repair of all damage to the existing pavement layers after access to the construction site has been given to the Contractor and that may occur before, during or after the construction of the reconstructed or rehabilitated pavement layers up until the Employer has taken over the works;
- Provision of additional material in excess of the compacted volume of the layers calculated using the layer dimensions given in the Contract Documentation for whatever reason including additional material required for the correct placing, mixing, levelling and compaction of the layers;
- The removal of oversize material up to 5% of the compacted layer volume;
- Construction of tie in joints to new or existing road layers or surfacing;
- The preparation and the inspection for cracks in an underlying layer after removal of a pavement layer;
- Excavation of benches in pavement layers when widening an existing pavement;
- The provision and maintenance of covers for stockpiled reclaimed materials;
- The provision of method statements and of the programme of reconstruction work along with regular updates of the programme, and
- The brooming during the slushing process whether by hand or by mechanical means.

(iii) Items to be measured and paid for using payment items specified elsewhere in the specifications

For activities in Table C5.6-1 payment items specified in other Chapters or Sections of the specification, where they relate to work under this Section, will be listed in the Pricing Schedule.

Table C5.6-1: Payment items from other Chapters or Sections

Activity	Clause reference	Section or Chapter
Traffic accommodation	A5.6.3.1	Section C1.5 of Chapter 1
Stabilising agents	A5.6.5	Section A5.6
Construction equipment Processing of pavement	A5.6.6.1 & A5.6.6.2	Section A5.6.6
Curing a stabilised layer	A5.6.9.2	Section A5.6.9
Tack or prime a layer	A5.5.3.7	C9.1.3 of Chapter 9
Surfacing a reconstructed layer	A5.6.3.5	Section A5.6

(iv) Payment items specifically for this Section of the Specifications

Item	**Description**	**Unit**
C5.6.1	Compiling and implementing M&U plans for the reconstruction of an existing road pavement number …………………………………………………..	(No)

The unit of measurement shall be the number of M&U plans for the reconstruction work. Several plans shall be required as specified in Clauses A5.6.3.8

The tendered rate shall include full compensation for gathering all information, compiling the plans and for ensuring the implementation of the plans during the RR construction work.

Item	**Description**	**Unit**
C5.6.2	Reconstruction preparatory work ………………………………………………………………..	km
C5.6.2.1	Undivided carriageway ………………………………………………………………………...	km

The unit of measurement shall be the kilometre of uniform section of road to be reconstructed and rehabilitated, measured along the centre-line of the existing road. Each uniform section shall be measured separately. In the case of an undivided road carriageway this shall be measured once along the centreline. In the case of a divided road carriageway this shall be measured once along each carriageway separately.

The tendered rate shall include full compensation for undertaking all the work required in preparation for reconstruction. This work includes all survey and survey-related work such as setting out, checking the design levels and the approval of the final design levels.

This work also includes the removal of standing water, grass and weeds from the road surface including the shoulders.

Item	Description	Unit
C5.6.3	Establishment Of Plant	
C5.6.3.1	Establishment of cold in-situ recycling equipment/plant on site …………………	Lump Sum
C5.6.3.2	Establishment of conventional equipment/plant on site …………………………..	Lump Sum

The tendered lump sum shall include full compensation for the provision of any number of recycling machine(s)/plant on the section of the site and the subsequent removal thereof, including additional plant required for carrying out cold in-situ processing, stabilisation and compaction operations.

The lump sum will become payable after the cold in-situ processing and stabilisation work has been completed and the equipment has been removed from the site. Payment will only be made for either C5.6.3.1 or for C5.6.3.2 dependent on the Contractor’s chosen method of construction

Payment will not distinguish between the number of recycling machines or conventional units of equipment brought onto and/or removed from the site. No payment will be made for the replacement of the defective plant.

Item	Description	Unit
C5.6.4	Cold in-situ recycled granular layer treated	
C5.6.4.1	Using a recycler	
	(a) Base-layer (depth to be specified) compacted to	
	the specified density (Table A5.6/1) using an NME or equivalent ………	cubic metre (m³)
	(b) Sub Base-layer (depth to be specified) compacted to	
	the specified density (Table A5.6.5/1)using an NME or equivalent ……..	cubic metre (m³)
C5.6.4.2	Using a conventional plant	
	(a) Base-layer (depth to be specified) compacted to	
	the specified density (Table A5.6.5/1) using an NME or equivalent ……..	cubic metre (m³)
	(b) Sub Base-layer (depth to be specified) compacted to	
	the specified density (Table A5.6.5/1) using an NME or equivalent ……..	cubic metre (m³)

The unit of measurement shall be the cubic metre of pavement processed and stabilised to provide the recycled base and or sub-base layer as specified.

The rate tendered shall include full compensation for the provision of all plant, labour, materials and all other incidentals necessary to produce the finished layer as specified but excluding the provision of the NME stabilising layer that shall be measured and paid for under item C10.03. The NME will consist of a material-compatible product as described in the preamble, which will be able to meet the required specifications (the Contractor will take responsibility for using a stabilising agent not meeting the minimum requirements in terms of stability resulting in inferior test results).

The tendered rate shall also include full compensation for the milling of existing pavement layers, blending of the materials in the nominal mix ratios specified, supply, diluting of the NME in potable water and mixing of the diluted NME, spreading and final blading of the recycled mix, compacting the material to the specified density and protecting and maintaining the work in accordance with the specifications.

The tendered rate shall also include full compensation for the cleaning of the surface and the referencing of lane and control survey markings as specified.

Where ordered by the Engineer for the processing and stabilisation of pavement layers to depths other than specified, the payment will be made on a pro-rata basis between the tendered rates for the nominal depths scheduled.

All failures due to the use of contaminated equipment (not thoroughly cleaned) will be for the cost of the Contractor.

Item	**Description**	**Unit**
C5.6.5	Nano Modified Emulsion (NME) or Equivalent	cubic metre (m³)

The unit of measurement shall be per cubic metre of the material stabilised (different stabilising agents may require different percentage additives to meet criteria) with the stabilising agent to be supplied to meet all the required criteria as specified and as instructed by the Engineer.

The tendered rate shall include full compensation for providing, diluting, mixing and applying the stabilising agent, irrespective of the rate of application. The material-compatible NME will be provided to the site by the supplier to meet the specifications. The Contractor will take full responsibility and liability for using a stabilising agent not meeting the END-PRODUCT specification. During the design phase, the Design Engineer should ensure that products are available that will meet the specifications with the given naturally available materials.

C5.6.6 Chemical additive

No chemical additives will normally be required with a material-compatible water-repellent NME stabilising agent. However, should the material characteristics dictate the use of any chemical additives the costs should be included in the cost of the NME stabilising agent (or alternative) must be included as part of Item C5.6.5

Item	**Description**	**Unit**
C5.6.7	Pre-treating the base layer with an NME stabilising agent	

No pre-treatment of lime, etc. will be required with an NME stabilising agent. Some minerals may require pre-treatment with an appropriate / proven product. Payment is to be included as part of Item 10.03.

Item	**Description**	**Unit**
C5.6.8	Blading of surplus material to windrow	cubic metre (m³)

The unit of measurement shall be the cubic metre of surplus material bladed to the windrow as specified by the Engineer. The tendered rate shall include full compensation for all labour equipment and any other incidentals required for blading to a windrow of surplus material with a motor grader.

Item	**Description**	**Unit**
C5.6.9	Removal from site of surplus material ……………………………………….	cubic metre (m^3)

The unit of measurement shall be the cubic metre of surplus material removed. The volume shall be determined as prescribed by the Engineer and shall be the loose volume in stockpiles or the equivalent thereof volume in hauling vehicles. Accurate load and haul sheets shall be kept on site and submitted to the Engineer. The tendered rate shall include full compensation for loading and transporting the surplus material to a designated spoil or stockpile site as approved by the client

Item	**Description**	**Unit**
C5.6.10	Construction of a temporary wearing course ……………………………..	square metre (m^2)

The unit of measurement shall be the square metres of stabilised base slushed in accordance with the requirements of section A5.6.7.15 of the Project Specification and the tendered rate shall include full compensation thereof.

Item	**Description**	**Unit**
C5.6.11	Trial sections where ordered (extra over items C5.6.4 and C5.6.5)	
	(a) Processing and stabilisation of layers………………………………	cubic metre (m^3)
	The unit of measurement shall be the cubic metres of processed and stabilised pavement layers as per instruction.	
	(b) Applying of prime, tack coat or surfacing layer ………………….	square metre (m^2)
	The unit of measurement of the prime coat shall be the square metres, independent of the applied surfacing as per instruction from the engineer.	

The tendered rate shall include full compensation for the construction of the trial section of recycled pavement layers complete as specified.

Item	**Description**	**Unit**
C5.6.12	Extra over Item C5.6.4 for adding extra material to the layer	
	(a) Gravel Base of a required quality as per specification ……………	cubic metre (m^3)
	(b) Gravel sub-base of a required quality as per specification ………..	cubic metre (m^3)
	(c) RA (when specified as per specific client)………………………….	cubic metre (m^3)

The unit of measurement shall be the cubic metre of material added on the instruction of the Engineer, which quantity shall be taken as 70 per cent of the loose volume measured in trucks unless instructed by the Engineer that the quantity be determined by way of cross-sections. The tendered rate shall include full compensation for procuring and adding the specified material to the layer, for spreading the material, for all haul and for other incidentals to add the material to the layer.

Item	Description	Unit
C5.6.13	Milling out existing bituminous material with an average milling depth	
	(a) Not exceeding 30 mm ……………………………………………….	cubic metre (m^3)
	(b) Exceeding 30 mm but not exceeding 60 mm ……………………..	cubic metre (m^3)
	(c) Exceeding 60 mm …………………………………………………….	cubic metre (m^3)

The unit of measurement shall be a cubic metre of asphalt milled out and removed to approved stockpiles. The tendered rate shall include the compensation for providing milling equipment and milling out the material to the specified depth and in accordance with the requirements for evenness and for all measurements, labour, supervision and incidentals tor executing the work and obtaining milled material which will comply with specified materials

The tendered rate shall also include full compensation for trading and transporting the material to approved stockpiles tor a free-haul distance 1.0 km irrespective of the method of loading and for unloading of the material and placing it in stockpile, also tor screening out the oversize material if necessary. Separate payment will be made for preparing stockpile site.

Payment for milling the material will distinguish between the various average depths of excavation, irrespective of the required number of passes by the plant for milling out material.

Item	Description	Unit
C5.6.14	Providing the milling machine on the site (size indicated) number ……………………	(No)

The unit of measurement shall be the number of milling machines provided on the site, or the number of times & milling machine is brought onto the site where t had to be removed temporarily with the approval of the engineer.

The unit of measurement shall be the number of times the machine is moved for more than 1,0 km, as may be approved or instructed by the engineer, in writing.

The tendered rate shall include full compensation for al! costs involved in such moving irrespective of as to whether the machine is moved to a new section of the site or returned to a previous position for further work), as well as for all delays and production losses. Payment will not be made for moving for the purpose of maintenance and repairs or for replacement with another machine.

Item	Description	Unit
C5.6.15	Break down of in-situ material ………………………………………………	cubic metre (m^3)

The unit of measurement shall be the cubic meter of material measured after compaction. The quantity measured shall be computed by the method of average end areas from levelled cross-sections prepared from the existing road surface before any ripping or breaking down of the existing surface and base course has taken place. All measurements shall be neat and material placed in excess of the authorized cross-section will not be paid for. The tendered price shall include the ripping, breaking down, preparing, processing, shaping and watering of the materials to the specified densities.

Item	Description	Unit
C5.6.16	Application of a prime or "clear seal" square metre……………..…………………..	(m^2)
	Application of a NPNS in-situ materials treatment ……………………………………	(m^2)
	Application of a NPNS gravel surfacing treatment ……………………………………	(m^2)

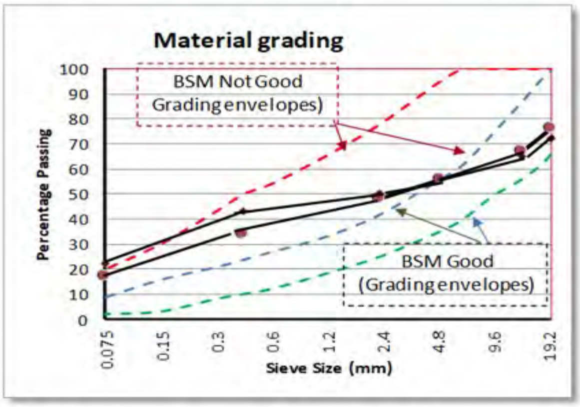
Rates should include the provision of the materials and suitable distribution equipment able to apply the prime or specified "clear seal" to meet the required specifications and at the required rate.

Appendix F. Examples of MC-NME Stabilising Agents Tested in Practice

HVS test site – "G8" base layer; "G7" sub-base layer on G10 sub-grade – design traffic loading – 3 million E80s.

The material properties, XRD-mineralogy tests and UCS and ITS results are summarised in Figure F 1.

Base and Sub-base material for Accelerated Pavement Testing (APT) (MMLS3) of thin (chip seal) surfacings



Material Test results

Fraction	%
Coarse Sand (CS)	29 - 33
Fine Sand (FS)	28 - 35
Coarse Fine Sand (CFS)	10 - 11
Medium Fine Sand (MFS)	11 - 17
Fine Fine Sand (FFS)	6 - 8
Silt and Clay (S & C)	35 - 39
OMC (%)	11.4
MDD (kg/cub m)	2030
GM	1.85
Atterberg Limits	
Liquid Limit (LL)	28 - 30
Plasticity Index (PI)	8 - 14
PI (0.075)	
Linear Shrinkage (LS)	4 - 7
CBR (mod AASHTO)	
95%	10 - 17
93%	9 - 14
Classification	
H.R.B.	A-2-6
COLTO	G8
TRH14	G8

Mineral Percentages present in Material Sample

Minerology	Total sample %		0.075 mm Fraction %	
Mineral Groups	**Individual**	**Combined**	**Individual**	**Combined**
Quartz	43.2	43.2	23.0	23.0
Plagioclase	14.8		6.6	
Augite	2.4		1.3	
Enstratite	0.0		0.5	
Actinolite	3.8		1.4	
Microcline	6.5		4.2	
		27.5		14.0
Mica: Muscovite	12.2	12.2	36.2	36.2
Clay: Kaolinite	6.1		15.0	
Clay: Smectite	7.5		3.0	
Calcite	0.5	14.1	6.5	24.5
Talc	3.1	3.1	2.3	2.3

Mineral Groups: (Weathering = chemical decomposition)
Primary (Not subject to Weatering)
Primary (Subject to Weathering)
Mica
Secondary minerals (Nano-scale crystals/molecules)

Results: Stabilisation

Agent	New-age Modified Emulsion (NME)				Conventional Emulsion stabilisation	Unit
%	0.7	1.0	1.2	1.5	1.5% SS60 Emulsion + 1.0% Cement	
UCS(dry)	3395	4807	4859	2620	3277	kPa
UCS(wet)	1745	1830	1671	1865	656	kPa
UCSw/d %	51	38	34	71	20	%
ITS(dry)	254	420	268	232	167	kPa
ITS(wet)	61	321	221	184	61	kPa
ITSw/d %	24	76	82	79	37	%

Figure F 1 MC-NME stabilisation of "G8" materials

Figure F 1 gives a comparison of the results with the MC-NME percentage stabilising agent varying form 0.7 per cent to 1.5 per cent. The results from an unmodified bitumen emulsion stabilisation consisting of 1.5 per cent SS60 and 1.0 per cent cement are shown on the right of the bottom table. The percentage passing the 0.075 mm sieve and the percentage of problematic minerals within the 0.075 mm fraction are plotted on Figure F 1, as shown in Figure F 2

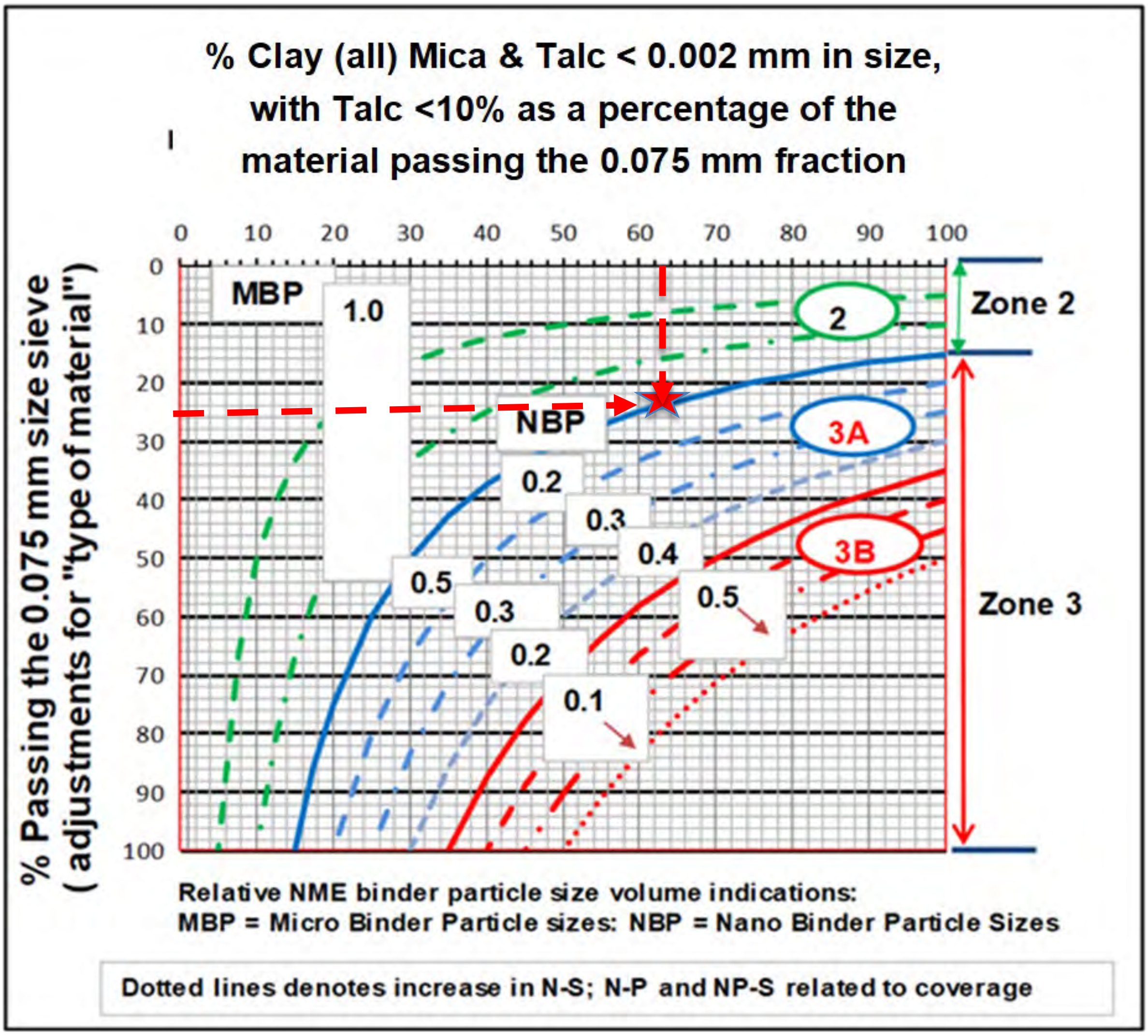


Figure F 2 Percentage of materials passing through the 0.075 mm sieve and the percentage of problematic minerals within the 0.075 mm fraction of the “G8 material results

The percentage of the granular material passing the 0.075 mm sieve size is 20 to 25 per cent. From the XRD-scan and analysis in Figure F 1, it is seen that the percentage problematic materials within the 0.075 mm fraction is in the order of 63 per cent. The combination of these granular material fractions put the material in the proximity where a micro-size modified binder (in this case bitumen applied in the form of a MC-NME stabilising agent) needs to be supplemented with a nano-size particle size binder (the blue line). It is also seen that the amount of organofunctional-silane will have to be increased by a factor of about 3 (dotted green lines Figure F 2) to effectively neutralise all the fine particles within this granular material.

From the results in Figure F 1, it is seen that the UCS as well as the ITS measurements decrease with an increase in the MC-NME stabilising agent. This is explained by the percentage of fines as indicated in Figure F 2**.** The high percentage of problematic minerals of a nano-size in the granular material is now being stabilised with a binder that is more than a thousand times bigger that the clay particle sizes in the material. Although the resultant measurements are still very good, more of the stabilising agent is not very effective and the small granular particles are basically "drowning" in the binder that is more than a 1000 times bigger than the clay particles in the granular materials. A nano-polymer combination within the binder should prove very effective in this case.

It is seen that that the Retained Tensile Strength (RTS) at 1 per cent MC-NME is 76 per cent with the ITS_{wet} at more than 320 kPa. The Retained Compressive Strength (RCS) exceeds 70 per cent at 1.5 per cent MC-NME. In this case stabilisation of the base was done at 1.5 per cent MC-NME where direct wheel-stresses need to be coped with and a high resistance to any water ingress from the top will be a future advantage. The sub-base was stabilised with 1 per cent MC-NME catering for any future increase in required tensile strength at the bottom of the stabilised layers together with a high resistance to any water ingress into the supporting layers.

Comparatively, the traditional emulsion stabilisation showed very poor resistance to the effect of water with low RCS and RTS measurements as shown in Figure F 1.

The comparison between the pavement structures of the "traditional design and the MC-NME design for this road is shown in Figure F 3.

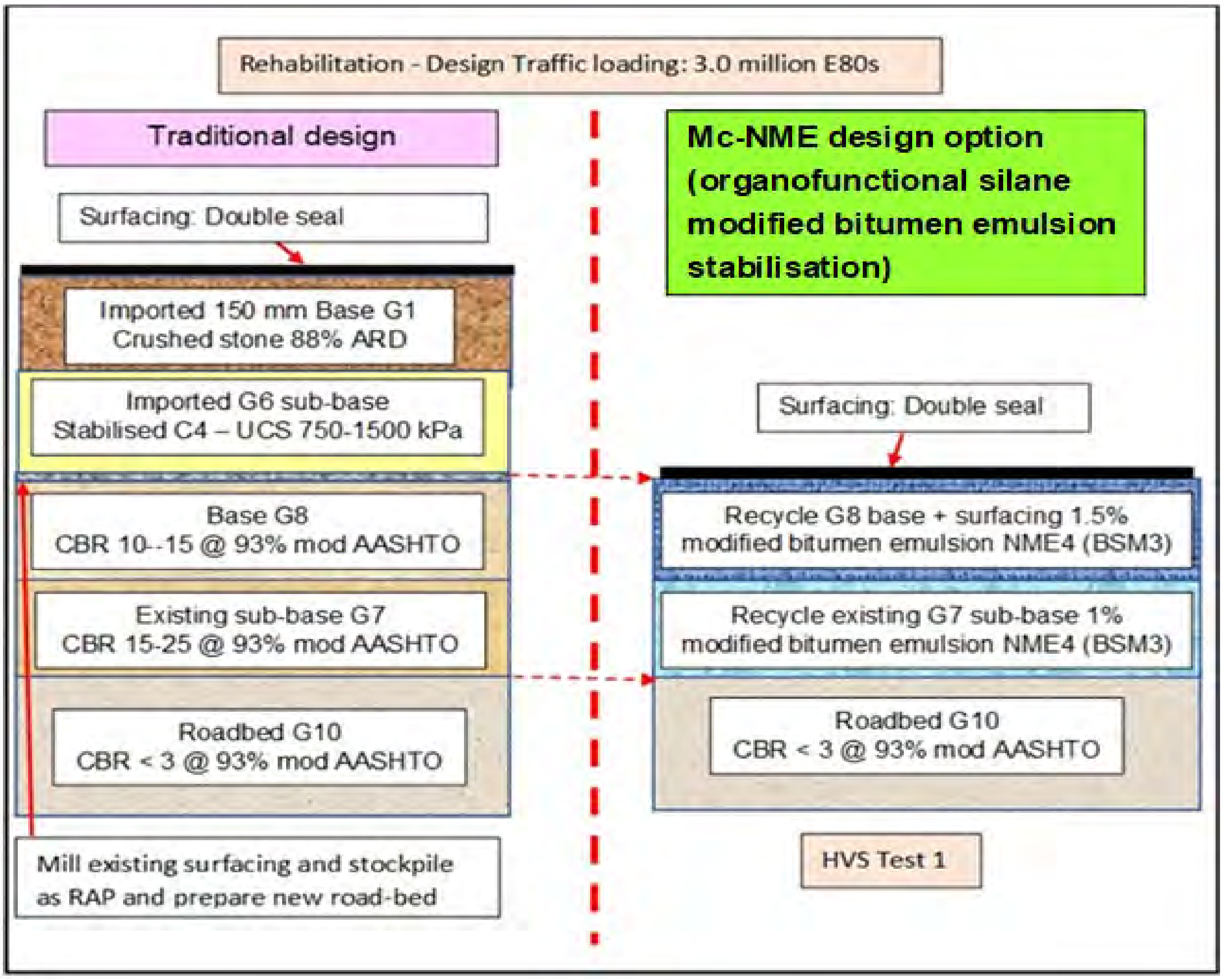


Figure F 3 Comparison between the "traditional" design on the left and the MC NME design on the right, for a design traffic loading of 3.9 million E80s

Upgrading of unpaved road rural road in Mpumalanga – 2.5 million E80s

The appointed contractor invited several possible suppliers to test their NME products using the End Product Specifications and test methods contained in Appendix E. On insistence of the client specifications in line with a NME3 material should be considered. In total, 14 different products from various suppliers were tested as shown in Table F 1. It is seen that only 3 products met the criteria within the "End Product Specification" (Appendix E). The MC-NME designed anionic stabilising agent exceeded the criteria by some margin at less than half the cost of a BSM design that also met the criteria.

These results clearly illustrate the advantages of a scientifically based materials design method based on the generic fingerprint of the granular materials, i.e., the mineralogy of the granular materials.

Table F 1 Results from the testing of various stabilising agents with an in-situ “G7” material with little cohesion

PROJECT: UPGRADING OF GRAVEL ROAD: South Africa

TEST RESULTS: UPGRADING OF GRAVEL ROAD USING IN-SITU MATERIAL CBR @ 93 % mod AASHTO between 15 and 45

MATERIAL REQUIREMENT: NME3

REQUIRED CRITERIA:

UCS_{wet} > (kPa)	1000	Retained Compressive Strength (RCS) (% (UCS_{wet}/UCS_{dry})) >	70
		RCS in relation to minimum criteria in a wet condition (RCS-Effective or RCS-E) (RCS x ($UCS_{wet}/UCS_{wet\text{-}criteria}$) (%) >	80
ITS_{wet} > (kPa)	160	Retained Tensile Strengthcohesion (RTS) (% (ITS_{wet}/ITS_{dry})) >	70
		RTS in relation to minimum criteria in a wet condition (RTS-Effective or RTS-E) (RTS x ($ITS_{wet}/ITS_{wet\text{-}criteria}$)) >	80

No	Product tested	Design Methodology	Supplier	UCS_{dry} kPa	UCS_{wet} kPa	RCS %	RCS-E %	ITS_{dry} kPa	ITS_{wet} kPa	RTS %	RTS-E %	Comments	Cost/m³ (Product)
1	2% Roadcem + 2.5% SS60 (55lts/m³) (BSM)	BSM*	1	2351	1790	76	136	289	217	75	102	Pass	R 790.00
2	2% Roadcem + 1.5 % SS60 (33lts/m³) (BSM)	BSM*	1	1585	1166	74	86	171	105	61	40	Fail	
3	2% Roadcem + 1.0 % SS60 (22lts/m³) (BSM)	BSM*	1	1409	887	63	56	121	48	40	12	Fail	
4	1.0 % Cationic NME (22 lts/m³)	T & E**	1	1238	705	57	40	108	29	27	5	Fail	
5	1.5 % Cationic NME (33 lts/m³)	T & E**	1	1308	739	56	42	112	27	24	4	Fail	
6	2.5 % Cationic NME (55 lts/m³)	T & E**	1	1370	798	58	46	138	37	27	6	Fail	
7	2% Roadcem + 2.5 % SS60 (55lts/m³) (BSM)	BSM*	2	2086	1515	73	110	233	166	71	74	Fail	R 840.00
8	2% Roadcem + 1.5 % SS60 (33lts/m³) (BSM)	BSM*	2	1565	971	62	60	139	86	62	33	Fail	
8	2% Roadcem + 1.0 % SS60 (22lts/m³) (BSM)	BSM*	2	1396	823	59	49	132	45	34	10	Fail	
10	1.0 % Cationic NME (22 lts/m³)	T & E**	2	1253	707	56	40	105	23	22	3	Fail	
11	1.5 % Cationic NME (33lts/m³)	T & E**	2	1329	746	56	42	135	29	21	4	Fail	
12	2.5 % Cationic NME (55lts/m³)	T & E**	2	1396	769	55	42	162	39	24	6	Fail	
13	1.0 % Anionic NME (22lts/m³)(Double Emulsification)	Mineralogy***	3	3110	3120	100	313	281	356	127	282	Pass	R 385.00
14	1.0 % Anionic NME (22 lts/m³)(Single Emulsification)	Mineralogy***	3	2090	2840	136	386	181	283	156	277	Pass	R 374.00

BSM* = Bituminous Stabilased Material (BSM) design approach - Industry Manuel - TG2 [54]

T & E** = Trail and Error design adding different percentages of stabilising agents as per supplier

Mineralogy*** = Design based on mineralogy of materials and chemical interaction with Nano-Modified Emulsion (NME) Stabilising agent

Upgrading of Pilot project at Lidgetton (KZN)

The in-situ material along the section of road has the following characteristics:

- Percentage passing the 0.075 mm sieve size > 80 per cent, and
- XRD results of the material are shown in Table F 2. The highlighted mineral in the fraction 56.5 per cent consisting mainly of clay (kaolinite (18.8 per cent) and smectite (18.2 per cent)) and 13 per cent muscovite.

Table F 2 Results from the XRD testing of the in-situ and locally available “G7” material

Sample	Quartz	Plagioclase (Albite)	Augite	Actinolite	Muscovite	Kaolinite	Talc	Smectite
Total	25.5	38.3	6.7	0.3	13.8	2.3	1.5	12.1
0.075 mm fraction	15.5	26.7	5.4	1.2	13.0	18.8	1.1	18.2

The in-situ material characteristics in terms of the various percentages are plotted on Figure F 4.

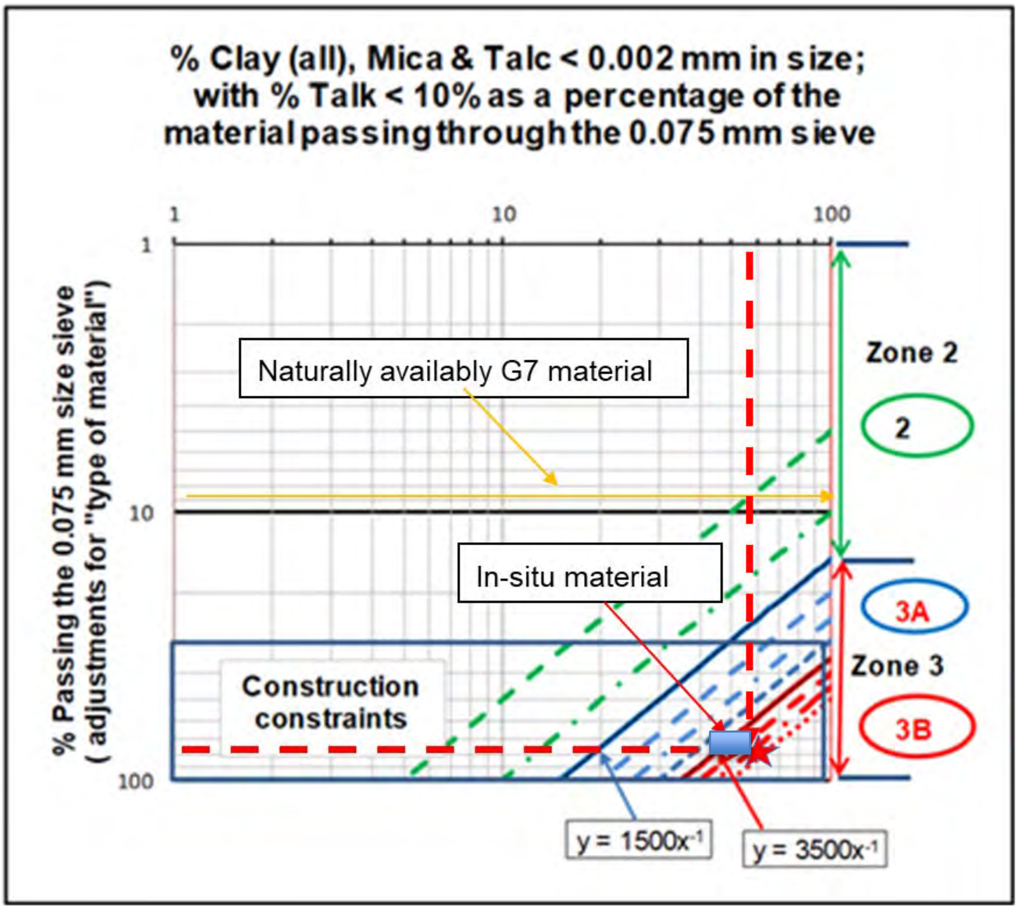


Figure F 4 In-situ material on pilot project Lidgetton

This material is an example of an extreme in-situ material that presents problems both in terms of workability as well as the ability to effectively be stabilised. The addition of any water to this material will result in an unworkable mud that cannot be effective within a pavement structure.

However, the material can be treated in-situ using MC-NME(NPNS) and bound together to form a hydrophobic (water-resistant) supportive layer for the construction works on top of the material as addressed in APPENDIX E “End Product Specifications” as described in **C1014 TREATMENT OF IN-SITU MATERIALS OF RELATIVELY POOR QUALITY TO FORM A SUPPORT LAYER ON WHICH TO CONSTRUCT A LAYER OF QUALITY NME4 OR TO BIND LOOSE MATERIAL BEFORE SURFACING OF LOWER ORDER ROADS**. To achieve the required penetration of at least 60 mm, a MC-MNE(NPNS) consisting of a high-quality anionic Nano-Polymer Nano Silane (NPNS) was tested to form a supporting layer for the construction of base layer on top of the bounded, hydrophobic support layer. Several applications of the MC-MNE(NPNS) were tested in a laboratory, to obtain the optimum dilution applicable for the specific material as supplied, the results of which are shown in Figure F 4. It is seen that both the 1:5 and 1:10 diluted application resulted in a good hydrophobic layer with well-rounded water particles on top of the layer.

The naturally available G7 material from a quarry close to the road has a percentage passing through the 0.075 mm sieve of less than 9 per cent. From Figure F 4, this material should present no problem with MC-NME stabilisation – even with the same problematic minerals present in the material. Even if the fines should double during construction, the MC-NME materials design should be able to neutralise the problematic minerals, resulting in a well-constructed layer for the upgrading of the road.

After curing within the Marshall mould, the measured DCP-DN value was measured as less than 3.5 mm/blow on the sample treated with a MC-NME(NPNS) diluted at 1:10. Hence, the in-situ material can successfully be treated as a supported layer APPENDIX E, Item C1014.

For a thicker supporting layer (e.g., 150 mm) it is recommended that the material be ripped to the required depth, spayed with the diluted MC-NME(NPNS) at 2.0 litres/m^2 material. A test section should be done beforehand to evaluate the workability and practicality of such an approach. The layer should be mixed with a grader and sprayed a second time before shaping and compaction as demonstrated in Figure F 5. (the example shown in Figure F 5 is for the surfacing of a local farm excess road where the in-situ material was treated with a MC-NME(NPNS) before shaping and compaction. In this case it is recommended to finally treat the layer with a MC-NME- Micro Polymer Nano Silane (MPNS) to give more adhesion to the granular material particles exposed to the friction of vehicles. A good MC-NME(MNPS) should contain particle sizes in the order of 0.6- 1.2 µm that will be able to give a longer maintenance free hydrophobic protection to the granular materials on an unsurfaced road while retaining the natural couloir of the granular materials.)

(a) Dilution 1part NPNS – 5 water
Depth of penetratio >60 mm

(b) Dilution 1 part NPNS – 5 water – depth
hydrohobic effect

(b) Dilution !: 10 – hydrophobicity

(d) Dilution 1:15 - hydrophobicity

Figure F 5 MC-NME(NPNS) spray-on treatment of in-situ material

Upgrading of a major rural road

This road was constructed in 1965 as a 2-lane road with a total surfaced width of 6.0 m to 6.3 m. Two main options are shown for upgrading the road to a total width of 13.4 m. The design traffic loading was estimated over a twenty-year period to vary between 7 million E80s and 10 million E80s. Two options are shown, i.e.:

- Traditional deign with a 150 mm G1 crushed stone base layer with 2 cement stabilised sub-bases as shown in Figure F 6, and
- MC-MNE stabilised base and sub-base, fully utilising the in-situ top 300 mm of the existing pavement as shown in Figure F 7.

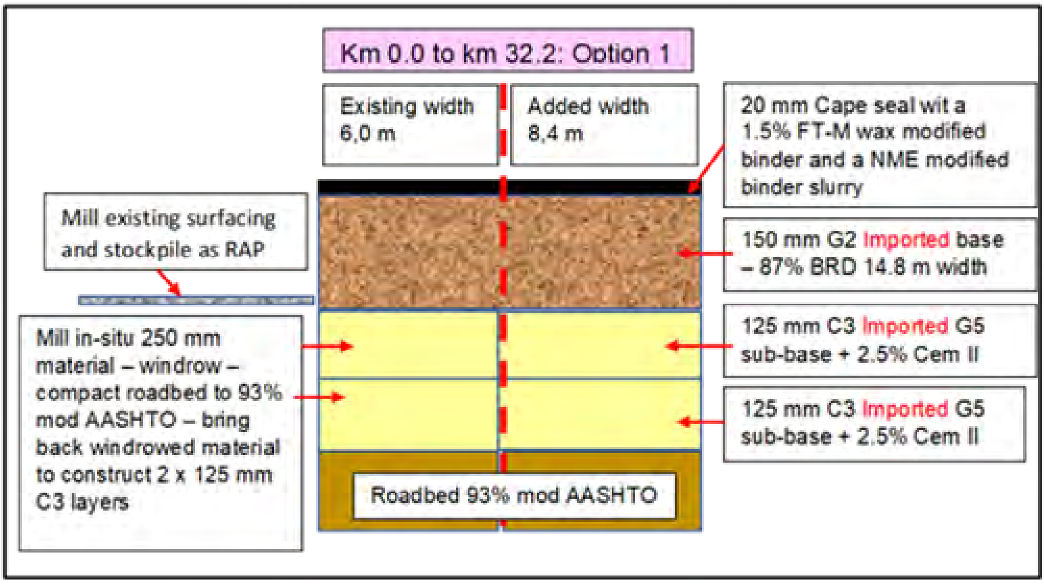


Figure F 6 Alternative - crushed stone base and two C3 cement treated sub-bases

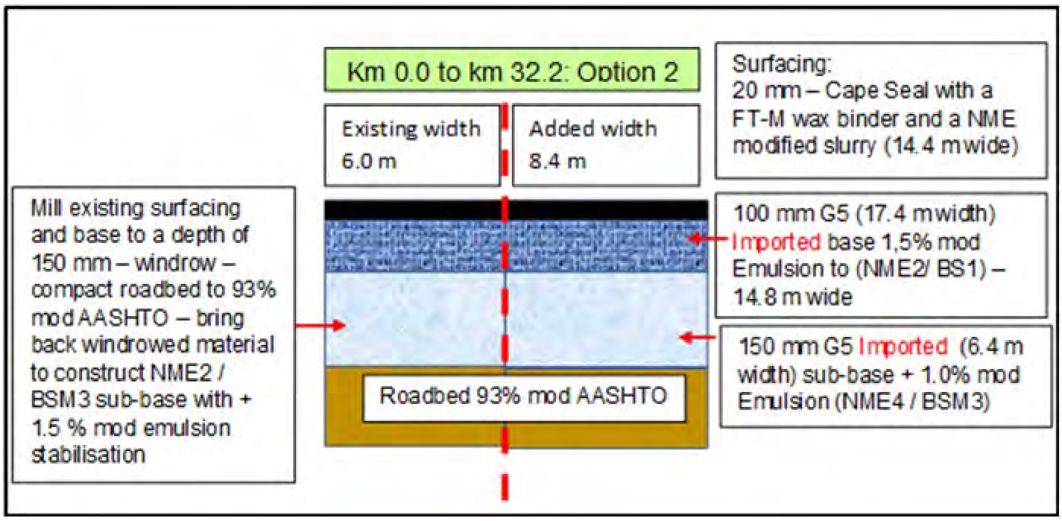


Figure F 7 MC-NME pavement alternative design

The top 300 mm of the existing pavement was sampled and tested per the MC-NME design requirements as contained in Chapter 5 and as an input into APPENDIX E -End Product Specifications. The gradings of the finer fractions of the top 300 mm tested along the length of the road per identified uniform pavement sections are shown in Figure F 8.

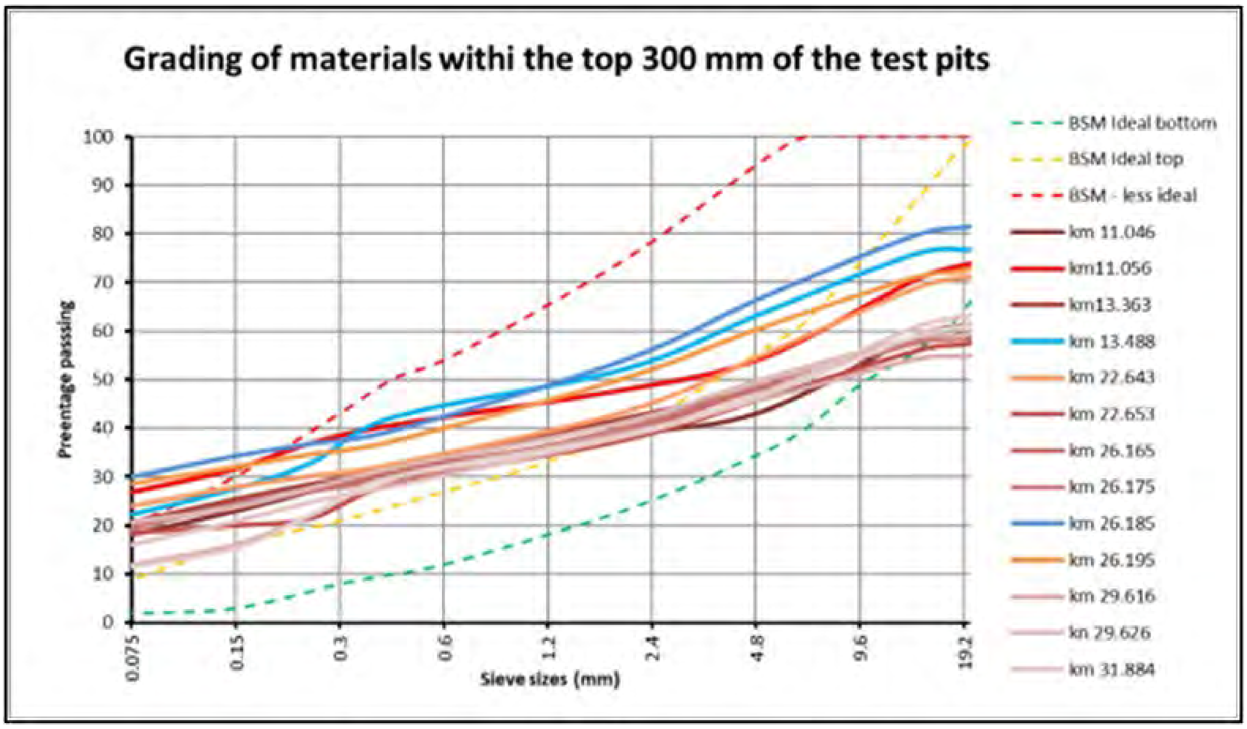


Figure F 9 Grading of the top 300 mm of the materials from each borrow-pit along the length of the road to be utilised within the new pavement structure using MC-NME stabilisation

It is seen from Figure F 10 that the percentage of the material passing through the 0.075 mm, mostly varies between 20 and 30 per cent. It is also clear that the material will not be suitable for a BSM design in terms of the required grading envelopes shown.

The XRD results of the top 300 mm of the samples taken from the test pits as well as the localised potential naturally available materials next to the road are summarized in Table F 3 It is seen that most of the fractions passing through the 0.075 mm sieve consists of quarzitic minerals, ideally suited for MC-NME stabilisation. At worst, the percentage of problematic minerals (highlighted in pink) was estimated at 16 per cent.

The worst combination of particle fractions combined in terms of percentage passing the 0.075 mm sieve size, together with problematic minerals within the 0.075 mm fraction is plotted on Figure F 8 and shown in Figure F 9. From Figure F 9 it is obvious that the material properties in terms of the measured particle sizes should present no problem in meeting those properties as required in a MC-NME design proposal.

The testing of the top 300 mm in-situ material was done according to prescribed test procedure contained in Chapter 6 and APPENDIX E. The results of the material testing using an anionic MC-NME stabilising agent are shown in Table F 3. From Figure F 9 it is seen that a material class of NME4 is required for the sub-base and a NME2 for the base layer. The detailed testing along the length of the road shows that an NME2 class material can be achieved comfortably with 1.5 per cent of an anionic MC-NME stabilising agent and a NME4 class material in most cases with 1.0 per cent anionic MC-NME stabilising agent.

Table F 3 Summary XRD-scans for the various uniform sections along the road taken from the top 300 mm of the existing road

XDR Minerology Scans		Quartz	Hematite	Kaolinite	Muscovite	Biotite	Goethite	Chlorite	Plagioclase	Dolomite	Talc	Gypsum
Pavement Section												
Section 1A	Total Sample	96.7%		2.8%		0.1%	0.4%					
Km 3.9 – km 24.2	0.075 Fraction	82.0%	1.8%	16.0%								
Section 1B	Total Sample	96.5%	0.7%	2.2%		0.2%	0.1%					
Km 24.2 – km 36.04	0.075 Fraction	85.5%	2.0%	12.2%		0.2%						
Section 2 Shoulder	Total Sample	98.2%	0.3%	0.4%	0.3%		0.2%	0.5%	0.3%			
Km 32.2 – km 52.2	0.075 Fraction	96.3%	0.6%	2.4%	0.6%							
Borrow Pits -Mine Dumps next to the road												
Source 1	Total Sample	82.4%			11.4%			3.5%		2.3%		0.4
	0.075 Fraction	70.3%			22.3%			3.6%		0.9%	0.6%	2.3
Source 2	Total Sample	78.0%			16.7%			4.3%		0.4%		0.6
	0.075 Fraction	74.7$			19.4%			3.0%		0.5%	0.3%	2.2

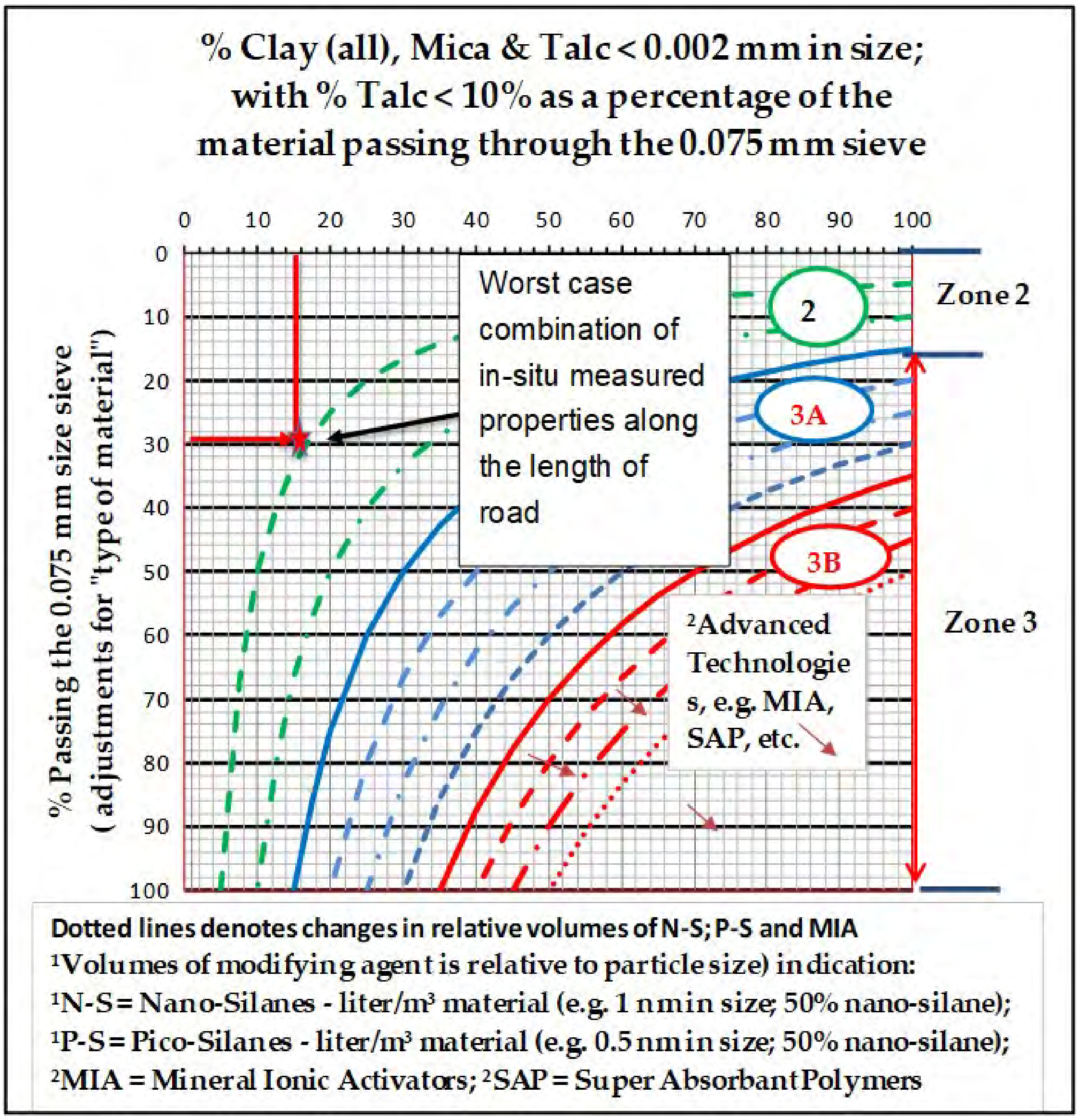


Figure F 11 Worst case scenario of the particle fractions measured along the length of the road indicating the potential of the material for utilisation in a MC-NME design

The different design options should be compared in a thorough economic evaluation. The estimated material costs of the two options are shown in Table F 5. These costs exclude savings in construction time and related costs between the options.

Table F 4 Summary XRD-scans for uniform sections along the length of the road - top 300 mm of the existing road

Results Summary : R501 Potch to Carletonville (New Modified Emulsions (NME) - UCS (dry & wet)) and ITS (dry and wet))										
DESIGN STRENGTHS FOR NME (As per NME Test Protocols - Rapid Curing) - refer Table 3.15										
Sample Information	Property	0.7% MC-NME	1.0 % MC-NME	1.3% MC-NME	1.5% MC-NME	Property	0.7% MC-NME	1.0 % MC-NME	1.3% MC-NME	1.5% MC-NME
Ch:11.046km (70-330mm)	UCS (Mpa) - Dry	2.80	3.00	3.10	3.40	ITS (Kpa) - Dry	208.00	239.00	254.00	282.00
80% Red material +	UCS (Mpa) - Wet	1.40	1.69	2.07	2.50	ITS (Kpa) - Wet	101.00	117.00	165.00	217.00
20% Asphalt	RCS	50.00%	56.33%	66.77%	73.53%	RTS	48.60%	49.00%	65.00%	77.00%
	NME CLASS			NME 4	NME 2	NME CLASS			NME 4	NME 2
Ch:11.056km (70-330mm)	UCS (Mpa) - Dry	3.30	3.50	3.65	3.90	ITS (Kpa) - Dry	231.00	275.00	312.00	371.00
80% Red material +	UCS (Mpa) - Wet	2.20	2.40	2.58	30.00	ITS (Kpa) - Wet	144.00	198.00	233.00	279.00
20% Asphalt	RCS	66.67%	68.57%	70.68%	769.23%	RTS	62.34%	72.00%	74.68%	75.20%
	NME CLASS	NME 4	NME 4	NME 3	NME 2	NME CLASS		NME 3	NME 3	NME 2
Ch:13.463km (70-330mm)	UCS (Mpa) - Dry	2.10	2.40	2.50	2.61	ITS (Kpa) - Dry	166.00	181.00	211.00	242.00
80% Red material +	UCS (Mpa) - Wet	1.10	1.30	1.64	2.03	ITS (Kpa) - Wet	79.00	108.00	147.00	189.00
20% Asphalt	RCS	52.38%	54.17%	65.60%	77.78%	RTS	47.59%	59.67%	69.67%	78.10%
	NME CLASS			NME 4	NME 2	NME CLASS			NME 3	NME 2
Ch:22.643km (70-330mm)	UCS (Mpa) -Dry	3.10	3.50	3.95	4.33	ITS (Kpa) - Dry	258.00	277.00	382.00	459.00
80% Red material +	UCS (Mpa) -Wet	1.80	2.28	2.90	3.40	ITS (Kpa) - Wet	146.00	232.00	285.00	358.00
20% Asphalt	RCS	58.06%	65.14%	73.42%	78.52%	RTS	56.59%	83.75%	74.61%	78.00%
	NME CLASS		NME 4	NME 3	NME 2	NME CLASS		NME 4	NME 3	NME 2
Ch:26.165km (70-330mm)	UCS (Mpa) - Dry	2.02	2.13	2.37	2.72	ITS (Kpa) - Dry	136.00	157.00	201.00	243.00
80% Red material +	UCS (Mpa) - Wet	1.09	1.44	1.61	2.10	ITS (Kpa) - Wet	87.00	103.00	133.00	170.00
20% Asphalt	RCS	53.96%	67.61%	67.93%	77.21%	RTS	63.97%	65.61%	66.17%	69.96%
	NME CLASS		NME 4	NME 4	NME 2	NME CLASS		NME 4	NME 4	NME 3
Ch:29.616km (60-290mm)	UCS (Mpa) - Dry	2.41	2.52	3.00	3.44	ITS (Kpa) - Dry	172.00	229.00	245.00	302.00
80% Red material +	UCS (Mpa) - Wet	1.50	1.66	1.96	2.60	ITS (Kpa) - Wet	109.00	152.00	187.00	236.00
20% Asphalt	RCS	0.52	0.66	0.65	0.76	RTS	63.37%	66.38%	76.33%	78.15%
	NME CLASS		NME 4	NME 4	NME 2	NME CLASS		NME 4	NME 2	NME 2
Ch:31.884km (70-330mm)	UCS (Mpa) - Dry	3.22	3.84	4.26	4.45	ITS (Kpa) - Dry	235.00	280.00	321.00	383.00
80% Red material +	UCS (Mpa) - Wet	2.45	2.93	3.40	3.84	ITS (Kpa) - Wet	185.00	223.00	310.00	328.00
20% Asphalt	RCS	0.76	0.76	0.80	0.86	RTS	78.72%	79.64%	96.57%	85.64%
	NME CLASS	NME 3	NME 3	NME 2	NME 1	NME CLASS	NME2	NME 2	NME 1	NME 1

Table F 5 Cost comparison between the crushed stone base and the MC-NME option

Item	Description	Pavement Option Crushed stone base	Pavement Option MC-NME design
		Amount	Amount
1	Traffic Accommodation	R36 375 000.00	R24 250 000.00
2	Concrete Drains	R1 541 000.00	R1 541 000.00
3	Lesser Culverts	R23 175 000.00	R23 175 000.00
4	Mass Earthworks	R0.00	R0.00
5	Pavement Layers	R279 172 307.00	R142 266 360.00
6	Access Roads	R30 000 000.00	R30 000 000.00
7	Guardrails	R9 975 000.00	R9 975 000.00
8	Fencing	R660 000.00	R660 000.00
9	Road Markings	R4 122 500.00	R4 122 500.00
10	Road Signage	R800 000.00	R800 000.00
11	Relocation of Services	R3 500 000.00	R3 500 000.00
12	Major Culverts	R7 200 000.00	R7 200 000.00
13	Railway Bridges Widening	R6 528 100.00	R6 528 100.00
14	Sinkhole Rehabilitation	R38 000 000.00	R38 000 000.00
Sub -Total		**R441 048 907.00**	**R292 017 960.00**
Add 20% P&G’s		**R88 209 781.40**	**R68 403 592.00**
Total Excluding VAT		**R529 258 688.40**	**R350 421 552.00**
Total Including VAT		**R608 647 491.66**	**R402 984 784.80**

A full economic evaluation of the various options using a HDM4 analysis is shown in Table F 6. The comparison for a full upgrading of the road is highlighted in red in Table F 6. The HDM4 analysis clearly shows the cost advantages of the implementation of the upgrading of the road, fully utilising the in-situ materials in the anionic MC-NME stabilisation thereof.

Table F 6 Results of a HDM4 analysis of the various option considered along the length of the road – the full upgrading and comparison between the Crushed stone base with cemented sub-base and the MC-NME option is highlighted in red

HDM-4
HIGHWAY DEVELOPMENT & MANAGEMENT

Economic Indicators Summary

Study Name: R Road Upgrade HDM-4 km0.0-km48.58
Run Date: 31-05-2021
Currency: Rands (R) (millions)
Discount Rate: 8.00%

Sensitivity: No Sensitivity Analysis Conducted

Alternative	Present Value of Total Agency Costs (RAC)	Present Value of Agency Capital Costs (CAP)	Increase in Agency Costs (C)	Decrease in User Costs (B)	Net Exogenous Benefits (E)	Net Present Value (NPV = B+E-C)	NPV/Cost Ratio (NPV/RAC)	NPV/Cost Ratio (NPV/CAP)	Internal Rate of Return (IRR)
Base Alternative	40.323	32.754	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Design Option 1A (120km/h Vert Alig +Traditional Pavemen	750.985	651.512	710.662	1,422.642	0.000	711.980	0.948	1.093	18.0 (1)
Design Option 1A (120km/h Vert Alig + Bitumen Emulsion)	600.852	501.586	560.530	1,761.952	0.000	1,201.422	2.000	2.395	26.5 (1)
Design Option 2 (Climbing Lanes +Traditional Pavement)	795.795	696.322	755.472	1,422.642	0.000	667.170	0.838	0.958	17.0 (1)
Design Option 2 (Climbing Lanes + Bitumen Emulsion Pave	635.242	535.963	594.919	1,764.397	0.000	1,169.478	1.841	2.182	25.3 (1)
Design Option 1B (100km/h Vert Alig + Traditional)	697.498	598.025	657.175	1,422.642	0.000	765.467	1.097	1.280	19.3 (1)
Design Option 1B (100km/ Vert Alig +Bitumen Emulsion)	539.513	440.246	499.190	1,761.952	0.000	1,262.761	2.341	2.868	29.0 (1)
Design Option 3: Crushed stone base & 2x Cemented	589.237	583.860	548.915	1,148.529	0.000	599.614	1.018	1.027	18.3 (1)
Design Option 3: MC-NME base & sub-base	410.974	402.548	370.652	1,744.113	0.000	1,373.462	3.342	3.412	35.3 (1)

Figure in brackets is number of IRR solutions in range -90 to +900

Appendix G. Surfacings for Low Volume Roads

Introduction

Appendix G provides details regarding different surfacing types used on Low Volume Roads and could be divided into bituminous and non-bituminous surfacings.

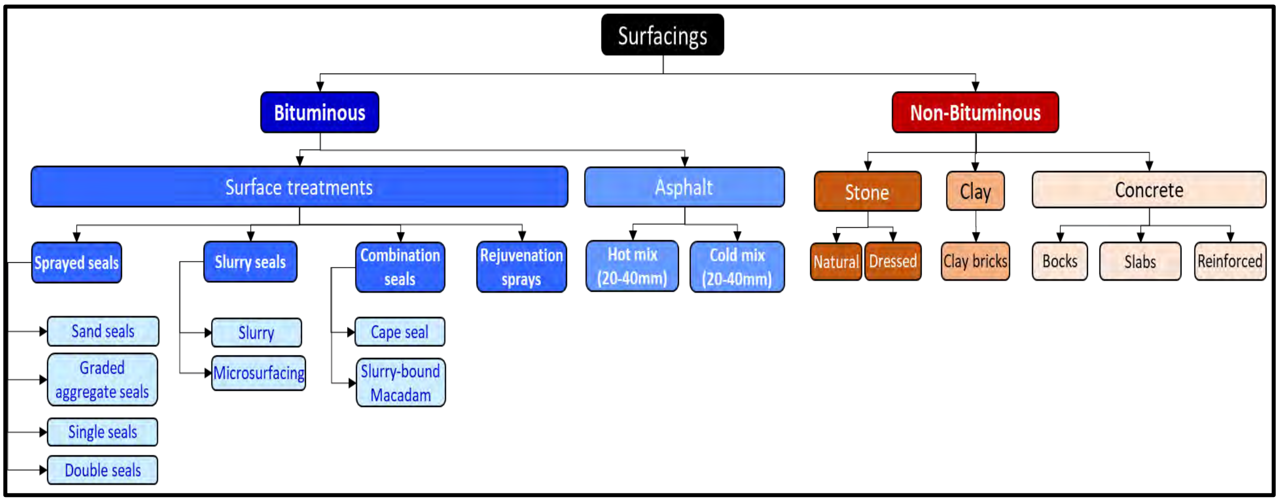


Figure G 1 Surfacing alternatives for LVRs

Bituminous surfacings

Sand seals

Consists of a film of binder (preferably cutback bitumen or emulsion) followed by graded natural sand or fine sand, machine or hand-broken aggregate (max. size typically 6 – 7 mm) which must then be compacted.

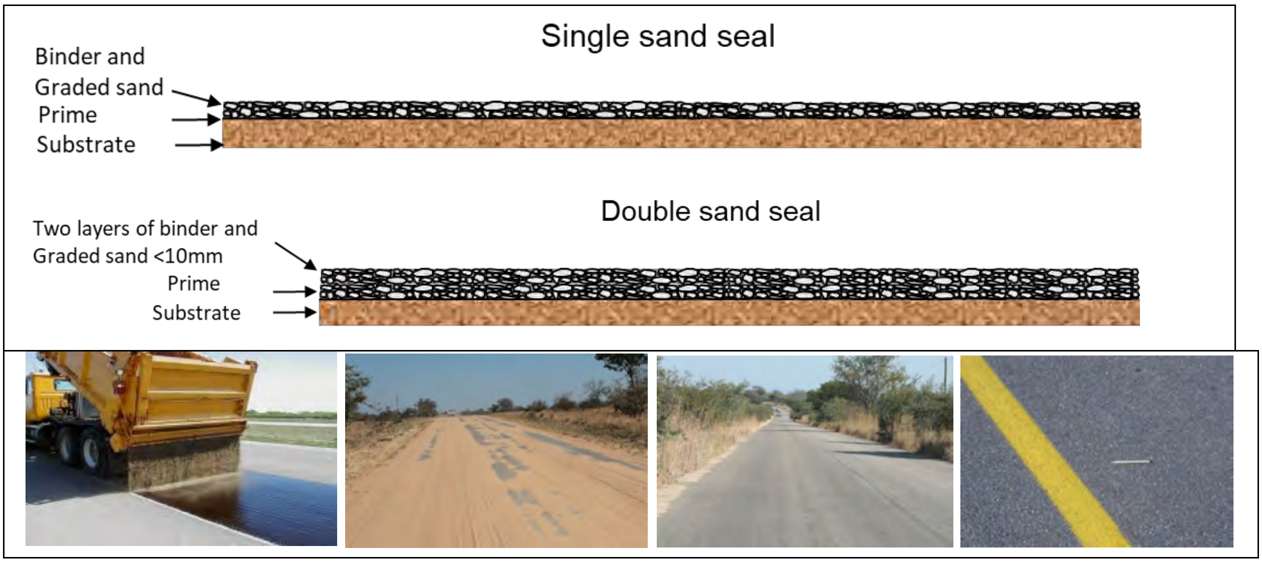


Figure G 2   Sand seals

Single sand seals are not very durable but performance can be improved with the application of a second seal within the first year. The double sand seal could then last for another 6-9 years before another reseal is required.

Thick graded aggregate seals

An Otta seal consists of a relatively thick layer of bitumen binder followed by a layer of aggregate that is rolled into the binder using a heavy pneumatic tired roller or loaded trucks. A graded gravel or crushed aggregate (19mm down) is used with a soft hot binder such as MC3000 or 150/200 Pen bitumen. Its success depends on the binder being squeezed up through the aggregate by the action of extensive rolling by pneumatic-tired rollers followed by traffic. A single Otta seal plus a sand seal or a double Otta seal is recommended as initial construction seals.

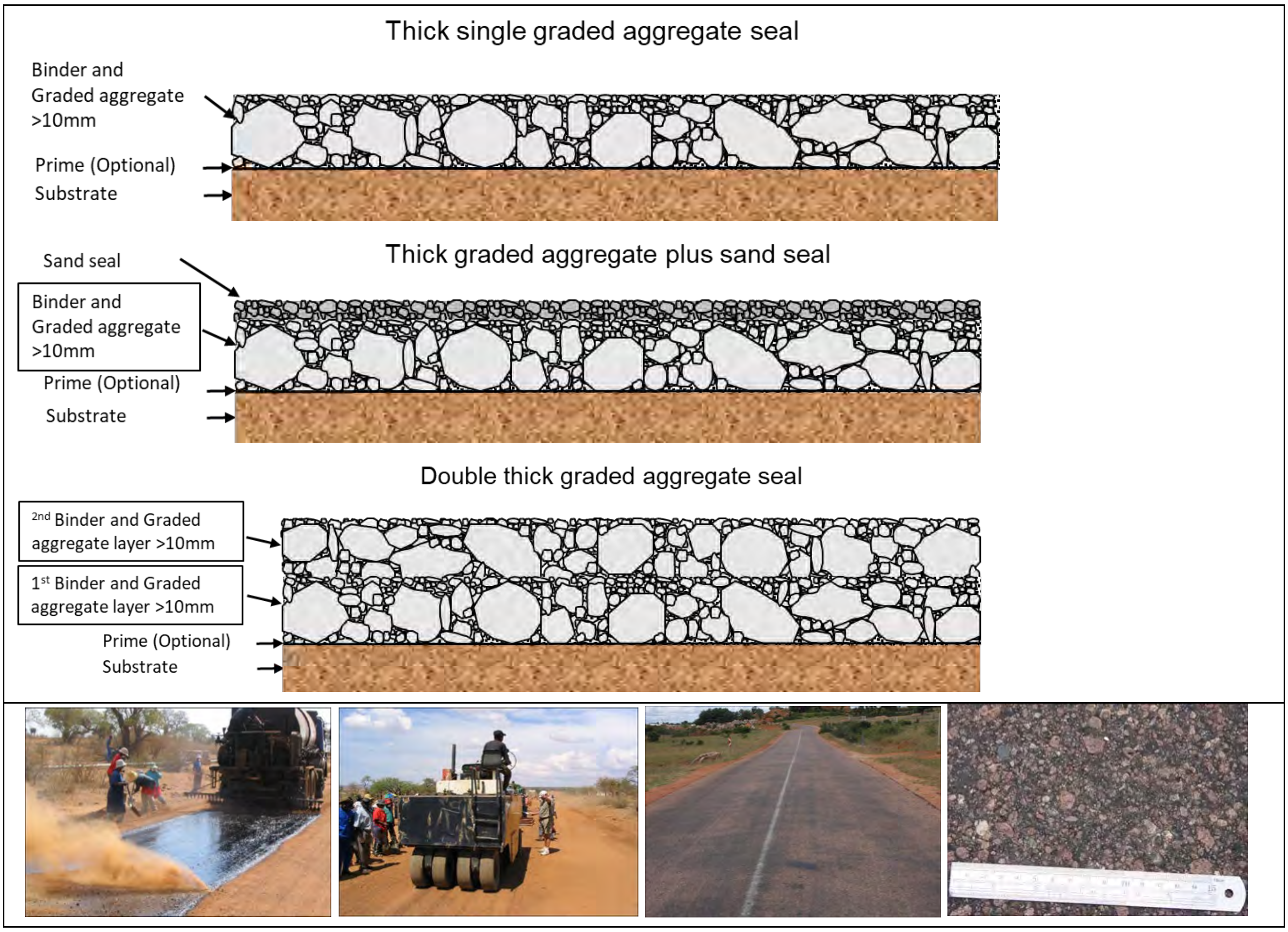


Figure G 3 Graded aggregate seals (Otta seals)

Although not defined as Otta seals, good performance of 10 to 16 mm graded aggregate seals has been recorded, single, double and single with thin sand seals.

Single seals

A single seal comprises the application of a suitable binder, the application of a single-sized aggregate and rolling to orientate and embed the stone in the bituminous binder. Application of an emulsion cover spray reduces the risk of early aggregate loss. An additional application of coarse sand in the emulsion cover spray further reduces the risk of aggregate loss.

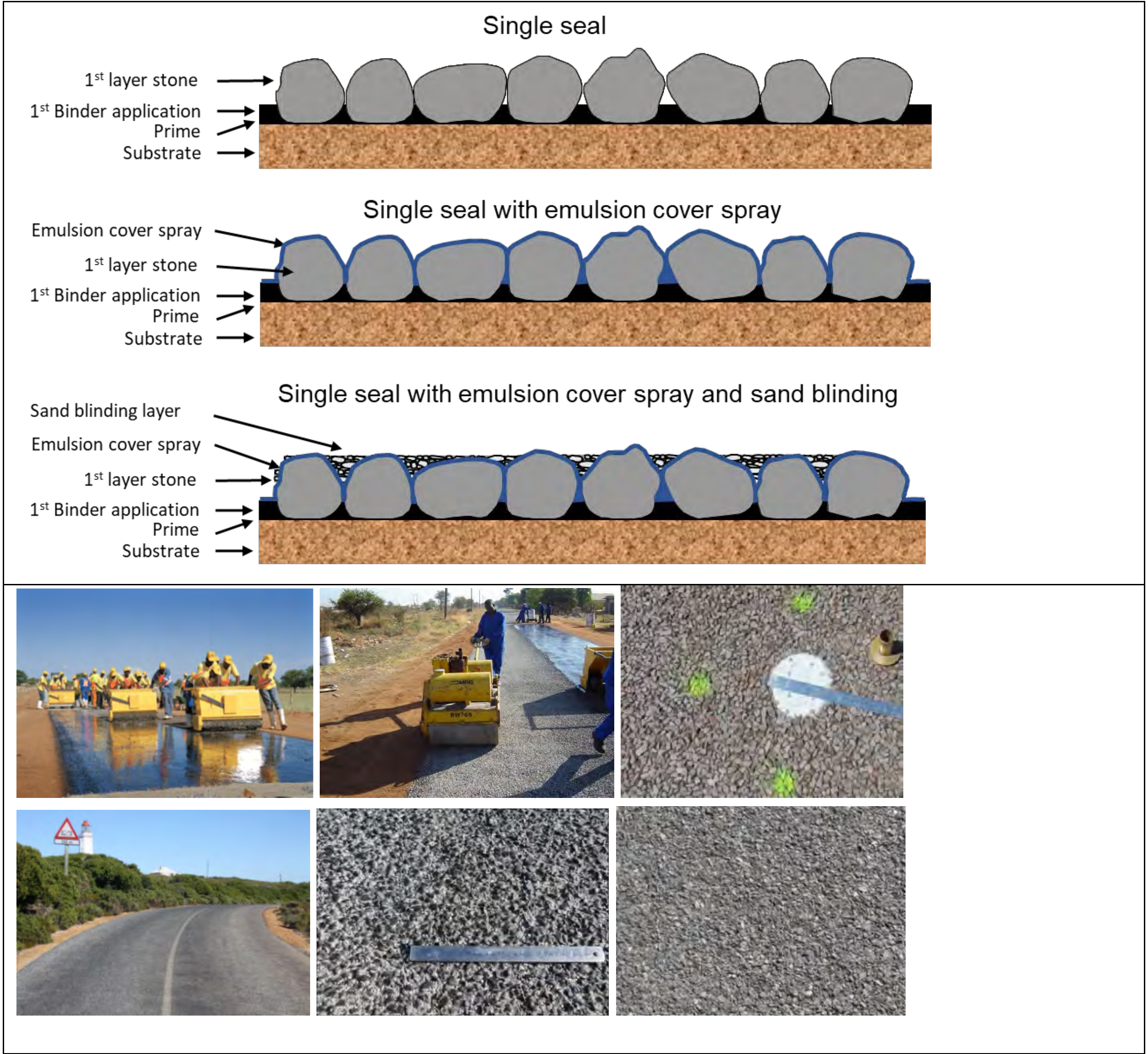


Figure G 4 Single seals

Double seals

A double seal consists of two applications of a suitable binder and spreading and rolling two layers of single-sized aggregate. The second layer of aggregate is normally half the size of the first aggregate layer, providing stability to the seal structure and minimising the risk of early aggregate loss. A diluted emulsion cover spray could be applied as a final layer, further reducing the risk of aggregate loss.

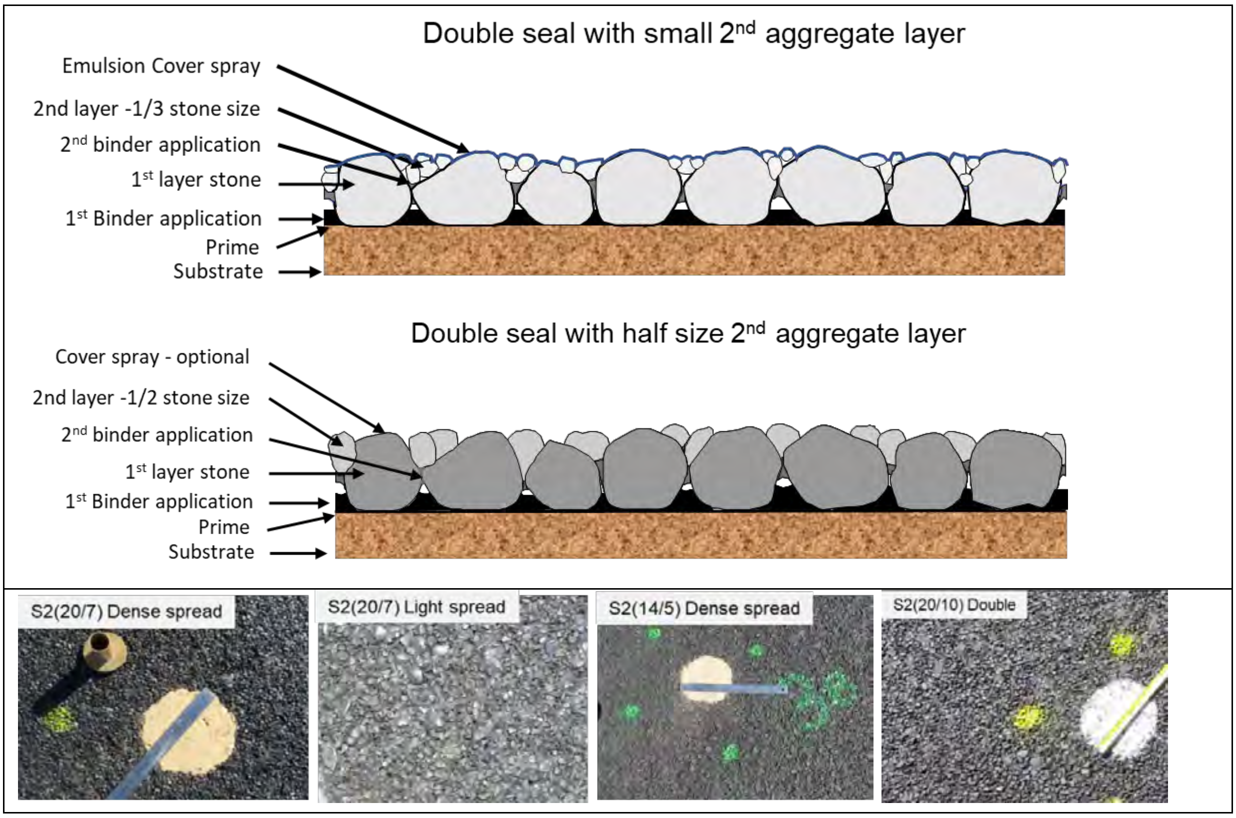


Figure G 5 Double seals

Slurry and Micro surfacing

Slurry Seals are a mixture of well-graded fine aggregate, Bitumen Emulsion, filler (usually Portland Cement or lime), and additional water. They are mixed in a concrete mixer or purpose-built equipment and are spread on a pre-prepared surface using wheelbarrows and squeegees or spreader box/drag spreaders. The slurry seal can be hand spread to the thickness of the large aggregate fraction. Following application at ambient temperature, the water in the emulsion separates from the emulsion and evaporates leaving the residual bitumen in place to adhere to the pavement surface and aggregates.

Micro surfacing differs from conventional slurry in the sense that chemicals are used to speed up the braking process (separation of water). The rapid curing characteristics require application by spreader box only but could be applied to 30 mm thickness and in high humidity conditions.

Recent research confirmed that New Modified Emulsions (NME) could be used in slurries without cement, at lower binder contents, using less water and providing significant additional flexibility.

Figure G 6 Slurry and micro surfacing

Cape seals

A Cape Seal is a multiple surface treatment consisting of an application of a single bitumen chip seal followed by a single or double application of bitumen slurry seal. Usually, a 14 mm single seal is combined with a single slurry application. A 20 mm first seal is normally combined with a double slurry application. The aim is that on completion the tops of the stone chips are just exposed above the slurry that fills the interstices between the stones.

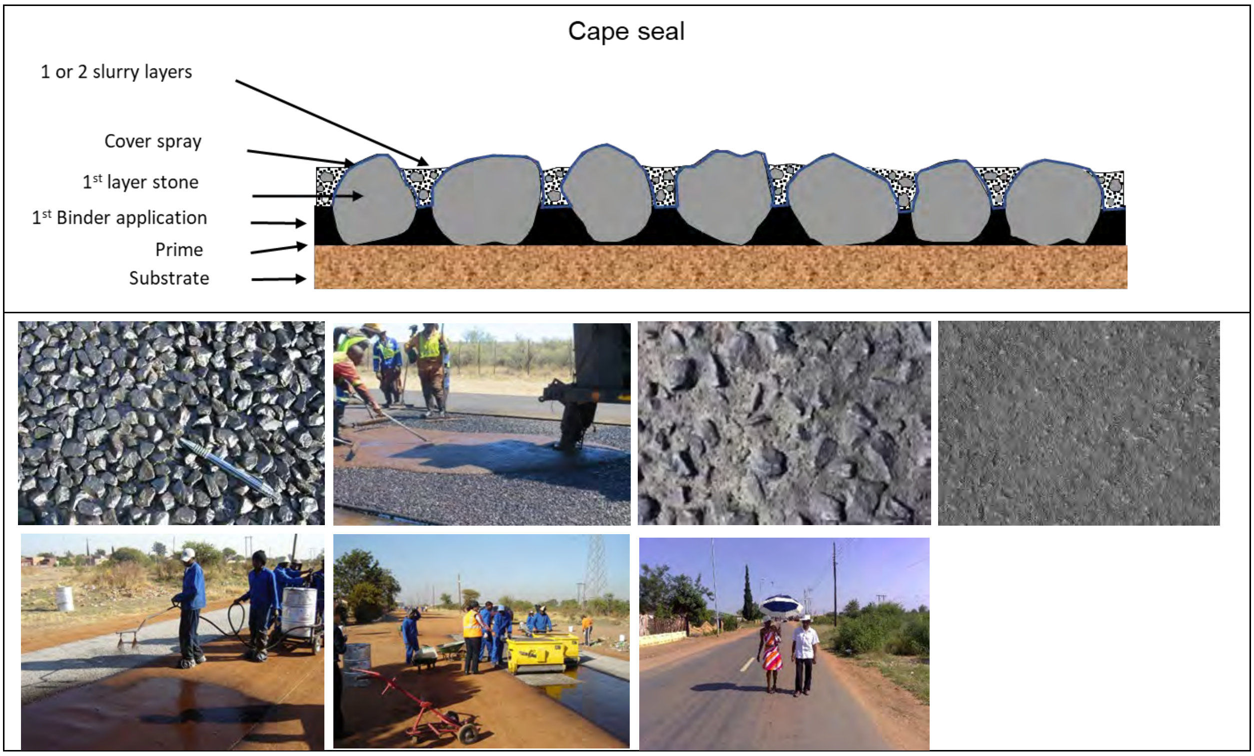


Figure G 7 Cape seals

The Cape Seal is durable (typical initial life 8 to 16 years) and enables the heavy-duty surfacing to be constructed with minimal equipment.

Slurry-bound Macadam seal

The slurry-bound macadam seal is a combination of single-sized aggregate and fine slurry.

A dry layer of 14 mm or 20 mm aggregate placed at a thickness of 20 to 50 mm, levelled and compacted. A fine slurry is then vibrated into the stone matrix, using a pedestrian roller. After curing the slurry, the layer is rolled with a static roller and a final slurry layer (4 to 6 mm) is applied.

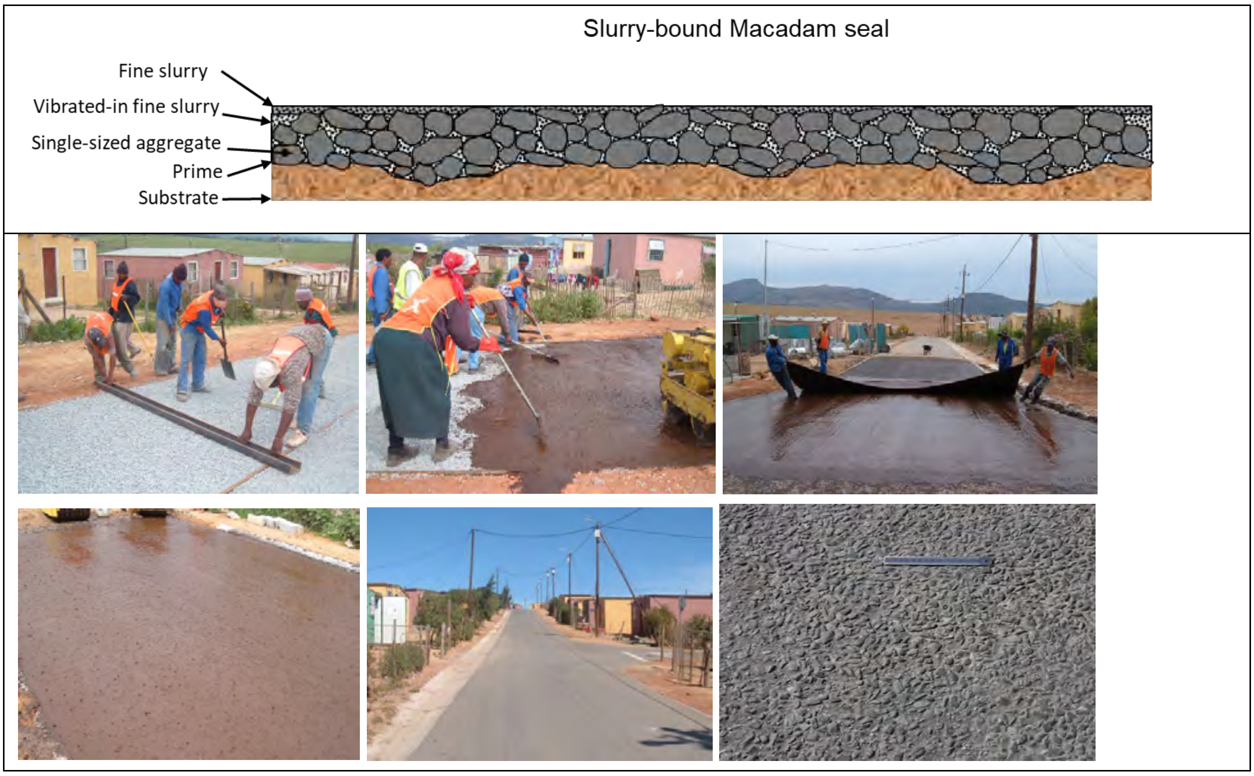


Figure G 8	Slurry-bound Macadam seal

Rejuvenation sprays

Diluted stable-grade emulsion or invert cut-back emulsion is sprayed on an existing surface treatment to prolong the effective service life. Typical rates of application are 0.8 litre/m^2 for diluted emulsions and 0.45 litre/m^2 for invert cut-back emulsions. Most aggregates in Africa are negatively charged resulting in anionic emulsions being preferred to run into the seal structure and not adhering immediately to the stone.

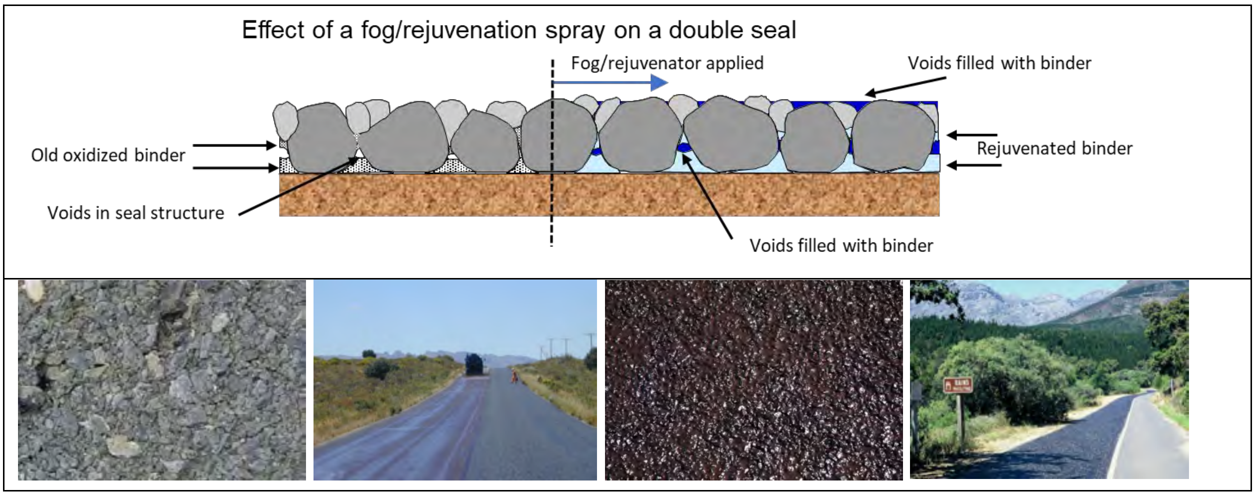


Figure G 9 Rejuvenation sprays

Asphalt surfacings

Hot premix asphalt consists of graded crushed aggregate, bitumen and an active filler e.g. lime, normally mixed in a plant, paved with a custom-built paver and compacted. **Note:** Could be mixed on site with small plant, spread by hand and compacted. Thickness could vary depending on nominal size aggregate

Cold mixes normally consist of a mixture of graded crushed aggregate, a filler and a stable, slow-breaking emulsion that is mixed by hand or in a concrete mixer. After mixing the material is spread on a primed road base and rolled. Thickness (20 to 40 mm) could vary depending on nominal size aggregate. Very suitable for labour-based construction, requires a very simple construction plant and reduces the potential hazard of working with hot bitumen.

Figure G 10 Asphalt (premix)

Non-Bituminous Surfacings

General

Surfacings constructed from materials such as stone, clay and concrete can be considered for use on LVRs instead of conventional bituminous surfacings. The current practice of utilising concrete pavements through villages, on very steep grades or where there is a risk of water overtopping the road is an example of an environmentally judicious choice of surfacing in circumstances where bituminous surfacings often do not perform well.

The non-bituminous surfacings listed all act simultaneously as a surfacing and base layer and provide a structural component to the pavement because of their thickness and stiffness. Bricks and blocks require the use of a sand bedding layer that also acts as a load transfer layer for the overlying construction.

In some circumstances (e.g., on steep slopes in high rainfall areas and areas with weak subgrades and/or expansive soils) it may be advantageous to use mortared options. This can be done with Hand-packed Stone, Cobblestone (or Dressed Stone), and Fired Clay Brick pavements. The construction procedure is largely the same as for the un-mortared options except that cement mortar is used instead of sand for bedding and joint filling.

Concrete blocks

Concrete brick paving is a well-established technique used in many countries for a variety of applications including successful adoption as an option for low-volume rural roads. The application is based on the proven ability of individual concrete bricks to effectively disperse load laterally to adjacent bricks through the sand joints. This option comprises rectangular concrete bricks (usually around 70 mm thick) being laid in a herringbone or other pattern to camber within confining edge kerbs (cast either before or after brick placement). They are compacted into place, with sand brushed in at the joints. A sand cement mortar joint or bituminous seal may be specified to be used to waterproof the finished surface as a separate operation, although this is usually unnecessary on a well-constructed sub-base. As a refinement, the concrete bricks may be cast with a top-edge chamfer to assist surface drainage.

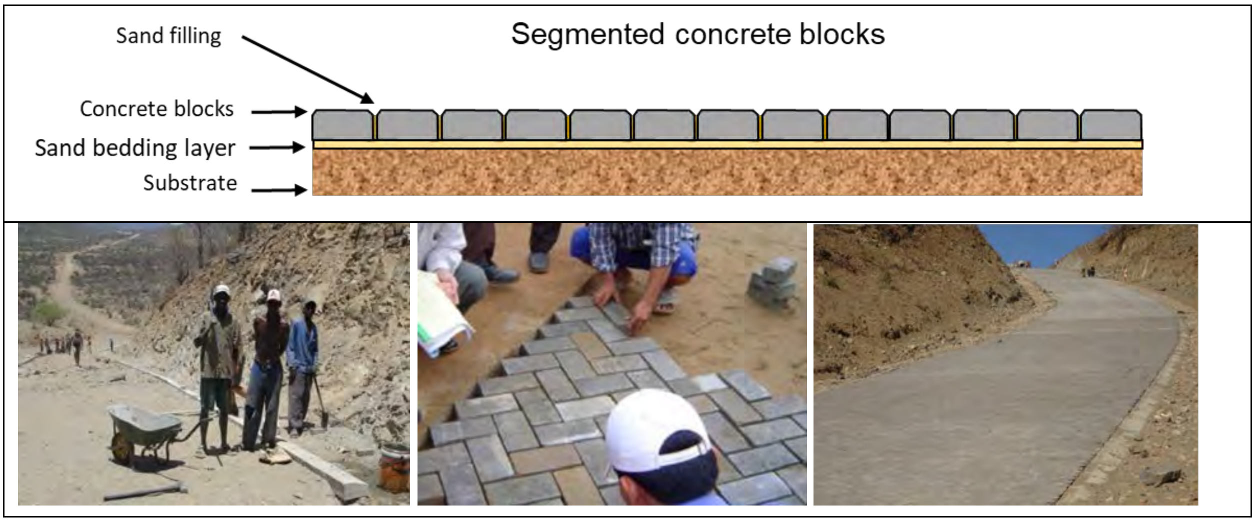


Figure G 11 Concrete blocks

Clay bricks

Fired Clay Bricks are the product of firing moulded blocks of silty clay and are commonly used in low-cost road pavement construction in areas with a deficiency of natural gravel or rock materials. This surfacing consists of placing a layer of edge-on engineering quality bricks within previously installed edge constraints. The bricks are laid in an approved pattern on a sand bedding layer. Joints between the bricks may be either in-filled with suitable sand or the bricks may be mortared in.

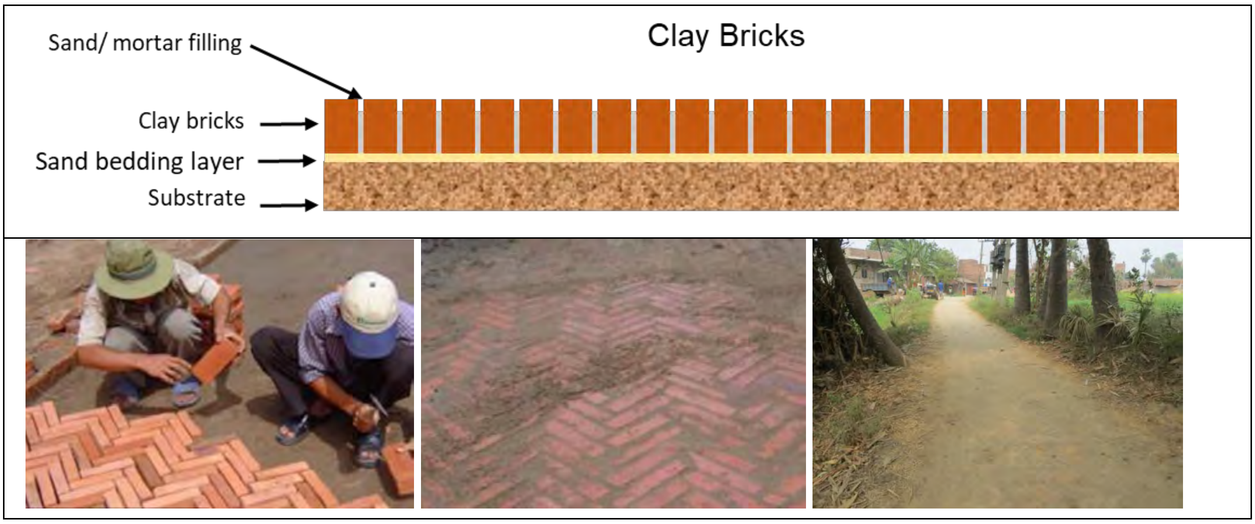


Figure G 12 Clay bricks

Dressed stone

A dressed stone surfacing is a historically well-established technique that has been adapted successfully as a robust alternative option for low-volume rural roads where there is a good local supply of suitable stone. Strong isotropic rocks such as granite that have inherent orthogonal joint stresses are ideal. Dressed stone surfaces have good load-spreading properties.

This technique comprises 150 to 200 mm thick dressed stones being laid to lines and levels between previously installed edge restraints and compacted into a sand bedding layer followed by cement mortaring of the joints. The dressed stones shall normally be hand cut from solid rock and trimmed (dressed) if necessary to form a regular rectangular shape, free from flaws and discontinuities with a reasonably smooth top surface.

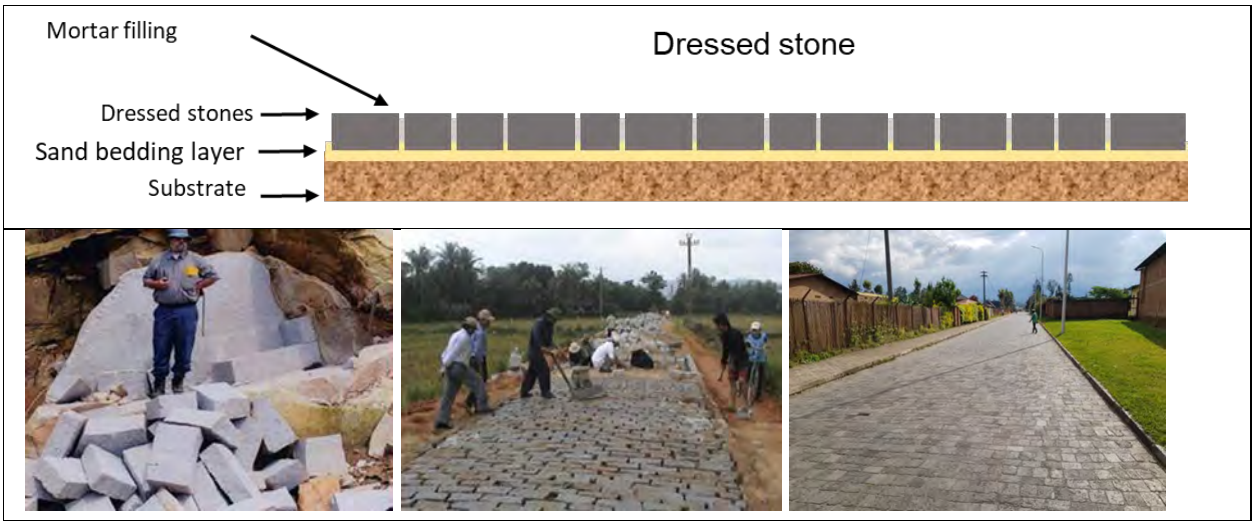


Figure G 13 Dressed stone

Cobble stone

Cobble Stone Paving is a historically well-established option consisting of a layer of roughly cubic-shaped or selected stones of thickness about 100 to 150 mm, laid on a bed of sand or fine aggregate within the mortared stone or concrete edge restraints. The individual stones should have at least one fairly smooth face, to be the upper or surface face when placed. Each stone (or cobble) is adjusted with a small (mason's) hammer and then tapped into position to the level of the surrounding stones. Sand or fine aggregates are brushed into the spaces between the stones and the layer and then compacted with a roller.

Note: Stone sets are a neater alternative and consist of a layer of cubic-shaped stones of approximate size 80 to 100 mm laid on a thin bedding sand layer (20 to 50 mm). The sets can be cut by hand from suitable hard rock such as granite or basalt, which easily breaks into smooth-faced pieces. Sand is brushed into the joints between the laid stones and they are compacted using a vibrating plate or light roller. An edge restraint or kerb constructed of large or mortared stones is required for durability. Sand-cement mortar joints can be used to improve durability and prevent water from penetrating the foundation layers and weakening them.

Figure G 14 Cobble stones

Concrete

Non-reinforced cement concrete is a well-established form of rigid pavement designed to spread the applied load due to traffic through a slab effect. The option as applied for LVRs usually involves the casting of 5 m long slabs between formwork, normally with load transfer dowels between them. In some cases, where continuity of traffic demands it, these slabs may be half carriageway width. The concrete slabs are cast onto a previously prepared and compacted sub-base. The concrete requires to be cured, by covering it with moisture-retaining material and kept moist, normally for a minimum period of 7 days.

It is most suitable for construction on high rainfall, steep gradient alignments and on routes prone to seasonal flooding and other major climatic impacts.

Continuously reinforced concrete could be used as an alternative, allowing a thinner layer, but higher skill levels.

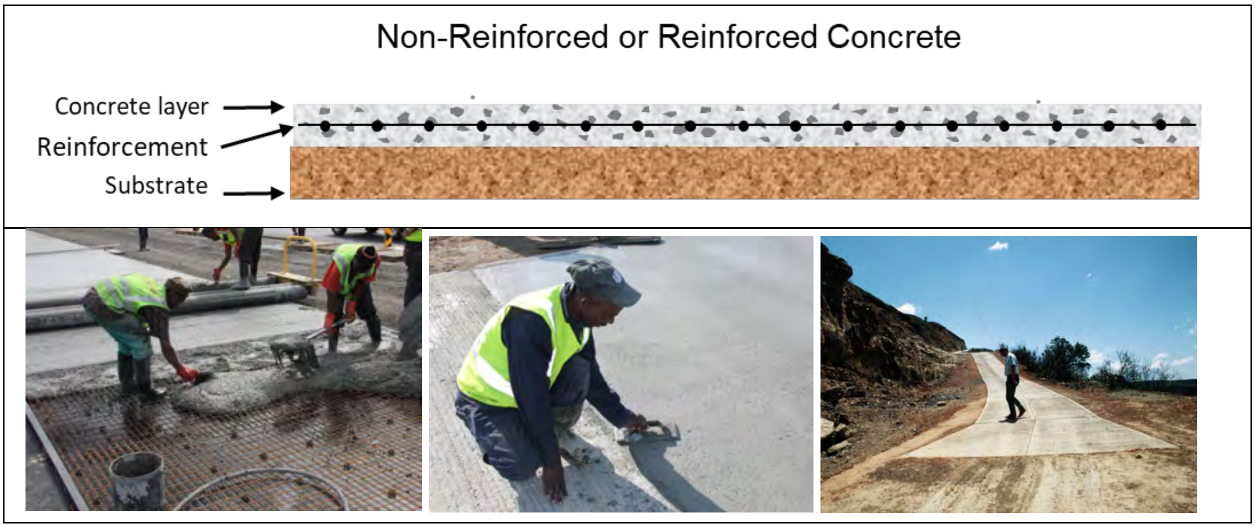


Figure G 15 Concrete

Appendix H. Maintenance Concepts

Introduction

The purpose of road maintenance is to ensure that the road remains serviceable and is kept to the specified LOS standards to provide safety and access to essential services at the least cost. Key aspects recorded include:

- Maintenance prolongs the life of the road by reducing the rate of deterioration, thereby safeguarding previous investments in construction and rehabilitation;
- Lowers the cost of operating vehicles on the road by providing a smooth-running surface;
- Keeps the road open for traffic and contributes to more reliable transport services;
- Sustains social and economic benefits of improved road access, and
- The importance of routine maintenance, particularly as regards drainage, cannot be over-stressed concerning pre-emptive measures to reduce the likelihood, or impact, of natural disasters.

Obligation of the Roads Authority

TMH22 provides guidance as to how Roads Authorities are required to manage the road infrastructure assets according to the Committee of Transport Officials (COTO) Road Infrastructure Asset Management Policy (RIAMP). This is the Policy framework setting RSA requirements for Roads Authorities to Manage Road Infrastructure Assets.

Road authorities in South Africa must plan, design, construct and maintain the road network, to protect the public investment in the road infrastructure, ensure the continued functionality of the transportation system and promote the safety of traffic on the road network. Authorities must also provide a reliable, effective, efficient and integrated transport system that supports the sustainable economic and social development of the country.

In terms of the maturity level of asset management, the minimum requirement is to have Level II systems operating in Provincial Road Authorities and larger municipal authorities (Refer to TMH22).

The "Direct line of sight" in terms of Road Asset Management processes is summarised in Figure H 1.

Road maintenance management forms part of the total asset management process and aims to apply appropriate strategies, planning and operational procedures to achieve the long-term objectives of the organisation.

The typical objectives incorporated in a Road Authority Policy Statement are:

- Preserving road asset condition by adopting a life-cycle approach;
- Minimising Total Transport Costs/ Society costs while maintaining acceptable levels of service;
- Improving road safety;
- Providing and maintaining access;
- Achieving stakeholder and customer satisfaction;
- Adopting a sustainable approach to the environment;
- Maximising social benefits;
- Reducing risk to the Roads Authority;
- Embracing new technologies to do more with less;
- Ensuring clarity on responsibility for road assets, and

- Accountability for the use and management of resources.

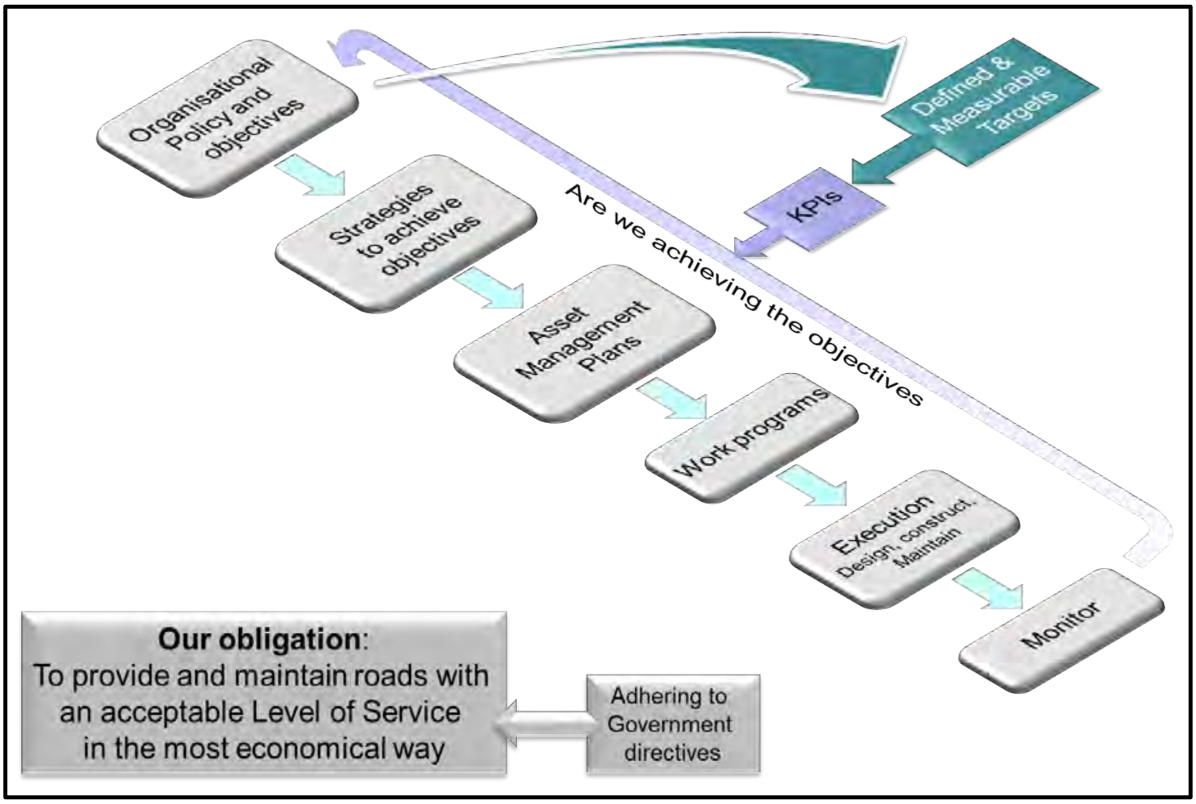


Figure H 2 Direct line of sight

Strategies are developed and the cost is determined to achieve the set objectives.

The policy and objective of Rural Development are to provide and maintain accessible and safe roads at an appropriate Level of Service (LOS). To achieve and maintain the selected LOS, stable long-term funding must be secured

The strategy development is followed by the development of Asset Management Plans, scheduling of works (Work Programs) and the execution thereof.

The success of the organisation in meeting the policy objectives is determined through monitoring Key Performance Indicators (KPI) defined in the LOS for the different road categories.

Cost of Maintenance

Taken from a responsible road authority with an established road network, a spread of approximately 80 per cent of the road network unpaved and, a drive towards upgrading, the typical distribution of funds is shown in Figure H 2. This distribution highlights that approximately 50 per cent of the available funding is allocated to the maintenance of the existing road infrastructure.

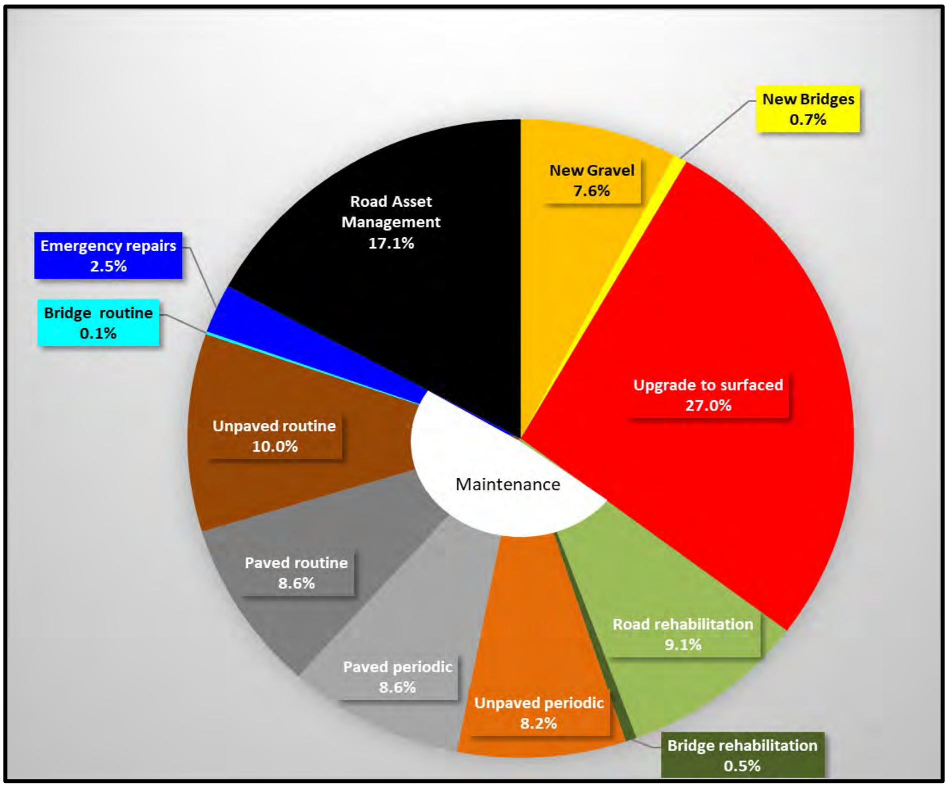


Figure H 3 Typical fund distribution

Road performance

Road performance is characterised by the deterioration of the functional and structural properties of a road. Performance indicators could either be individually measured defects or combined indices, describing the condition of a road at a particular point in time. Typical individual performance indicators are road roughness, expressed in terms of the International Roughness Index (IRI), rut depth, skid resistance, percentage cracking etc. Combined indices are often used to describe the current condition and change over time and are normally an aggregation of different defects. A typical scale used is where 100 per cent defines the perfect condition and 50 per cent defines an unacceptable condition. The effect of maintenance on the condition is shown in Figure H 3, highlighting that both routine maintenance and periodic maintenance are required to extend the effective service life before rehabilitation is required.

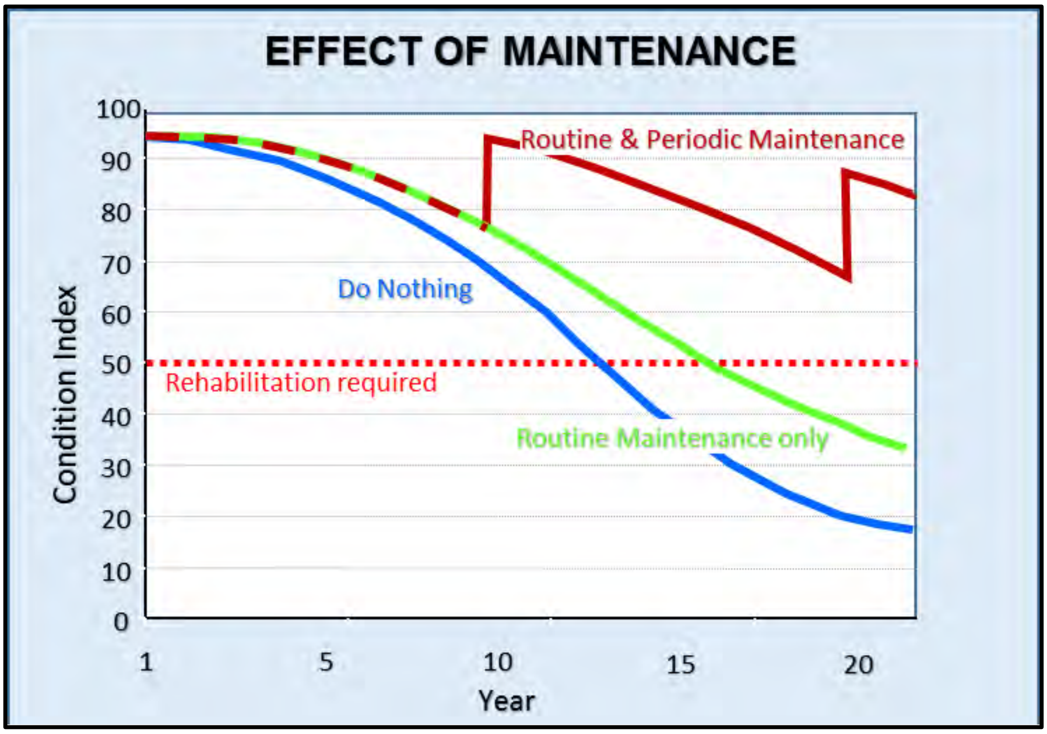


Figure H 4 Importance of routine and periodic maintenance

The performance of a surfaced road is influenced by the selected pavement structure and surfacing, traffic load and actions, environmental conditions as well as the maintenance life-cycle strategy applied and quality thereof.

Bituminous surfacings become hard/brittle and permeable with time resulting in water ingress into and softening of the granular base. Any loads applied result in cracking of the surfacing, further moisture ingress and potholing, “The proverbial example of a glass plate on a foam mattress”. The mechanism is shown in Figure H 4 and Figure H 5.

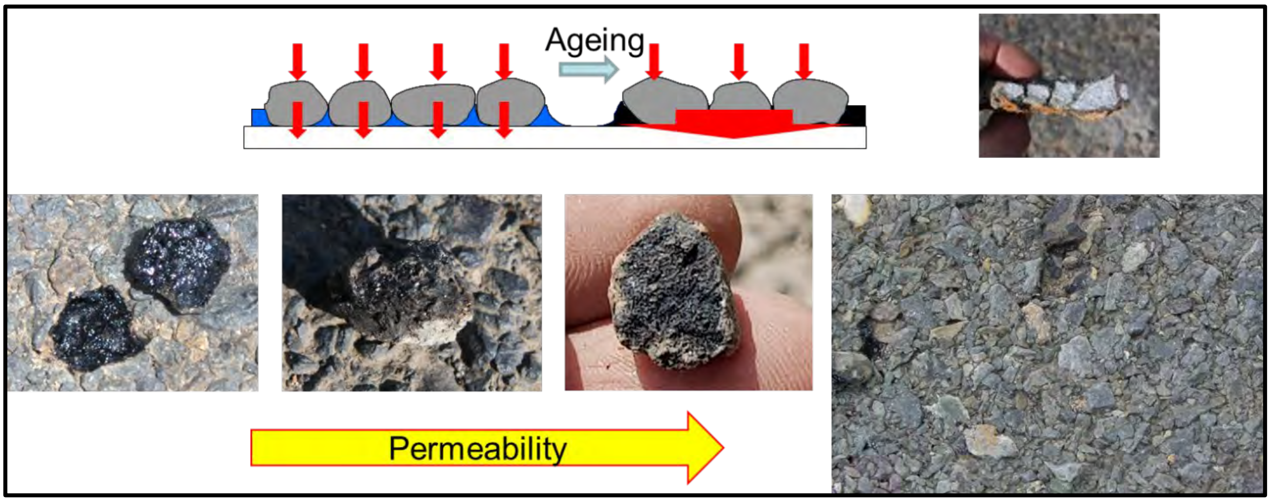


Figure H 5 Ageing of bituminous surfacings leading to permeability

Figure H 6 Moisture ingress resulting in cracking and potholing

The average effective life of bituminous surface treatments on low-volume roads, reported in South Africa, Australia and New Zealand, is approximately ten years. Resealing (waterproofing) before fine cracking starts to occur extends the effective pavement life. The result of effective periodic maintenance is that well-maintained surfaced road networks in southern Africa are still in a "Good" condition with an average age of the pavement structures exceeding fifty years.

Life-cycle strategies

A life-cycle strategy defines the timing of sequential maintenance activities executed on a road throughout its life. The immediate effects, longer-term effects, sequence, timing and costs are utilised to obtain an optimised strategy for maintaining a selected level of service at the least possible cost. For a surfaced road, the optimum life-cycle strategy is also a function of the pavement structure composition and selected initial surfacing.

As an example, and assuming that the pavement structure is adequate to carry the traffic load for 20 years, three different surfacing types could be considered as initial surfacings e.g. 30 mm Continuous graded asphalt (AC), a double surface treatment (DS) and a single sand seal (SS). Dependent on the rate of deterioration and defects developing, different life-cycle strategies would be required to maintain the road in an acceptable condition. Three possible scenarios are presented in Figure H 6, Figure H 7 and Figure H 8, showing the timing and costs of expected periodic maintenance activities. By discounting the costs of the different activities and the remaining life value to current-day costs after 20 years (Net Present Value), the most cost-effective life-cycle strategy could be selected.

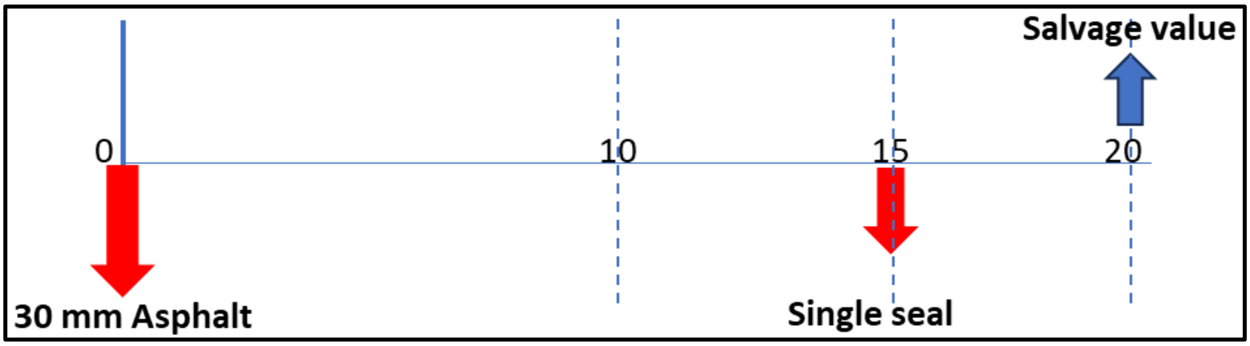


Figure H 7 Maintenance strategy A: Asphalt

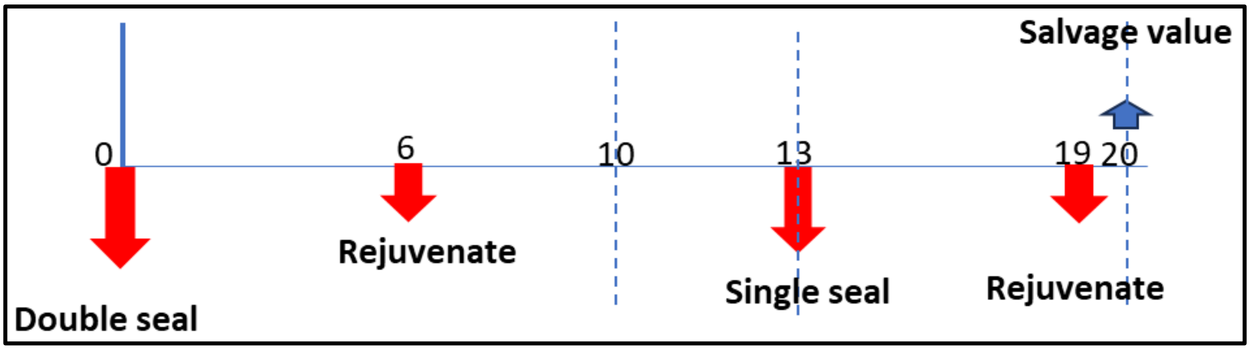


Figure H 8 Maintenance strategy B: Double seal

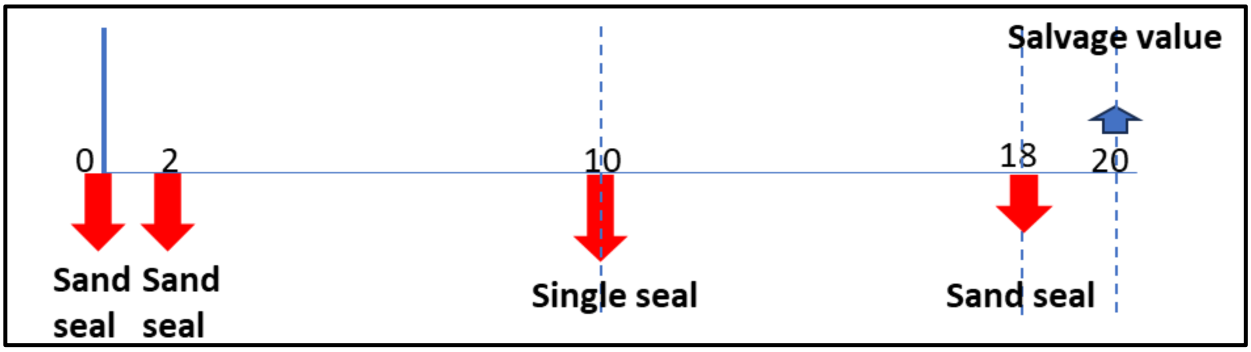


Figure H 9 Maintenance strategy C: Sand seal

Risk of poor maintenance

Even with adequate funding, poor maintenance strategies, planning and operational procedures will result in the objectives not being achieved (Figure H 9).

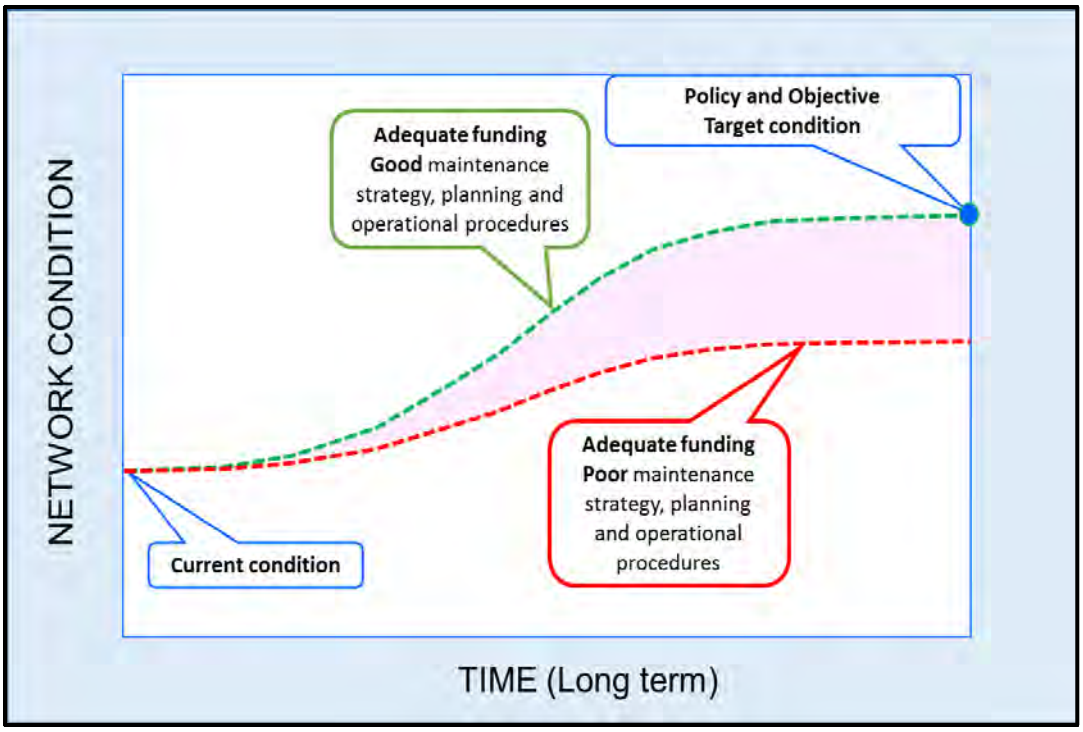


Figure H 10 Impact of poor maintenance planning and execution

The consequences of poor maintenance could be summarised as follows:

- Loss of assets: the resulting loss in value of road assets due to neglect in maintenance:
- According to a 1988 World Bank study, allocations over twenty years for road maintenance in developing countries were so low that nearly 15 per cent of the capital invested in main roads - roughly US$ 43 billion equivalent to 2 per cent of these countries' GNP - had eroded due to lack of maintenance. The same study demonstrated that reconstructing these roads - costing US$ 40 to US$ 45 billion worldwide - could have been avoided by spending US$ 12 billion on maintenance. This is a ratio of about 3.5 to 1, not taking into consideration the time value of money;
- Loss of agricultural outputs: Sensitive agricultural produce e.g., soft fruit, eggs;
- Loss of time and access: More working time is lost as a result of poor or inadequate maintenance which will cause delays or prevent access to work, services like schools, medical facilities, and places of worship, and generally can isolate communities for long periods;
- Increased rehabilitation cost;
- Experience has shown that neglect of maintenance at the right time could lead to the complete loss of the asset. An example is shown in Figure H 10, where "not resealing" at the right time at a cost of Rx results in the need to rehabilitate at six to eighteen times the cost of the reseal. To apply the reseal at the optimum time, the need for reseal be identified at an early stage to allow sufficient time for the required processes before construction. This emphasises the need for regular condition assessments, and

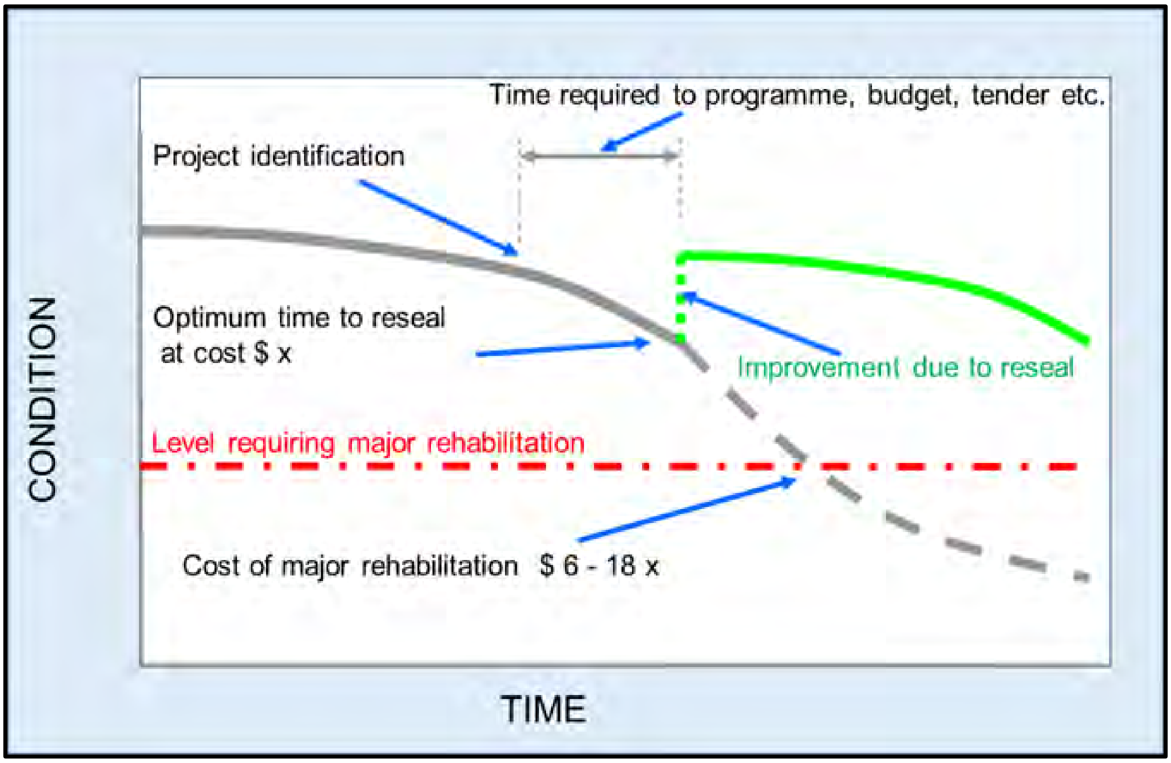


Figure H 11 Early identification of need required and impact of deferment

- Vehicle deterioration and vehicle operating cost: Not only do roads deteriorate due to lack of maintenance, but the vehicles using the road also get damaged, break down and often cause accidents.